Green City, Clean Waters

Sewer System Evaluation Survey

Consent Order & Agreement

Regulatory Deliverable

City of Philadelphia Combined Sewer Overflow Long Term Control Plan Update

Submitted to
The Commonwealth of Pennsylvania
Department of Environmental Protection

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Errata

1. The errata submitted on July 31, 2014 include replacements to pages 23 and 54 of Section 4.0, Analysis Results.

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Glossary of Acronyms

ADDWF	Average daily dry weather flow
ASOS	Automated Surface Observing System
BWWF	Base wastewater flow
CAPIT	Capital Program Integrated Tracking System
CCTV	Closed circuit television
CDF	Cumulative distribution function
CDP	Cumulative distribution plot
COA	Consent Order Agreement
CSO	Combined sewer overflow
DBMS	Database management system
DWF	Dry weather flow
GARR	Gage adjusted radar rainfall
GIS	Geographic information system
gpcd	Gallons per capita per day
GWI	Groundwater infiltration
H&H	Hydraulic and hydrologic
I/I	Inflow and infiltration
IAMP	Implementation and Adaptive Management Plan
IDF	Intensity-duration-frequency
IT	Information technology
LTCPU	Long Term Control Plan Update
mgd	Million gallons per day
MIT	Minimum inter-event time
NASSCO	National Association of Sewer Service Companies
NCDC	National Climactic Data Center
NEXRAD	Next Generation Weather Radar
NWS	National Weather Service
O&M	Operation and maintenance
ODBC	Open database connection
PACP	Pipeline Assessment and Certification Program
PADEP	Pennsylvania Department of Environmental Protection
PHL	Philadelphia International Airport
QA/QC	Quality assurance / quality control
QC	Quality controlled
RDII	Rainfall dependent infiltration and inflow
RTU	Real-time control unit
SAP	Sewer Assessment Program
SSES	Sewer System Evaluation Survey

SSOAP	Sanitary Sewer Overflow Analysis Program
SSS	Sanitary sewer system
SWMM	Storm Water Management Model
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WWF	Wet weather flow

1.0 Introduction

This report describes the activities conducted by the Philadelphia Water Department (Water Department) to perform a Sewer System Evaluation Survey (SSES) and document the corresponding assessment and analysis results. This SSES is a requirement of the Water Department's Consent Order and Agreement (COA). On June 1, 2011, the Commonwealth of Pennsylvania approved the City of Philadelphia's Combined Sewer Overflow (CSO) Long Term Control Plan Update (LTCPU) and issued the COA to provide the regulatory framework for the implementation of the plan. The approved LTCPU and its supplements are called the *Green City, Clean Waters* program and represent the City's commitment towards meeting regulatory obligations while helping to revitalize the City. The SSES report explains the data assessment evaluation process for sanitary sewer systems, and the wastewater flows they convey, to determine the magnitude of wet weather inflow and infiltration (I/I) and identify any areas with the potential for significant I/I reduction. The primary goal of the SSES is to address I/I in the separate sewer areas tributary to the City's water pollution control plants by quantifying and characterizing monitored wastewater flows and identifying critical sewers with relatively high I/I volumes.

1.1 SSES Approach

The development of the SSES approach was derived from the American Society of Civil Engineers (ASCE) and the Water Environment Federation (WEF) Manual of Practice FD-6, "Existing Sewer Evaluation and Rehabilitation". The first phase of the SSES is intended to identify available historical data, assess its reliability, decide if additional data is needed, and determine how this additional data would be collected. This first phase involves the cataloging and evaluation of existing historical data that is critical to successfully and efficiently performing the SSES. The second phase of the SSES, the analytical study phase, involves using reliable data for performing global analyses and evaluations of sanitary sewer systems during dry and wet weather conditions. A primary part of the evaluation involves analysis of monitored precipitation and sewer flow data to quantify and characterize dry weather flow and rainfall dependent infiltration and inflow (RDII). The analysis results allow for the identification of monitored separate sanitary sewershed areas that may convey relatively high extraneous flows through the Water Department system. The results of these analyses are summarized and presented in this report, the *Green City, Clean Waters Sewer System Evaluation Survey*.

1.2 Overview of Report Contents

This SSES Report is organized into four sections and four appendices that are described briefly below.

Section 1 provides the context for the report, including descriptions of the regulatory history behind the SSES, where the scope of work and required elements of the SSES were documented, a brief explanation of the Water Department's approach for meeting the regulatory and reporting requirements, and activities to be conducted by the Water Department following the submission of this SSES report.

Section 2 documents the completed Phase 1 SSES activities. The available historical data is documented and an assessment of its reliability and completeness is provided. The following categories of pertinent available data are included in the report.

- Sanitary sewer flow monitoring data collected within the City and from outlying community service area billing meters
- Regional precipitation monitoring data providing coverage for the City and outlying community service areas
- Sanitary sewer system infrastructure data and geographic information system (GIS) coverages within the City and from the outlying communities
- Other pertinent data categories such as demographic, topographic, population and land use data; both within the City and for outlying community service areas
- Sanitary sewer inspection and assessment data within the City
- Sanitary sewer rehabilitation projects completed and planned within the City

Section 3 provides summary documentation for the analytical and assessment approaches used to conduct the SSES. The narrative explains how sewershed delineations and sewershed precipitation were refined and verified from the available historical data. The associated quality assurance review procedures that were conducted for the monitored precipitation and wastewater flow data are also documented. The section concludes with descriptions of the analysis methods, tools, and procedures that were used to quantify and characterize dry and wet weather flow conveyed from the monitored separate sanitary sewershed areas.

Section 4 provides a summary of the SSES analysis results and conclusions. Analysis results from the precipitation gage and radar-rainfall system monitoring data analyses are provided. Dry weather analysis results are presented using a series of summary tables, cumulative distribution function (CDF) curves, and color coded GIS maps. Similarly, wet weather analysis results for each of the analyzed sewersheds are provided.

The four appendices provide more detailed information and results for the various analyses that were conducted. The first appendix provides the long-term record regional precipitation characterization analysis results as a series of plots comparing historical average monthly precipitation volumes and event frequencies to those monitored from 1999 through 2013. The second appendix provides more detailed information on the dry weather flow analysis results; including average weekday and weekend dry weather flow hydrographs and ground water infiltration ratios. The third appendix provides a series of spreadsheets that document the wet weather flow analysis results, including the RDII quantification for each successfully monitored storm. Finally, the fourth appendix includes a series of spreadsheets that present the results of the storm hydrograph curve fitting analyses used to characterize the sewer system response to each successfully monitored wet weather event. All four appendices are provided in digital format on the enclosed Compact Disc (CD) found in the back of the report.

2.0 Summary of Available Historical Data from Phase 1 Activities

Section 2 of this report describes and documents the Sewer System Evaluation Survey (SSES) Phase 1 processes for the identification and gathering of available historical data and assessing its reliability. Subsequently, the data were assessed to verify that the collected data were sufficiently complete and up to date to quantify and characterize dry and wet weather flow from the separate sanitary sewershed areas within the City limits. Finally a determination was made to see if additional data would be needed, and if so, how this data would be collected.

2.1 Sanitary Sewer Flow Monitoring Data Collected within the City

The Philadelphia Water Department (Water Department) maintains a network of sanitary sewer flow monitors within the City limits which have been used for monitoring wastewater flow through sanitary sewers, the characterization of tributary sewershed areas, estimating average dry weather and peak wet weather flows, and quantifying rainfall derived infiltration and inflow (RDII). The monitors are also used to derive input parameters for the Water Department's hydraulic and hydrologic (H&H) models,(*i.e.,* base wastewater flow (BWWF), groundwater infiltration (GWI), rainfall dependent inflow and infiltration (RDII)), and then also used for validation of the models. There also is a telemetered network of depth-only monitoring equipment that is used by the Water Department to monitor the hydraulic performance of the interceptor system. While this depth-only monitoring information is important for the operation of the system and the calibration and verification of the H&H models, the data has little value to these SSES efforts, and as a result, was not inventoried or evaluated as part of this study.

The range of completed activities conducted for the Phase 1 SSES assessment included a review of the historical and current sanitary sewer flow monitoring data collected within the City. The existing available data were identified and evaluated to assess reliability. During this inventory and assessment, it was determined that since the commencement of monitoring in September 1999, the Water Department has collected data at 86 sanitary sewer monitoring sites within the City. In the course of this time, monitors were rotated throughout the sanitary sewer areas in order to maximize the coverage of the Water Department's service area.

In order to process the flow data collected in the field, all data were converted to text files that could be recognized by and loaded into a spreadsheet, such as Microsoft Excel®. These files were then compiled along with all applicable field documentation necessary to assess the accuracy and reliability of the data. Finally, in preparation for the quality assurance / quality control (QA/QC) process, both the data and supporting documentation were archived by interceptor and site name in a folder directory structure. Additional details regarding data management can be found in Section 2.9 (Data Management Approach).

Once the current and historical data were compiled, the data then went through a series of established QA/QC protocols in order to determine reliability for use in sewershed characterization and for the estimation of dry and wet weather flows. These QA/QC protocols and procedures are discussed in detail in Section 3.4 (Quality Assurance Reviews for Flow Monitoring Data). Once the collected data were quality-reviewed, the amount of data considered to be reasonably reliable was quantified as a percentage for each monitoring site. This percentage was calculated by dividing the amount of missing and/or errant data by the total quantity of data collected. Of the 86 monitoring sites, 43 of them were determined to have 100% usable data, while five of them were determined to have 0% usable data for the entire monitoring period. Table 2-1 lists these monitoring sites with unreliable data and provides a short description of the quality concerns of the data collected. Overall, the final data capture percentage for all sanitary sewer flow monitors within the City was 89%, meaning that 89% of the total quantity of data collected from the 86 sanitary sewer monitoring locations was determined to be reasonably reliable.

Table 2-2 provides a list of all past and present sanitary sewer flow monitors located within the City. The table includes the interceptor sewer the monitor is located on or tributary to, the pipe diameter, the tributary drainage area and service population, tributary drainage area, land use statistics, the date(s) monitoring started and ended, the monitoring duration, and the percentage of data collected that was determined to be reasonably reliable.

From a system-wide perspective, the total area of sanitary sewer system within the City is approximately 40 square miles, and the total drainage area covered by all of the historical sanitary sewer flow monitors with quality rated data within the City is approximately 32 square miles. Thus, approximately 80 percent of the total sanitary sewer system within the City was monitored. Figure 2-1 is an overview map showing the locations of the sanitary sewer monitoring sites within the City. Figures 2-2 through 2-4 display the coverage provided by the flow monitoring sites at a greater level of detail and divide the City's separate sanitary sewer areas into northeast, northwest and southwest areas of the City, respectively. The manholes where monitoring was conducted are represented by green circles. The tributary sewershed areas are depicted by green shading. The majority of the monitoring sites provided wastewater flow data from individual tributary sewershed areas. Interceptor monitoring sites, on the other hand, included flows from all upstream composite tributary areas that discharge into the interceptor.

The completed SSES Phase 1 inventories and the subsequent QA/QC reviews and data assessments confirmed that the existing archived flow monitoring data for sewered areas within the City limits had sufficient geographical coverage, were up to date, and were sufficiently reliable to meet the needs and requirements of the SSES. The existing archive of collected wastewater flow data was verified to be sufficient to quantify and characterize dry and wet weather flow through the Water Department sanitary sewer system, quantify and characterize rainfall dependent infiltration and inflow from City sewershed areas, and identify any City sewershed areas that have relatively high wet weather flow. The monitored data collected from these sites should reflect the total flow generated from the sewershed areas, as the monitored areas do not included the two locations with documented SSO discharges. Additional flow monitoring data did not need to be collected to meet the requirements of the SSES. The existing available data can be successfully extrapolated to characterize dry and wet weather flow from unmonitored sewershed areas.

Table 2-1: Sanitary Sewer Flow Monitoring Locations with Unusable Data for the Duration of the Monitoring Period

MANHOLE ID	Data Start	Data End	Duration (months)	Data Capture Percentage	Comments
PC-0470	9/30/04	5/4/05	7	0%	The collected data have been determined to be unusable and will not be used for sewershed characterization. No field documentation for the entire monitoring period. The level data appears to be unreliable due to drifting and fouling.
S051-08-S0012	6/12/00	10/10/00	4	0%	The collected data have been determined to be unusable and will not be used for sewershed characterization. The metered velocities were reading significantly lower than field measured velocities throughout the entire monitoring period.
THL-B0705	4/15/03	6/24/03	2	0%	The collected data have been determined to be unusable and will not be used for sewershed characterization. The level data are very erratic and appears to drift throughout the monitoring period. This site was reinstalled at the end of 2012 and that data will be used for sewershed characterization.
USE-0400	11/8/01	11/21/01	< 1	0%	No field documentation to accompany the short period of data. Data will not be used for sewershed characterization.
W095-01-S0020	6/6/13	7/18/13	1	0%	The collected data have been determined to be unusable and will not be used for sewershed characterization. The velocity data are very erratic and the level data appears to drift throughout the monitoring period.
WHL-0265	5/3/00	9/14/00	4	0%	The velocity data are very erratic and has a large degree of uncertainty. This erratic data eclipses the magnitude of the monitored storm responses, thus making the monitoring data unsuitable for sewershed characterization.

Table 2-2: Summary of Available Sanitary Sewer Flow Monitoring Data Collected within the City of Philadelphia

Site	Interceptor	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population	Tributary Drainage Area Land Use [1]					Available Flow Monitoring Data			
					Industrial and Commercial	Recreational	Residential	Roads and Utilities	Undeveloped	Data Start	Data End[2]	Duration (months)	Data Capture Percentage[3]
BC-0010	Byberry Creek	48	3,271	40,961	36%	2%	53%	5%	3%	7/26/08	1/31/10	18.2	100%
BC-0055	Byberry Creek	51 x 48	2,715	33,648	41%	2%	48%	6%	3%	11/30/11	9/30/13	22.0	100%
BC-0200	Byberry Creek	42	2,326	23,909	46%	2%	43%	6%	4%	11/3/99	2/14/00	3.4	100%
BC-B0675	Byberry Creek	20	230	2,374	13%	5%	79%	1%	2%	1/1/09	12/31/09	12.0	92%
BC-B0755	Byberry Creek	18	275	4,752	7%	5%	84%	4%	0%	12/11/12	10/16/13	10.2	99%
BC-B1575	Byberry Creek	24	169	1,676	21%	0%	73%	3%	3%	5/18/01	6/30/02	13.4	98%
Q101-03-S0020	Byberry Creek	15	112	1,773	2%	0%	94%	4%	0%	10/21/11	12/4/12	13.5	100%
Q109-07-S0025	Byberry Creek	15	164	2,092	30%	5%	55%	2%	7%	12/11/12	9/30/13	9.6	100%
Q114-12-S0010	Byberry Creek	12	68	2,217	3%	0%	92%	4%	1%	1/27/12	2/3/13	12.3	99%
T089-04-S0055	Cheltenham	15	98	1,819	39%	0%	58%	1%	2%	12/1/11	4/4/12	4.1	100%
THL-B0705	Cheltenham	12	200	1,942	30%	1%	66%	0%	3%	4/15/03	6/24/03	2.3	0%
THL-B0705	Cheltenham	12	200	1,942	30%	1%	66%	0%	3%	12/11/12	9/30/13	9.6	100%
CV-0145	Cresheim Valley	27 x 18	882	9,340	28%	3%	65%	2%	2%	3/8/13	9/30/13	6.8	97%
W077-02-S0060	Cresheim Valley	15	225	1,810	9%	14%	74%	3%	0%	1/8/10	1/11/11	12.1	89%
W086-01-S0060	Cresheim Valley	18	225	2,546	6%	4%	89%	0%	2%	1/30/12	2/29/12	1.0	100%
IALL-B0355	Island Avenue Lower Level	24	214	1,308	0%	5%	29%	7%	58%	7/1/12	9/30/13	15.0	100%
IALL-B0810	Island Avenue Lower Level	20	211	3,779	18%	0%	65%	10%	7%	1/7/10	12/31/10	11.8	100%
IALL-B0862	Island Avenue Lower Level	24	202	2,201	29%	13%	38%	20%	0%	2/16/02	9/9/02	6.7	80%
M-0045	Monoshone	30	868	15,682	12%	1%	83%	1%	3%	6/1/13	9/30/13	4.0	89%
W068-05-S0047	Monoshone	30	520	8,863	10%	0%	88%	0%	2%	11/30/11	12/3/12	12.1	99%

Site	Interceptor	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population	Tributary Drainage Area Land Use [1]					Available Flow Monitoring Data			
					Industrial and Commercial	Recreational	Residential	Roads and Utilities	Undeveloped	Data Start	Data End[2]	Duration (months)	Data Capture Percentage[3]
W068-05-S0078	Monoshone	30	691	11,780	9%	0%	87%	0%	3%	10/17/00	4/23/01	6.2	81%
P108-17-S0010	Paul's Run	12	79	675	23%	0%	70%	6%	0%	9/24/10	9/29/11	12.2	97%
P113-04-S0463	Paul's Run	12	80	1,327	8%	12%	80%	0%	0%	11/29/11	6/6/12	6.2	99%
PR-0060	Paul's Run	30	1,421	23,030	16%	2%	74%	3%	5%	11/30/11	12/6/12	12.2	100%
PR-0150	Paul's Run	27	1,069	19,728	19%	3%	69%	3%	6%	10/20/11	12/6/12	13.6	99%
PR-B0405	Paul's Run	24	441	9,757	15%	6%	72%	3%	3%	12/11/12	9/30/13	9.6	100%
PR-B0455	Paul's Run	24	391	9,369	11%	7%	77%	2%	3%	8/9/99	4/27/00	8.6	100%
PR-B0540	Paul's Run	15	133	2,221	6%	0%	85%	3%	5%	7/11/01	9/10/02	14.0	90%
P104-09-S0025	Pennypack Creek	10	50	993	1%	0%	96%	2%	1%	1/1/11	6/30/12	18.0	99%
P105-06-S0035	Pennypack Creek	18	184	3,174	24%	0%	51%	8%	18%	6/11/10	6/13/11	12.1	100%
PP-0215	Pennypack Creek	63 x 54	10,986	115,729	13%	3%	74%	2%	8%	6/6/13	9/30/13	3.8	100%
PP-B0650	Pennypack Creek	15	181	5,372	8%	0%	90%	0%	2%	8/12/99	4/28/00	8.5	100%
PP-B0790	Pennypack Creek	15	187	4,893	14%	0%	81%	0%	5%	8/10/99	4/10/00	8.0	89%
PP-B0840	Pennypack Creek	24	368	7,121	7%	0%	86%	0%	6%	8/30/99	6/12/00	9.4	100%
PP-B1035	Pennypack Creek	15	392	4,469	14%	1%	75%	0%	10%	3/9/13	9/30/13	6.7	100%
PP-B1080	Pennypack Creek	24	2,549	11,596	13%	3%	77%	1%	6%	1/27/12	3/19/12	1.7	100%
PP-B1215	Pennypack Creek	21	2,225	9,181	15%	3%	75%	1%	6%	11/3/99	6/12/00	7.3	98%
PC-0010	Poquessing Creek	60	10,349	74,868	22%	3%	66%	2%	7%	4/1/12	1/16/13	9.5	100%
PC-0010	Poquessing Creek	60	10,349	74,868	22%	3%	66%	2%	7%	7/29/08	1/31/10	18.1	100%
PC-0045	Poquessing Creek	60	10,330	74,868	22%	3%	66%	2%	7%	7/29/08	7/9/09	11.3	93%
PC-0470	Poquessing Creek	12	145	849	49%	4%	39%	5%	4%	9/30/04	5/4/05	7.1	0%

Site	Interceptor	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population	Tributary Drainage Area Land Use [1]					Available Flow Monitoring Data			
					Industrial and Commercial	Recreational	Residential	Roads and Utilities	Undeveloped	Data Start	Data End[2]	Duration (months)	Data Capture Percentage[3]
PC-1210	Poquessing Creek	24	732	6,745	13%	0%	81%	1%	5%	8/12/99	4/27/00	8.5	100%
PC-B1330	Poquessing Creek	18	478	9,427	20%	4%	62%	6%	8%	2/14/09	1/31/10	11.5	100%
PC-B1360	Poquessing Creek	18	374	6,435	25%	4%	53%	8%	10%	3/9/13	9/30/13	6.7	99%
PC-B1440	Poquessing Creek	12	212	1,894	16%	0%	77%	3%	4%	10/1/04	5/18/05	7.5	96%
PC-B1530	Poquessing Creek	18	224	219	87%	1%	6%	0%	5%	1/1/09	1/3/10	12.1	100%
Q107-02-S0025	Poquessing Creek	15	176	2,954	15%	11%	67%	5%	2%	10/1/03	8/5/04	10.2	62%
Q110-17-S0015	Poquessing Creek	12	59	709	16%	4%	70%	8%	1%	5/31/13	9/30/13	4.0	100%
Q120-02-S0010	Poquessing Creek	12	85	1,131	28%	0%	66%	3%	3%	12/8/07	12/10/08	12.1	48%
Q120-08-S0010	Poquessing Creek	12	108	1,069	10%	8%	78%	0%	4%	3/26/08	3/18/09	11.7	100%
Q120-10-S0010	Poquessing Creek	10	67	323	1%	23%	75%	0%	1%	12/7/07	2/24/08	2.6	100%
Q120-11-S0010	Poquessing Creek	12	81	932	25%	0%	63%	10%	3%	12/6/07	12/9/08	12.1	99%
Q121-02-S0015	Poquessing Creek	10	73	1,076	16%	0%	70%	0%	14%	12/11/07	12/9/08	12.0	96%
P090-02-S0090	Sandy Run	27	581	11,971	19%	2%	74%	3%	3%	5/30/13	9/30/13	4.0	96%
P090-02-S0590	Sandy Run	24	635	9,971	21%	10%	65%	3%	1%	12/11/12	9/30/13	9.6	100%
P090-02-S0715	Sandy Run	24	388	5,559	22%	6%	67%	3%	1%	11/29/11	12/5/12	12.2	100%
P090-02-S0865	Sandy Run	24	148	1,537	52%	8%	39%	0%	1%	12/11/12	9/30/13	9.6	100%
T088-01-S0050	Tacony High Level	24	497	12,452	30%	1%	66%	1%	1%	10/21/11	12/3/12	13.4	100%
T088-01-S0155	Tacony High Level	18	380	9,816	28%	2%	68%	0%	1%	8/10/99	6/12/00	10.1	100%
T088-01-S0220	Tacony High Level	15	62	3,044	7%	0%	92%	0%	1%	12/11/12	9/30/13	9.6	99%
THL-B0375	Tacony High Level	15	186	4,704	11%	19%	67%	3%	1%	11/9/10	6/3/12	18.8	98%
P083-03-S0050	Upper Delaware Low Level	24	270	4,775	24%	9%	60%	3%	5%	10/12/11	7/29/13	21.6	98%

Site	Interceptor	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population	Tributary Drainage Area Land Use [1]					Available Flow Monitoring Data			
					Industrial and Commercial	Recreational	Residential	Roads and Utilities	Undeveloped	Data Start	Data End[2]	Duration (months)	Data Capture Percentage[3]
UDLL-0270	Upper Delaware Low Level	72 x 62	14,644	118,393	28%	3%	60%	3%	6%	10/5/12	9/30/13	11.8	100%
S051-05-S0020	Upper Schuylkill East Side	15	90	2,264	30%	1%	65%	0%	5%	2/16/01	4/24/01	2.2	100%
S051-08-S0012	Upper Schuylkill East Side	15	252	6,501	20%	4%	71%	0%	5%	6/12/00	10/10/00	3.9	0%
S051-08-S0175	Upper Schuylkill East Side	12	68	2,092	9%	1%	80%	0%	9%	2/13/01	9/10/01	6.9	86%
S059-01-S0010	Upper Schuylkill East Side	15	134	1,565	15%	2%	70%	2%	11%	12/12/12	9/30/13	9.6	98%
S059-02-S0010	Upper Schuylkill East Side	10	86	2,029	18%	1%	78%	0%	3%	6/27/00	9/27/01	15.0	74%
S059-04-S0035	Upper Schuylkill East Side	15	141	3,734	15%	1%	77%	0%	7%	6/13/00	9/10/01	14.9	83%
USE-0365	Upper Schuylkill East Side	48	773	13,233	22%	1%	63%	2%	12%	4/1/12	1/7/13	9.2	100%
USE-0365	Upper Schuylkill East Side	48	773	13,233	22%	1%	63%	2%	12%	5/1/10	8/23/10	3.7	100%
USE-0400	Upper Schuylkill East Side	43 x 34	637	9,351	20%	1%	62%	2%	14%	11/8/01	11/21/01	0.4	0%
USE-0500	Upper Schuylkill East Side	43 x 34	397	3,193	21%	1%	56%	3%	20%	4/1/12	6/30/12	3.0	100%
USE-0660	Upper Schuylkill East Side	31	246	1,627	19%	0%	52%	4%	26%	7/12/12	8/4/13	12.8	100%
USE-0760	Upper Schuylkill East Side	32	184	1,310	4%	0%	63%	3%	31%	11/29/07	11/30/08	12.1	100%
USE-0855	Upper Schuylkill East Side	15	171	1,260	3%	0%	65%	2%	30%	5/4/00	4/24/01	11.7	85%
W067-01-S0060	Wissahickon High Level	15	257	3,990	11%	6%	77%	0%	6%	6/1/13	9/30/13	4.0	100%
W095-01-S0020	Wissahickon High Level	15	57	93	17%	13%	69%	0%	1%	6/6/13	7/18/13	1.4	0%
WHL-0110	Wissahickon High Level	54	1,834	13,706	16%	6%	70%	2%	6%	5/30/13	9/30/13	4.0	100%
WHL-0110	Wissahickon High Level	52.25	1,834	13,706	16%	6%	70%	2%	6%	1/18/01	3/31/02	14.4	99%
WHL-0265	Wissahickon High Level	43	269	831	9%	18%	64%	1%	8%	5/3/00	9/14/00	4.4	0%
W075-01-S0018	Wissahickon Low Level	12	141	1,185	20%	4%	57%	11%	9%	5/31/13	7/9/13	1.3	100%
W076-13-S0100	Wissahickon Low Level	12	110	2,175	5%	3%	85%	4%	3%	7/9/10	6/30/11	11.7	98%

Site	Interceptor	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population	Tributary Drainage Area Land Use [1]					Available Flow Monitoring Data			
					Industrial and Commercial	Recreational	Residential	Roads and Utilities	Undeveloped	Data Start	Data End[2]	Duration (months)	Data Capture Percentage[3]
WLL-0028	Wissahickon Low Level	42 x 28	5,639	37,760	11%	8%	70%	2%	9%	8/11/10	8/11/11	12.0	98%
WLL-0100	Wissahickon Low Level	36.5	5,626	37,746	11%	8%	70%	2%	9%	5/30/13	9/30/13	4.0	100%
WLL-0105	Wissahickon Low Level	36	5,626	37,746	11%	8%	70%	2%	9%	10/1/00	11/6/01	13.2	81%
WLL-0332	Wissahickon Low Level	36	4,966	27,664	11%	8%	70%	2%	9%	5/3/00	2/1/01	9.0	77%
WLL-0565	Wissahickon Low Level	27.5	4,214	19,592	10%	9%	70%	1%	9%	3/8/13	9/30/13	6.8	100%
WBR-0375	Wooden Bridge Run	24	301	4,310	22%	0%	69%	8%	1%	1/14/04	6/28/05	17.5	64%
WBR-B0585	Wooden Bridge Run	18	278	3,693	35%	0%	54%	7%	3%	1/1/03	9/9/04	20.3	81%

(1) Land Use data courtesy of The Delaware Valley Regional Planning Commission. Data was collected from aerials flown in Spring, 2010. Changes to Land Use occurring after Spring, 2010 are not reflected.

(2) As of September 30, 2013

(3) Data capture percentage is defined as monitored flow data that was deemed to be reasonably reliable after undergoing QA/QC reviews. This percentage reflects the amount of reasonably reliable data that were analyzed within the date ranges listed under the "Data Start" and "Data End" columns.

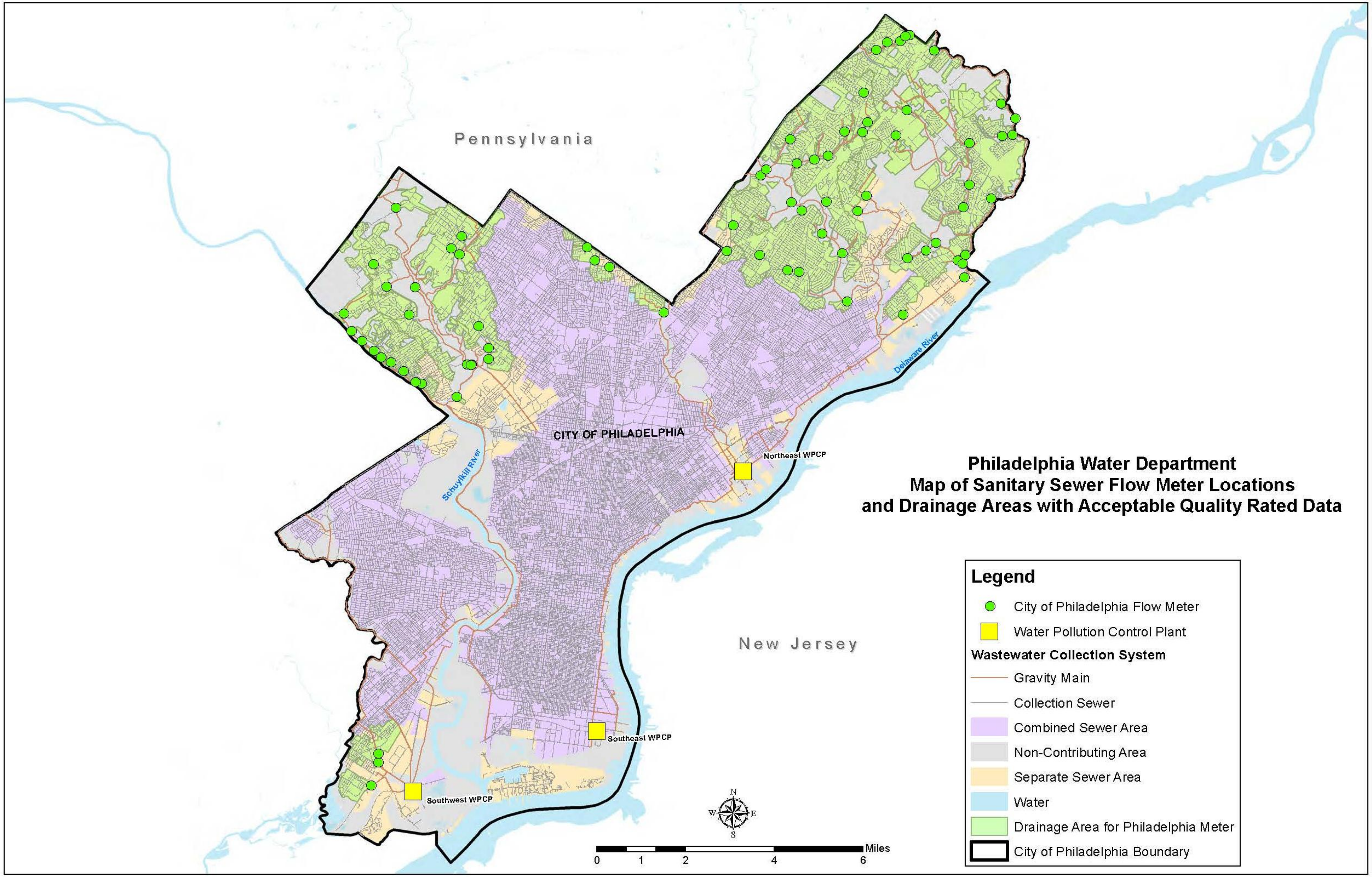


Figure 2-1: Map of the City of Philadelphia Sanitary Sewer Flow Meter Locations and Tributary Drainage Areas

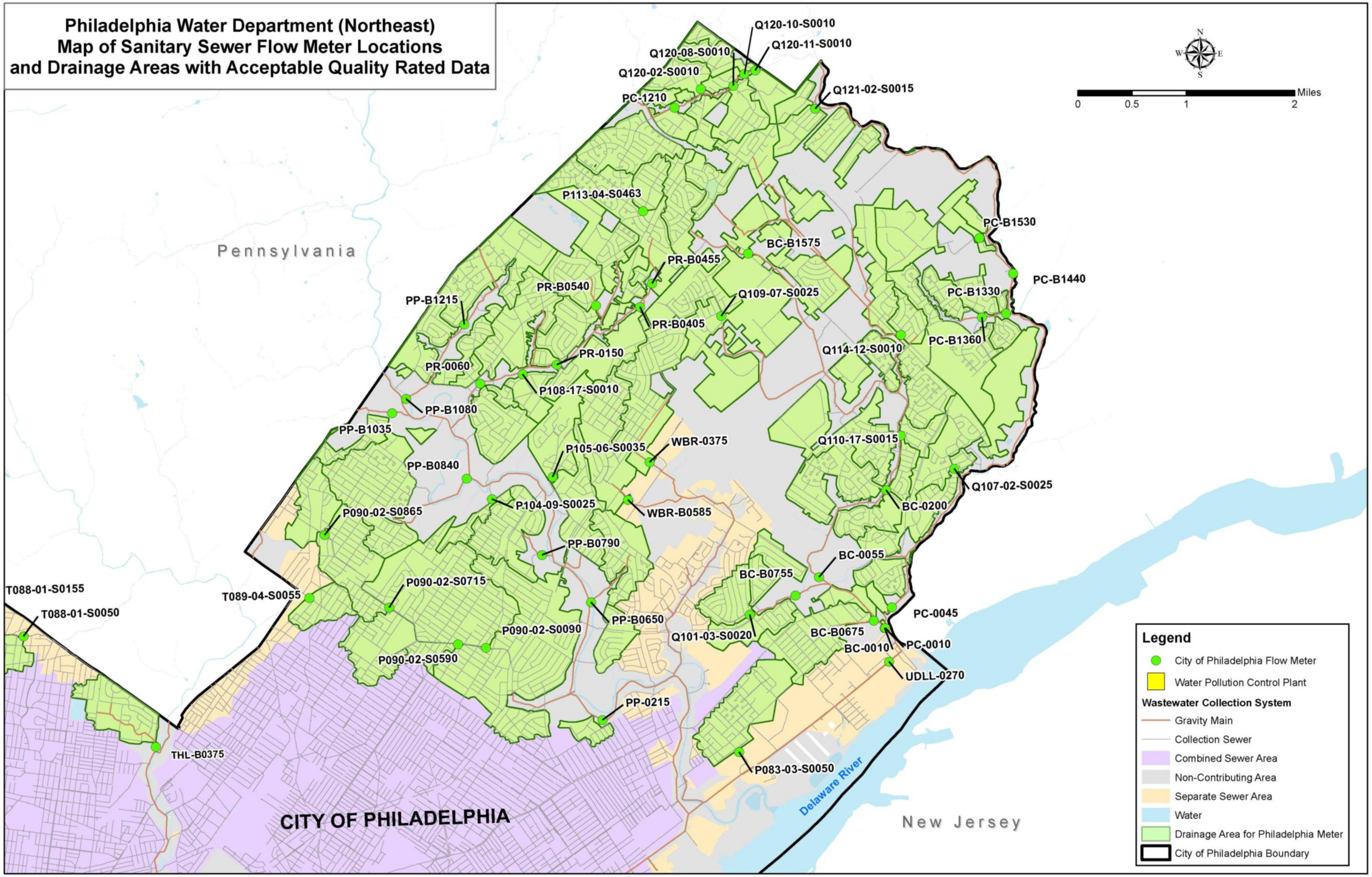


Figure 2-2: Map of the City of Philadelphia Sanitary Sewer Flow Meter Locations and Tributary Drainage Areas (Northeast Area)

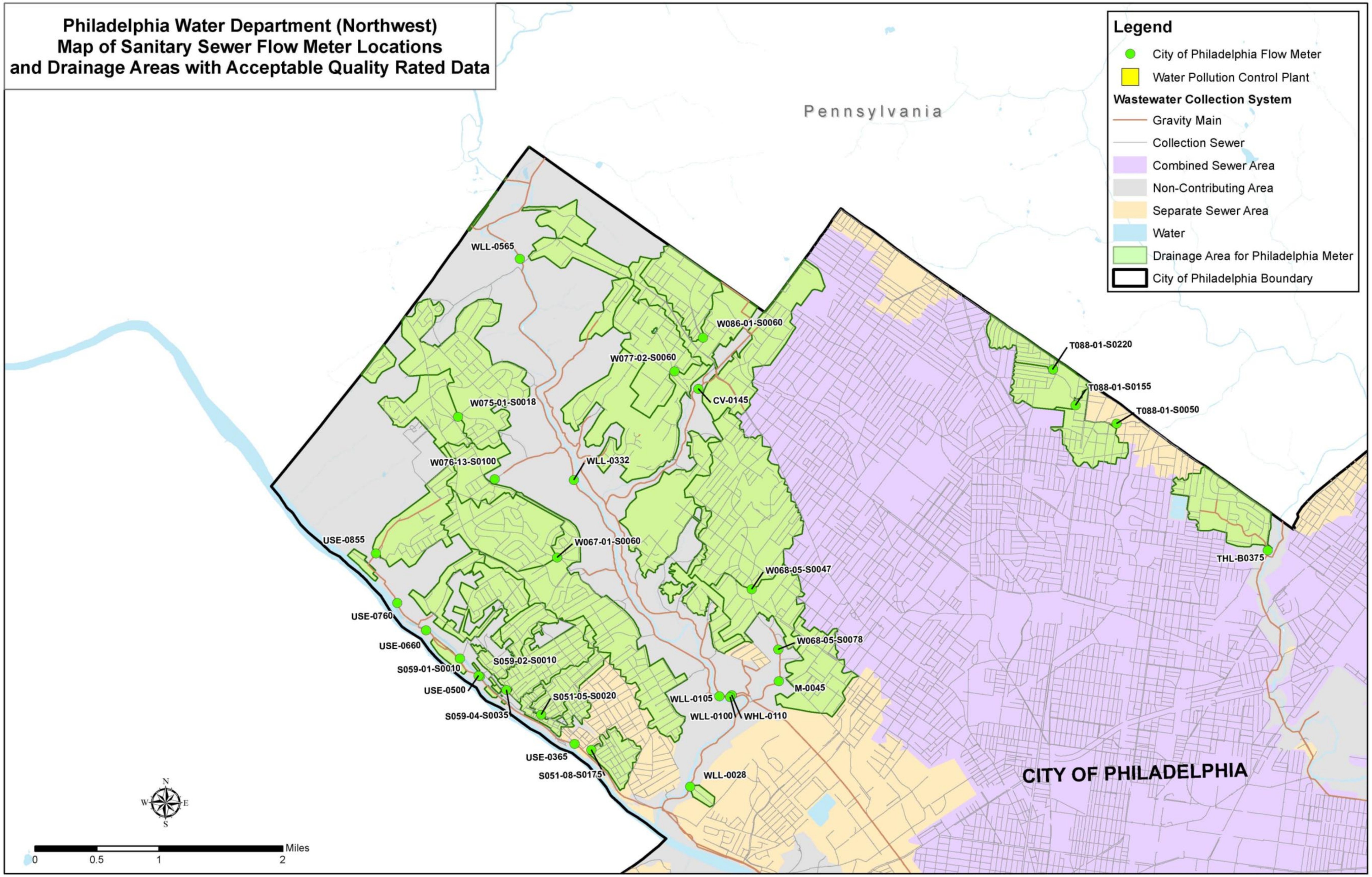


Figure 2-3: Map of the City of Philadelphia Sanitary Sewer Flow Meter Locations and Tributary Drainage Areas (Northwest Area)

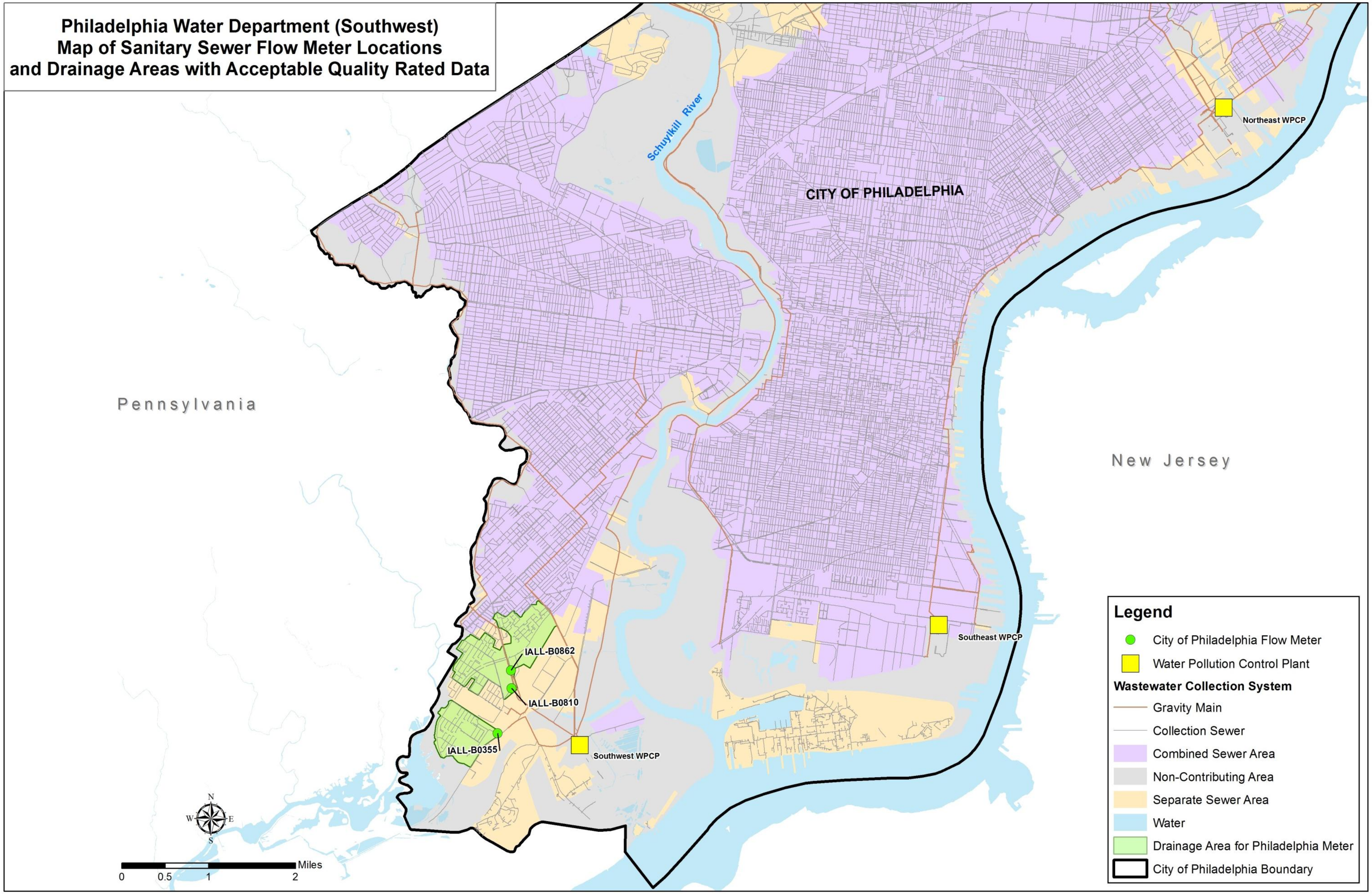


Figure 2-4: Map of the City of Philadelphia Sanitary Sewer Flow Meter Locations and Tributary Drainage Areas (Southwest Area)

2.2 Sanitary Sewer Flow Monitoring Data from Outlying Community Billing Meters

The Water Department maintains a network of permanent continuously recording sanitary sewer flow meters at all major points of connection from outlying communities contributing sanitary sewer flows to the City wastewater collection system. These meters are used to quantify the flow contributions to the City sanitary sewer system from outlying customer communities for purposes of billing and evaluating compliance with contractual flow limits.

In addition to the permanent outlying community billing meter installations, the City identifies non-major points of connection with outlying community sanitary sewer collection systems as standardized billing connections. The City has deployed portable flow meters at many of these locations for approximately three months once every three years to identify changes in flow quantities and update standardized billing rates if needed.

While primarily established for estimating flow contributions from outlying communities for billing purposes and evaluating contractual flow limits, these monitors can be also used for characterization of tributary sewershed areas, estimating average dry weather and peak wet weather flows, base wastewater flow (BWWF), groundwater infiltration (GWI), and rainfall dependent infiltration and inflow (RDII).

The range of completed activities conducted for the Phase 1 SSES included a review of the historical and current sanitary sewer flow monitoring data collected at the outside billing meter locations. The existing data were identified and evaluated to assess data availability. During this inventory and assessment, it was determined that since the commencement of monitoring, the Water Department has collected data at 53 billing meter locations. Per the *Implementation and Adaptive Management Plan* (IAMP), this report documents the completed Phase 1 scope of work and the Phase 2 work for the separate sanitary sewershed areas located within the City limits. On June 1, 2015, the Water Department will submit an Outlying Communities Report documenting the completed Phase 2 work for the network of sanitary sewer flow monitors along the City limits and outlying community boundaries that contribute wastewater flow to the Water Department collection system and water pollution control plants.

Table 2-3 provides a list of all past and present sanitary sewer flow monitors located along the outlying communities. The table describes the interceptor sewer the monitor is located on or tributary to, the outlying contract community, the monitoring location, the meter type, the pipe diameter, the tributary drainage area, and the tributary population.

Figure 2-5 is an overview map showing the location of the outlying community billing meters. The manholes where the monitoring was conducted are represented by blue circles. The tributary drainage areas are depicted by the blue shading. Figures 2-6 through 2-8 display the coverage provided by the flow monitoring sites at a greater level of detail in the northeast, northwest and southwest areas of the City, respectively.

Table 2-3: Outlying Community Billing Meter Locations

SITE ID	Interceptor	Contract Community	Location	Meter Type	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population
MA_1	Pennypack Creek	Abington	Pine Road	Portable	10	32	169
MA_2	Pennypack Creek	Abington	Pine Road and Pennypack Creek	Permanent	20	3,161	10,222
MA_3	Pennypack Creek	Abington	Shady Lane	Portable	12	353	3,456
MA_4	Pennypack Creek	Abington	Pine Road	Portable	10	120	432
MBE_1	Poquessing Creek	Bensalem	End of Interplex Drive, Kay & Poquessing Creek	Permanent	12	241	879
MBE_2	Poquessing Creek	Bensalem	Dunks Ferry Road and Mechanicsville Road	Permanent	10	212	1,894
MBE_3	Poquessing Creek	Bensalem	Emerson Lane and Evelyn Avenue	Portable	12	90	554
MBE_4	Poquessing Creek	Bensalem	Red Lion Road and Frankford Avenue	Portable	12	193	1,377
MBE_5	Poquessing Creek	Bensalem	Grant Avenue and James Street	Permanent	24	1,024	2,563
MBE_6	Poquessing Creek	Bensalem	Gravel Pike at Poquessing Creek	Permanent	16	742	4,567
MBE_7	Poquessing Creek	Bensalem	Morrow Drive and Bellview Drive	Permanent	12	204	2,110
MBE_8	Poquessing Creek	Bensalem	Bensalem Country Club	Portable	12	230	1,318
MBE_9	Poquessing Creek	Bensalem	Tillman Drive and Poquessing Creek	Portable	10	290	2,023
MBE_10	Poquessing Creek	Bensalem	Colonial Avenue at Poquessing Creek	Portable	12	37	272
MBE_11	Poquessing Creek	Bensalem	GE Water parking lot - Somerton Road	Portable	8	71	0
MBE_12	Poquessing Creek	Bensalem	Creekside Apartments North	Portable	12	36	1,288
MBE_13	Poquessing Creek	Bensalem	Route 1 and Poquessing Creek	Permanent	10	17	12
MBE_14	Poquessing Creek	Bensalem	Old Lincoln Highway and Old Trevose Road	Permanent	8	15	30
MBE_15	Poquessing Creek	Bensalem	Knights Road and Poquessing Creek	Permanent	9.5	145	849
MBE_16	Poquessing Creek	Bensalem	Creekside Apartments South	Permanent	12	25	904

SITE ID	Interceptor	Contract Community	Location	Meter Type	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population
MBE_17	Poquessing Creek	Bensalem	Beechwood Development	Permanent	8	27	3
MB-1	Upper Delaware Low Level	Bucks	Totem Road	Permanent	42	24,992	96,028
MC_1	Tacony High Level	Cheltenham	Cheltenham Avenue	Permanent	16	203	3,533
MC_2	Tacony High Level	Cheltenham	Tookany Circle	Permanent	36	8,444	64,742
MC_3	Tacony High Level	Cheltenham	Fillmore Street	Permanent	10	139	1,208
MD_1	Southwest Main Gravity	DELCORA	Penrose Avenue	Permanent	66	41,340	277,202
ML_1	Southwest Main Gravity	Lower Merion	51st Street	Permanent	24	2,671	15,278
ML_2	Southwest Main Gravity	Lower Merion	59th Street	Portable	8	55	379
ML_3	Southwest Main Gravity	Lower Merion	63rd Street	Permanent	14	618	3,782
ML_4	Cobbs Creek High Level	Lower Merion	66th Street	Permanent	24	7,486	26,716
ML_5	Cobbs Creek High Level	Lower Merion	73rd Street	Permanent	16	1,064	8,883
ML_6	Southwest Main Gravity	Lower Merion	Conshohocken Avenue	Permanent	8	58	420
ML_7	Southwest Main Gravity	Lower Merion	City Avenue	Permanent	12	205	373
MLM_1	Poquessing Creek	Lower Moreland	Philmont Avenue and Byberry Road	Permanent	10	448	1,748
MLM_2	Poquessing Creek	Lower Moreland	Welsh Road and Huntington Pike	Permanent	12	1,797	6,529
MLM_3	Poquessing Creek	Lower Moreland	Ramage Run and City Limit Boundary	Portable	8	96	344
MLM_4	Pennypack Creek	Lower Moreland	Pine Road	Portable	10	22	80
MLM_5	Pennypack Creek	Lower Moreland	Jonathan Place	Portable	8	13	54
MLM_6	Pennypack Creek	Lower Moreland	Pine Road	Portable	8	17	79
MLM_7	Pennypack Creek	Lower Moreland	Welsh Road	Portable	10	23	87
MSH_1	Poquessing Creek	Lower Southampton	Trevose Road at Poquessing Creek	Permanent	30	5,132	21,642

SITE ID	Interceptor	Contract Community	Location	Meter Type	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Population
MSH_2	Poquessing Creek	Lower Southampton	Lukens Street	Portable	8	60	282
MSHX_1	Poquessing Creek	Lower Southampton	Winding Lane	Portable	8	121	575
MSHX_2	Poquessing Creek	Lower Southampton	Trevose Road	Portable	27	1,175	11,202
MS_1	Wissahickon Low Level	Springfield	Northwestern Avenue and Thomas Road	Portable	12	77	404
MS_2	Wissahickon Low Level	Springfield	Northwestern Avenue and Wissahickon Creek	Permanent	30	2,648	12,155
MS_3	Wissahickon Low Level	Springfield	Erdenheim Avenue and Stenton Avenue	Permanent	20	1,429	6,941
MS_4	Cresheim Valley	Springfield	Stenton Avenue	Portable	12	64	399
MS_5	Cresheim Valley	Springfield	Cresheim Valley Drive	Portable	8	69	410
MS_6	Cresheim Valley	Springfield	Woodbrook Avenue and Stenton Avenue	Permanent	12	189	1,169
MS_7	Cresheim Valley	Springfield	Stenton Avenue	Portable	12	13	110
MS_8	Wissahickon Low Level	Springfield	Ridge Avenue	Portable	10	5	11
MUD_1	Cobbs Creek Low Level	Upper Darby	South 60th Street and Cobbs Creek Parkway	Permanent	24	7,668	100,393

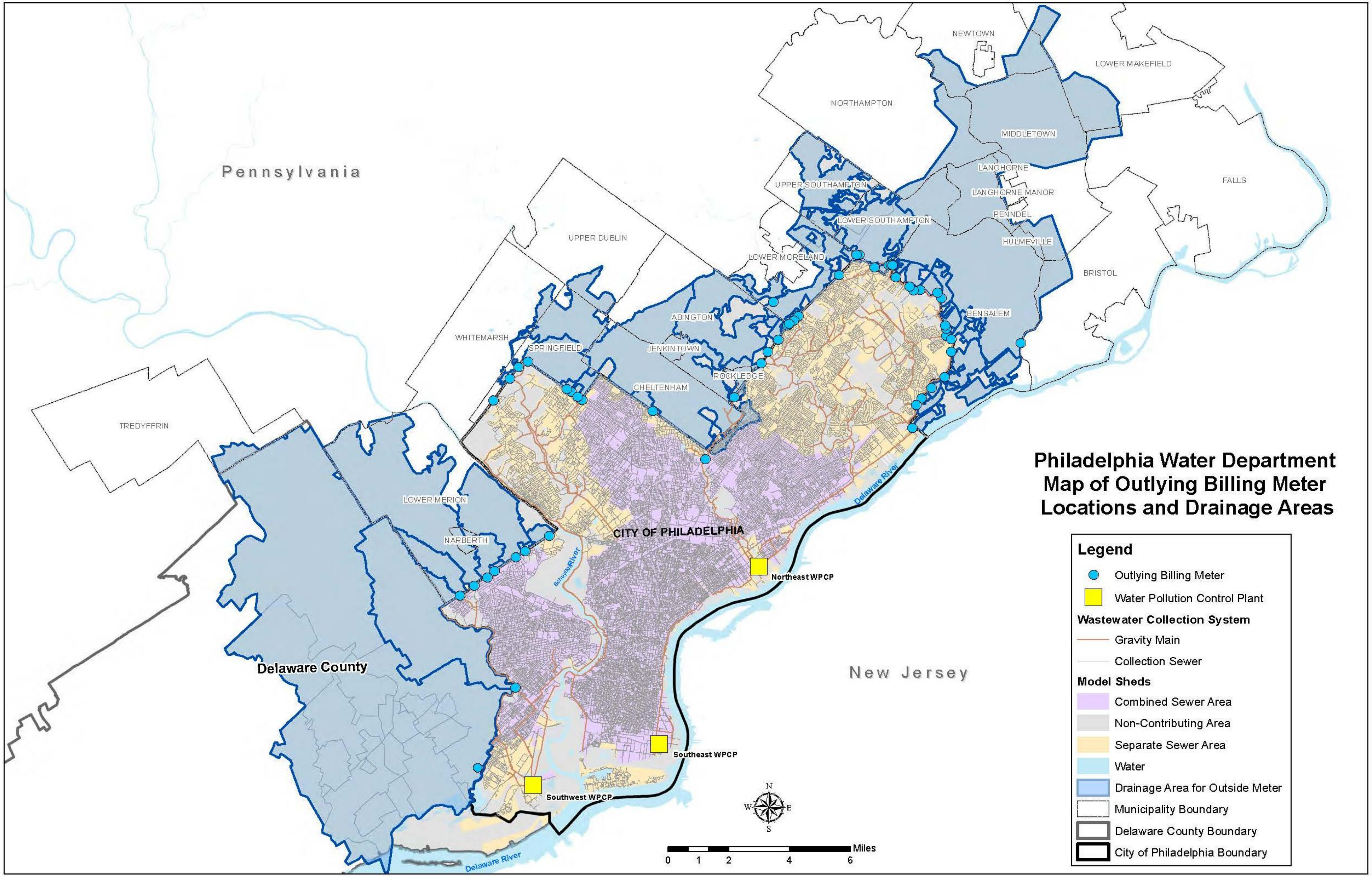


Figure 2-5: Map of the Outlying Community Billing Meter Locations and Tributary Drainage Areas

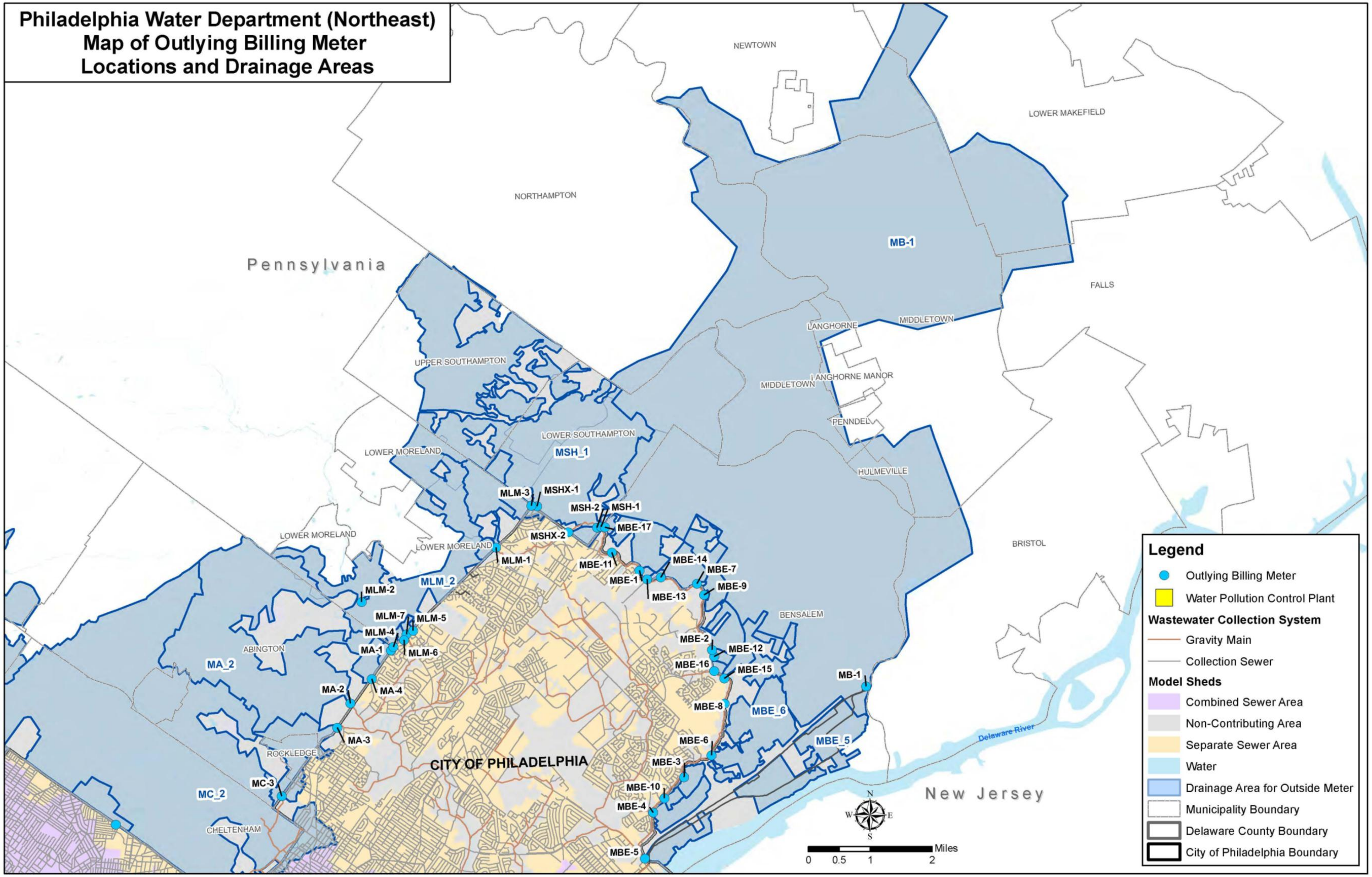


Figure 2-6: Map of the Outlying Community Billing Meter Locations and Tributary Drainage Areas (Northeast Area)

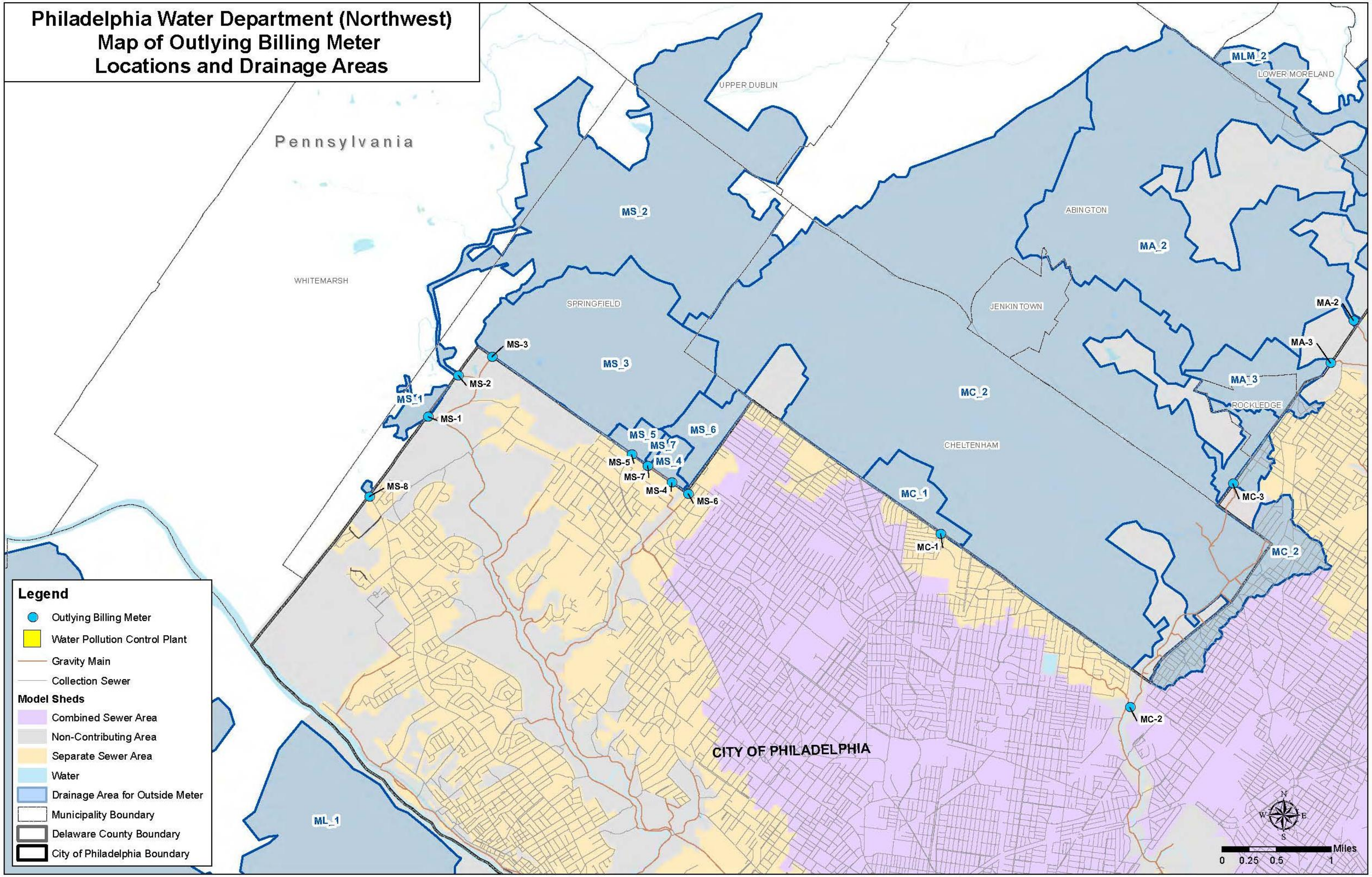


Figure 2-7: Map of the Outlying Community Billing Meter Locations and Tributary Drainage Areas (Northwest Area)

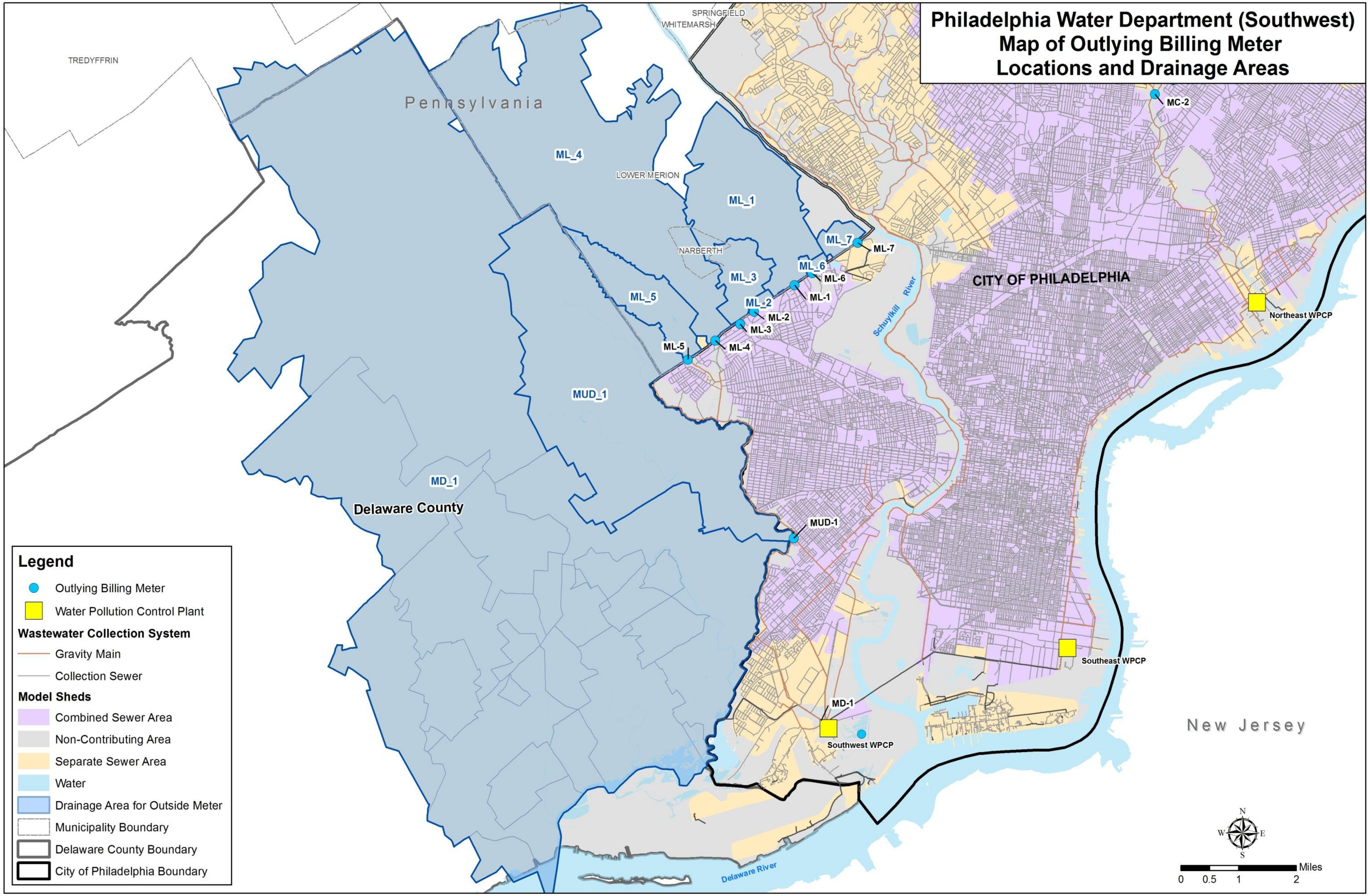


Figure 2-8: Map of the Outlying Community Billing Meter Locations and Tributary Drainage Areas (Southwest Area)

The SSES Phase 1 inventories, quality assurance / quality control reviews, and data assessments were successfully completed for the existing archived flow monitoring data from the network of permanent continuously recording flow meters at the major points of connection from outlying community sewershed areas that contribute wastewater flow to the Water Department system. The monitoring data from the temporary billing meter sites has limited value in quantifying extraneous flow during wet weather, but the total tributary area to these sites is relatively small. The completed activities confirmed that the historical data had sufficient geographical coverage, were up to date, and were sufficiently reliable to meet the needs and requirements of the SSES. The existing archive was verified to be sufficient to quantify and characterize dry and wet weather flow from the outlying community areas that are conveyed through the Water Department sanitary sewer system, quantify and characterize RDII from outlying community areas, and identify any outlying community sewershed areas that have relatively high wet weather flow. The monitored data may not always reflect the total flow generated from the outlying community sewershed areas, as it would not include any flows lost from possible SSO discharges upstream in the municipal collection systems. Additional flow monitoring data did not need to be collected to meet the requirements of the SSES, although future analyses will need to address any lost flow volumes from upstream SSO discharges. The existing available data from the network of permanent billing meter sites can be successfully extrapolated to characterize dry and wet weather flow from unmonitored sewershed areas.

2.3 Historical Precipitation Data within the City and Outlying Community Areas

Phase 1 of the SSES included a review and assessment of the available historic precipitation data. Precipitation data are a fundamental component of the Water Department's SanitarySewer System (SSS) monitoring program. Accurate and representative precipitation data has been, and will continue to be, used in conjunction with the SSS flow monitoring data to conduct sewershed characterization analyses and to validate the regional hydrologic and hydraulic (H&H) models developed by the Water Department.

In conjunction with the Phase 1 monitoring activities the Water Department has implemented, there are four primary sources of precipitation data used in the SSES.

- The Philadelphia International Airport (PHL) rain gage
- The Water Department's city-wide rain gage network
- Gage adjusted radar rainfall system (GARR)
- Area-weighted, sewershed specific precipitation data

The availability of the four categories of precipitation data are detailed in Table 2-4 below. The remainder of this section will focus on the first three sources of data. The area-weighted sewershed specific precipitation data will be briefly discussed here; however, it is discussed in detail in Section 3.2 (Refinement and Verification of Sewershed Precipitation) of this report. Section 3.2 will describe how this source of precipitation data is derived and also how it is used in conjunction with the United States Environmental Protection Agency's Sanitary Sewer Overflow Analysis and Planning (SSOAP) toolbox to perform subsequent sewershed characterization analyses.

Table2-4: Precipitation Data Utilized in the SSES

Precipitation Data Source	Data Start	Data End	Primary Use
PHL Rain Gage	1940	Present	Establishing long-term precipitation characteristics over the Water Department service area
City-wide Rain Gage Network	1990	Present	Flow data QA/QC for pre and post 2010 flow data, and sewershed characterization for pre 2010 flow data
Calibrated Radar Rainfall System	2010	Present	Flow data QA/QC for post 2010 flow data
Sewershed Specific Data	2010	Present	Sewershed characterization for post 2010 flow data

2.3.1 The Philadelphia International Airport Rain Gage

The first source of precipitation data used in the SSES is the PHL rain gage. The data gathered from this gage was used to establish long-term precipitation characteristics over the Water Department service area. Data from this gage were available from 1940 through the present. While this gage provides a long-term record, it does not account for the spatial distribution of rainfall over the service area. Section 4.1 (Precipitation Data Analysis Results) further discusses these long-term characteristics and how they were derived.

2.3.2 The Water Department's City-Wide Rain Gage Network

The Water Department maintains a rain gage network consisting of 24 tipping bucket rain gages located throughout the City that record rainfall depths (minimum recorded depth of 0.01 inches) in 2.5-minute increments. The Water Department data is considered reliable from 1990 through the present, with several of the 24 gages replaced with heated units beginning in the year 2004 in order to allow for accurate measurement of frozen precipitation events. The impacts of the unheated gages prior to 2004 needed to be taken into account, but the majority of the data utilized for the Phase 2 SSES analyses were collected after 2004. The raw 2.5-minute tipping bucket rain gage data was extracted from a link to the Water Department Collector System's real-time control unit (RTU) database which collects data directly via automatic telephone polling of the gages. The Water Department's raw 2.5-minute data were then summed to fixed 15-minute intervals. The approximate locations of the 24 Water Department rain gages are presented in Figure 2-9.

2.3.3 Gage Adjusted Radar Rainfall Measurements

Like any rain gage network, the City rain gage network cannot fully quantify and characterize the spatial variability of precipitation volumes and patterns that occur between the gage locations. To better characterize the natural spatial variability of rainfall, the Water Department obtained a more spatially detailed set of rainfall estimates to be used along with their existing rain gage network. An engineering firm, specializing in providing radar rainfall data, generated gage adjusted radar rainfall (GARR) data with a 1 km by 1 km pixel resolution in 15 minute reporting increments covering the Water Department's service area for the period of January 2010 through the present. This high-resolution, spatially distributed precipitation data were acquired for the SSS flow monitoring program and the calibration of H&H models as part of the Phase 1 and Phase 2 SSES activities.

In order to produce quality controlled GARR over the Water Department service area, the radar rainfall provider utilizes the National Weather Service's (NWS) Next Generation Weather Radar (NEXRAD). The NEXRAD program generates products used for estimating spatially variable rainfall data. The Water Department's rain gage data, along with neighboring United States Geological Survey (USGS) and NWS rain gages, are used to calibrate NEXRAD data to create a detailed and accurate rainfall record that preserves the total rainfall volume reported at the gages while incorporating the spatial variability provided by the NEXRAD data. In the production of GARR, radar rainfall is bias corrected through comparison with rain gage accumulations. Due to the large extent of the GARR grid, a local bias adjustment method is used to adjust the radar rainfall using the ratio of gage to radar accumulations from surrounding gages with the closest gage having the most weight. The local bias approach distributes the variation of bias over the region, and is computed and applied to the data.

Precipitation data from as many as 40 gages were used to adjust the radar. The City of Philadelphia provided locations and data for 24 Water Department rain gages. In addition, rain gage data were obtained from ten USGS stations and six NWS Automated Surface Observing System (ASOS) stations. The City also provided GIS files showing the extent of the system, which determined the extent of the 1 km by 1 km pixel domain. Figure 2-9 depicts the spatial distribution of the GARR network along with locations of the 24 Water Department rain gages. Note that USGS and NWS rain gages used for producing the GARR are located outside the bounds of the GARR grid.

2.3.4 Area-Weighted Sewershed Specific Precipitation Data

In addition to acquiring the calibrated radar rainfall data, the Water Department then distributed this data to the specific sewershed areas tributary to each of the individual flow monitoring locations. This was done by intersecting the delineated tributary drainage areas (described in Section 3.1) for each flow monitor with the 1 km by 1 km pixel grid, and calculating area-weighted precipitation data for each tributary drainage area. By doing this, a precipitation data set unique to each flow monitor's tributary drainage area was produced. More information regarding this process is found in Section 3.2 (Refinement and Verification of Sewershed Precipitation) of this report.

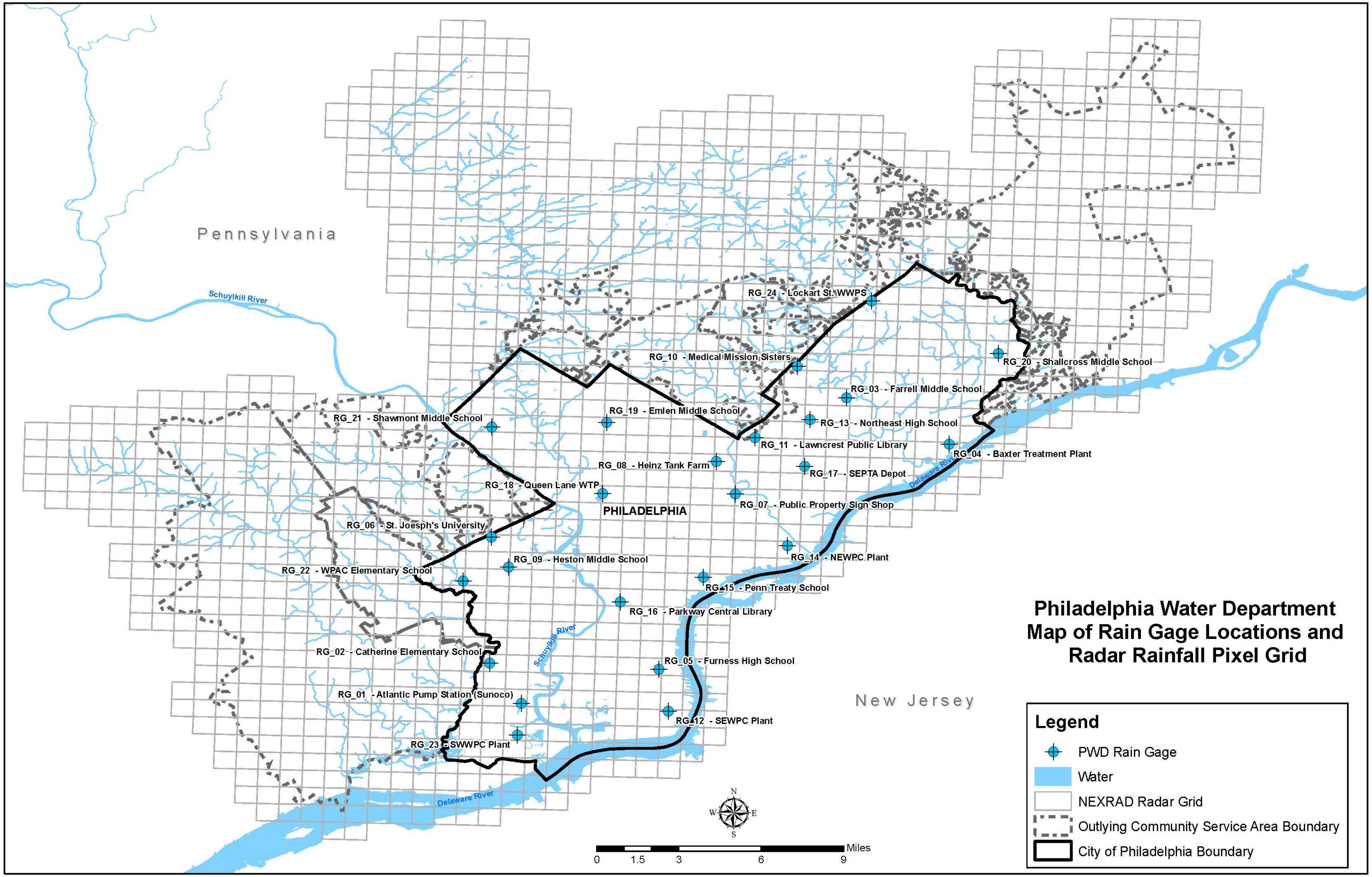


Figure 2-9: The Philadelphia Water Department Rain Gage Network Locations and 1x1 km Radar Rainfall Pixel Grid

2.3.5 Precipitation Data in the Flow Monitoring QA/QC Process

In order to assess the quality of the collected flow monitoring data, the aforementioned precipitation data were used by the data analysts in the quality assurance and quality control (QA/QC) process, in order to ensure the quality of the collected flow data. During the QA/QC process, precipitation data were superimposed onto time-series plots in order to correlate the observed rainfall to the sanitary sewer responses. This also aided in confirming that increases in level, velocity, and corresponding flow rates throughout the monitoring period were attributed to precipitation events and not spurious discharges or errant data. Data from either the nearest network gage or the calibrated radar-rainfall network (if available) was used as an acceptable source of precipitation data. Figure 2-10 illustrates an example time-series plot with precipitation data superimposed. Additional information about these plots and the flow data QA/QC process is located in Section 3.4 (Quality Assurance Reviews for Flow Monitoring Data).

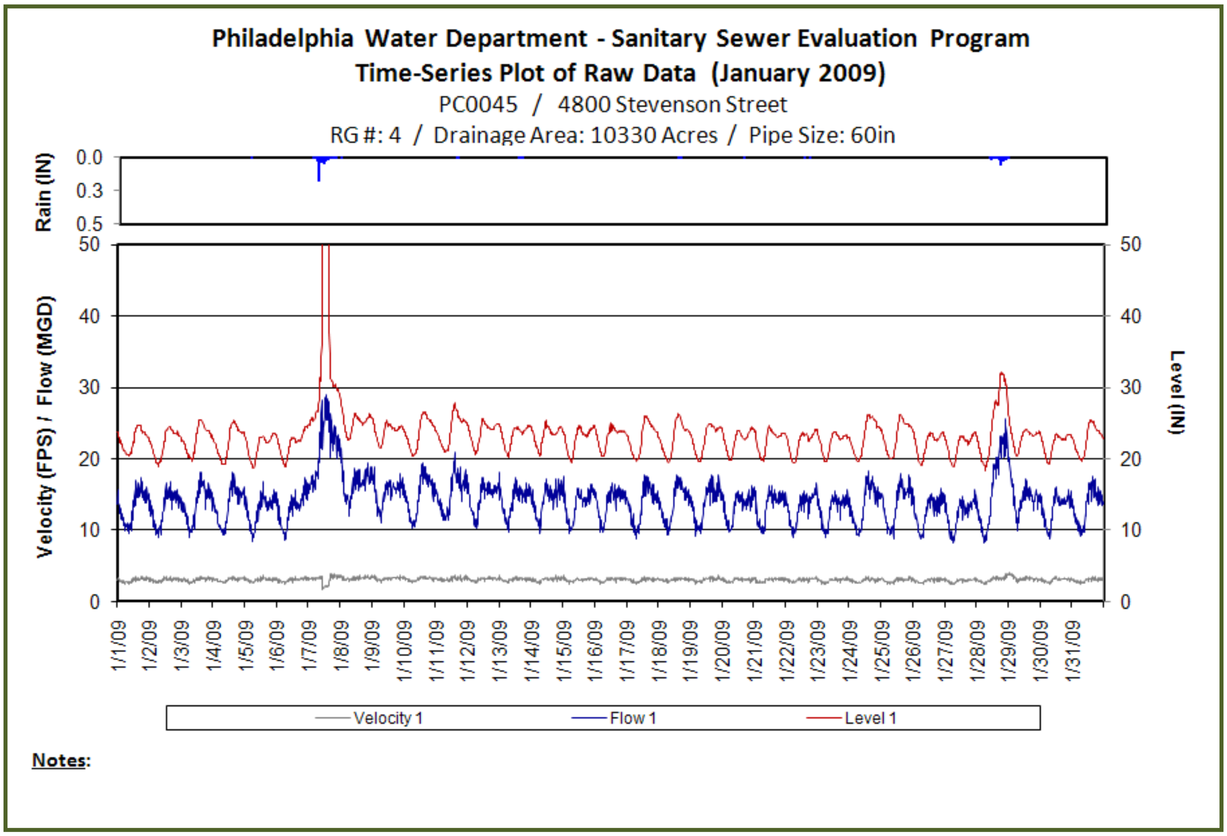


Figure 2-10: Example Time-Series Plot with Precipitation Data Superimposed

The completed Phase 1 SSES confirmed that the available historic record for precipitation data was adequate to meet the needs and requirements of the SSES. The long-term record from the PHL gage provided the needed historic context, while the data from the Water Department gage network, coupled with the data from the high-resolution radar-rainfall system, provided the needed spatially distributed data. The archived record data were verified to be adequately accurate, reliable, and up to date to conduct the Phase 2 SSES analyses, and quantify and characterize precipitation over the Water Department service area. It was further determined that no additional data needed to be collected to meet SSES requirements.

2.4 Available Sewer System Data and GIS Coverage within the City Limits

The range of completed activities conducted for the Phase 1 SSES included a review of the historical map and drawing data available for the separate sanitary sewer infrastructure within the City, and the associated Geographic Information System (GIS) coverage. The existing available data were inventoried, cataloged and evaluated to assess its age, completeness and reliability. The GIS coverage of the sanitary sewer collection system network within the City was evaluated for completeness and connectivity, and subsequently modified as needed to allow flow routing and other collection system network analyses to be performed.

The Water Department's sanitary sewer collection system is cataloged and documented in a series of archived as-built drawings, an archived set of sewer plats, and other archived plans and drawings. These drawing sheets have been scanned and digitized, and the information has been incorporated into a GIS database. The Water Department's GIS system contains links from the wastewater collection system geo-dataset elements to the scanned drawings, so that users may readily access and use the information. This linkage between the GIS, and the archived reference drawings allowed analysts to inspect record drawings for verification and refinement of the representation of system elements and connectivity. The sewer system information available from the GIS includes the coordinate locations of manholes and pipes, pipe sizes and materials, CSO regulator chamber and outfall information, junction structure invert elevations, network connectivity, and flow direction. The GIS can generate maps showing the overall configuration of the selected collection system network and associated sewer structures.

The GIS database is updated on an as-needed basis as revisions or improvements to the sewer system are implemented, new buildings or sewer system elements are constructed, or new information is received. The GIS also includes tools that allow the analyst to check flow direction and the connectivity of the collection pipe network, and allow tracing the system upstream of a selected point of interest. This sewer system GIS information was applied to available digital topographic and census population information (described in Section 2.6), allowing sewershed delineations and corresponding service populations to be generated and checked to each of the wastewater flow monitoring locations in and along trunk lines and interceptor sewers.

The completed SSES Phase 1 evaluations of the archived mapping/drawing information and GIS database information allowed data gaps to be identified and filled, and the evaluations successfully identified inconsistencies that were subsequently reconciled and corrected. The completed SSES inventories and assessments confirmed that the existing archived sets of sanitary sewer collection system maps and drawings, and the associated GIS coverages are sufficiently complete, up-to-date, and reliable. They were verified to be able to support hydrologic and hydraulic (H&H) modeling, the quantification of dry and wet weather flow at critical points along the sewer system, and the identification of any sewershed areas that may convey relatively high infiltration and inflow quantities. The existing available information on the Water Department's sanitary sewer collection system within the City was found to be adequate to meet the needs of the SSES, to meet the input data needs for H&H modeling tools and system characterization, and to be sufficient to support the implementation of the City's *Green City, Clean Waters* program.

2.5 Available Sewer System Data and GIS Coverage for Outlying Community Service Areas

Phase 1 of the SSES included a review and evaluation of the historical map and drawing information available for the separate sanitary sewers located within the outlying community service areas. These outlying communities were identified and shown on Figure 2-5. Points of connection between these community systems and the Water Department sewer system were identified and analyzed, and the extent and location of the corresponding tributary areas from the outlying communities were delineated. The existing available data for each customer community were inventoried, cataloged, and evaluated to assess the age, completeness and reliability. The availability and extent of GIS coverage were also investigated. The available information was evaluated for completeness and where gaps and/or inconsistencies were identified, the outlying communities were contacted and the needed information was obtained.

The completed SSES Phase 1 assessment confirmed that all of the outlying communities that convey flow to the Water Department have maps of their sanitary sewer collection systems. Some communities also had other archived sewer system plans and drawings. The sewer map information was typically superimposed over street system base maps and provided the locations of manholes and pipes, pipe sizes, direction of flow, and often the invert elevations of junction structures. Each of the outlying communities has a service agreement with the City for the collection and treatment of their sanitary wastes. These service agreements require the outlying communities to provide the City with mapping of the existing tributary sewer systems and to provide updated information if any changes or extensions to the system are made. The completed Phase 1 SSES activities included contacting the outlying communities, verifying the sewer mapping in possession of the Water Department was current, and obtaining any needed updated information.

Few of the outlying communities were found to have integrated the sewer system information from their maps into GIS databases. Therefore, it was usually the information contained within the sewer maps that was assessed for Phase 1 of the SSES to determine the age, completeness and reliability of available outlying community data. The outlying community paper maps, or scanned copies of the sewer maps, were geo-referenced into the PA Southeast state plane coordinate system so they could be viewed together and overlaid with other GIS data such as surface topography and census population information (described in Section 2.6). The resulting GIS database information for the outlying community service areas was subsequently integrated into the Water Department's GIS database.

GIS pipe networks were generally unavailable for outlying community areas, and visual inspections of the rectified map layers along with orthophotographic overlays were performed to determine connectivity and flow direction. This GIS information on the outlying community service areas was applied to available digital surface topography, orthophotography and census population data, allowing sewershed delineations and corresponding service populations to be generated and checked to points of connection to the Water Department's system. The completed analyses were able to identify specific gaps and inconsistencies within the available community data. The affected outlying communities were subsequently contacted and the needed information was obtained.

The completed SSES inventories and assessments confirmed that the existing information collected and archived by the Water Department on the outlying community service areas, after gaps and inconsistencies identified in the Phase 1 assessments were remedied, were sufficiently complete, current, and reliable to support hydrologic and hydraulic (H&H) modeling activities. The outlying community information was also confirmed to be sufficient for the quantification of dry and wet weather flow at the points of connection with the Water Department's system, and the identification of any sewershed areas that may convey unreasonably high infiltration and inflow to the Water Department's system that will be conducted and documented in the 2015 Outlying Communities Report. The existing available information on the sanitary sewer collection system within the outlying community service areas was found to be adequate to meet the requirements of the SSES, to meet the input data requirements for H&H modeling tools and system characterization, and be sufficient to support the implementation of the City's Green City, Clean Waters program.

2.6 Other GIS Coverage within the City and Outlying Community Service Areas

The Phase 1 activities conducted for the SSES included an inventory and review of spatially referenced GIS information that would supplement the collected sanitary sewer infrastructure information, and be useful and relevant to supporting the City's Green City, Clean Waters program. This supplemental data was explored both for areas within the City and for the outlying community areas. The existing available data were identified, inventoried and evaluated to assess the age, completeness and reliability. Pertinent data categories that were successfully identified and obtained included the following.

- 2010 census block data
- Surface topography data
- Land use data
- Orthophotography data
- Street center line data
- Building parcel data
- Sewer and water billing use class data

All the data categories listed above were found to contain useful and relevant information that could supplement the information found within the sanitary sewer maps and the GIS database. The surface topography and orthophotography data were used to support the delineation of sewershed areas tributary to wastewater flow monitoring sites and points of connection between outlying community collection systems and the Water Department system. The census block and building parcel data were used to help derive the service populations associated with the delineated sewershed areas. Land use, building parcel and sewer/water billing use class data were used in the analyses to delineate contributing areas and estimate service populations within the City. The street centerline data were used to help interpret and display the results of completed and planned sanitary sewer rehabilitation projects.

The completed Phase 1 SSES inventories and assessments confirmed that other spatially referenced GIS information collected and archived by the Water Department was relevant and useful in supplementing the collected sanitary sewer system information. The SSES was able to verify that the total inventory of all the various categories of GIS database information obtained, archived and utilized by the Water Department was sufficiently complete, current, and reliable to support H&H modeling, the quantification and characterization of dry and wet weather flow, and the identification of any sewershed areas that may convey relatively high inflow and infiltration to the Water Department system.

2.7 Sanitary Sewer Inspection Data within the City

Archived data from the Philadelphia Water Department's ongoing sewer inspection program were gathered, reviewed, and assessed under Phase 1 of the SSES. The Water Department's Closed Circuit Television (CCTV) Inspection Group is responsible for providing the CCTV inspections needed to investigate known or suspected problem areas, identify and document the severity and extent of observed sewer system defects, and provide the information needed to develop and implement a repair or replacement strategy. The Water Department CCTV Inspection Group currently has a work force of 16 approved positions and seven CCTV trucks. The seven CCTV trucks log approximately 60 miles of sewer inspections on an annual basis.

In 2002, the Water Department commenced the Sewer Assessment Program (SAP) initiative to provide a well-documented, technically sound, and uniform assessment and evaluation procedure to assess the condition of the City's sanitary, storm, and combined sewer systems. The SAP is a systematic methodology that was used to inspect and evaluate the sewers, capture and analyze the resulting information in computerized databases, and apply a uniform protocol to prioritizing sewers for repair and replacement.

2.7.1 Systematic Manhole Identification System

In order to conduct the CCTV inspections, process the data, and analyze the results, a systematic method was necessary for identifying the sewer segments being evaluated. Because the access points to and from the sewer for inspection activities are manholes, and because the crews inspect and report on the basis of manhole to manhole segments, a comprehensive methodology for manhole identification numbering was developed. The beginning of every manhole identification code is an alphanumeric designation of the outfall to which its sewers drain. The outfall is generally an entry point into a Water Department interceptor sewer for separate sanitary sewers, a storm water outfall for separate storm sewers, and a combined sewer overflow location for combined sewers. This beginning designation thus identifies the sewer drainage system or sewershed area within which every manhole carrying that prefix resides. Following the prefix is a number containing up to six digits.

2.7.2 Standardized Inspection Codes

To provide standardization for the inspection methods that are employed and the digital inspection data that are collected, CCTV Inspection Group crews utilize the protocol standards and procedures of the Pipeline Assessment and Certification Program (PACP) of the National Association of Sewer Service Companies (NASSCO). The PACP is the U.S. industry standard for coding the nature and severity of sewer defects, maintenance conditions, and construction features from CCTV inspection videos, and allows inspectors and decision makers to utilize a common terminology. The PACP has allowed the Water Department to more easily and accurately assess and compare the inspection data gathered over a multi-year period since the same coding definitions were used. To standardize the archiving and reporting of CCTV inspection data, the Water Department chose to utilize a commercially available sewer inspection data entry and reporting software package, "WinCan", which has been installed on all inspection vehicles. Therefore, the SAP program was conducted using the same WinCan program for all CCTV inspections.

The PACP codes are organized into four categories as follows. Two of the categories are used to document observed sewer system defects, and two of the categories are used to document sewer system configuration information and other general observations.

- Structural Defects - such as improper sewer taps, offset or separated sewer joints, cracked or damaged pipe, holes in pipe walls, observed infiltration, surface damage to pipe walls, and lining failures.
- Operation and Maintenance (O&M) Defects – such as solids deposits and debris, grease deposits, water level sags, and root infiltration.
- Construction Features – such as taps and saddles with clock position, incoming sewers with clock position, changes in pipe material, point repairs, manholes, cleanouts, and other access points.
- Miscellaneous General Observation – such as sewer size and shape, general photograph, and confirmation that the sewer segment inspection was successfully completed.

The PACP uses a rating system of 1 through 5, with 5 being the most severe defect. The defect rating system is applied to all categories of observed structural and O&M defects. Since the category of sewer defect codes most directly relevant to this SSES are the infiltration codes, these were used and evaluated as part of this study. The numeric rating system implemented with the five infiltration codes is described below.

1. Weeper code "IW": Slow ingress, without visible drips, of infiltration through defects, faulty joints or pipe walls.

2. Dripper code "ID": Infiltration dripping through a defect, faulty joint, or pipe wall. There is no continuous flow. Only drips are visible.
3. Runner Light code "IRL": light continuous infiltration running in through a defect, faulty joint or pipe wall.
4. Runner Heavy code "IRH": heavy continuous infiltration running in through a defect, faulty joint or pipe wall.
5. Gusher code "IG": an enormous amount of infiltration entering the pipe through a defect, faulty joint or pipe walls, which requires immediate attention.

Figures 2-11 through 2-13 provide representative photographic images, obtained from the SAP CCTV inspection database, that illustrate the three highest infiltration ratings.

Figure 2-11: Example 5-Rating Infiltration Gusher

Figure 2-12: Example 4-Rating Heavy Infiltration Runner

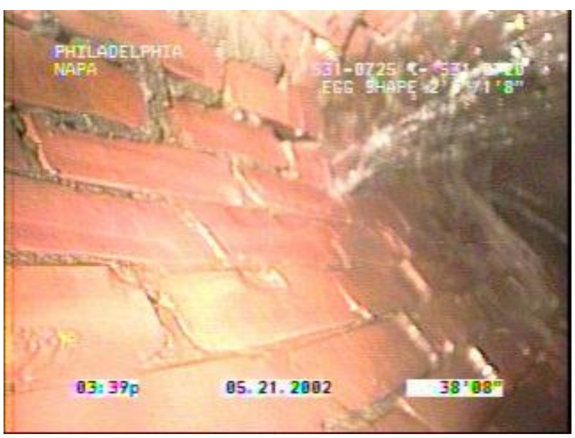


Figure 2-13: Example 3-Rating Light Infiltration Runner

2.7.3 CCTV Database Management System

The SAP data management system is a database that is viewable throughout Water Department offices via intranet using a web browser. The user has the ability to generate a series of standard and customized reports. A myriad of queries and non-standard reports can also be performed through the data management system. Additional information on the SAP database management system, and the types of reports and queries generated and used by Water Department staff are described in Section 2.9 (Data Management Approach.)

2.7.4 GIS Maps Depicting CCTV Inspection Results

The *Implementation and Adaptive Management Plan*, indicates that under Phase 1 of the SSES, the observations of the available archived sanitary sewer inspections performed within the City were to be collected, along with GIS spatial information, to generate maps that summarize the sewer assessment results. Since infiltration defects within the separate sanitary sewer system are most directly relevant to the SSES, a City-wide series of GIS maps was prepared displaying the locations and numeric PACP scores of observed infiltration within the City's separate sanitary sewer areas. Figure 2-14 provides an overview of the sanitary sewer CCTV inspection results for the entire City. The map information does not include CCTV inspections that were conducted in combined sewer areas. Figures 2-15 through 2-17 display the observed infiltration defects at a greater level of detail in the City's northeast, northwest and southwest areas, respectively. Observed level 5 *Infiltration Gushers*, the most severe PACP infiltration defect code, are represented by red dots. Observed level 4 *Infiltration Runners*, the second highest infiltration defect code, are represented by orange dots. Other less significant observed infiltration defects, with PACP codes from 3 to 1, are shown on the maps with green circles. Some of the observed infiltration defects identified by the CCTV inspection program were subsequently corrected by an implemented sewer rehabilitation or sewer lining project (see Section 2.8, Sanitary Sewer Rehabilitation Projects Completed and Planned within the City). These corrected defects are shown on the maps as purple dots. To show the geographic extent of the CCTV inspections with the separate sanitary sewer system, blue dots representing all inspection observations are provided.

2.7.5 Sewer Inspection Data Conclusions

The completed Phase 1 SSES inventory and assessment activities confirmed that the archived historical CCTV inspection database information is sufficient to characterize the condition of the City's separate sanitary sewer system, quantify the magnitude of observed infiltration defects, and show the location and geographic extent of observed infiltration defects. The use of a national protocol standardization system for the collected digital data provided consistency and allowed the Water Department to more easily and accurately assess and compare inspection data gathered over a multi-year period.

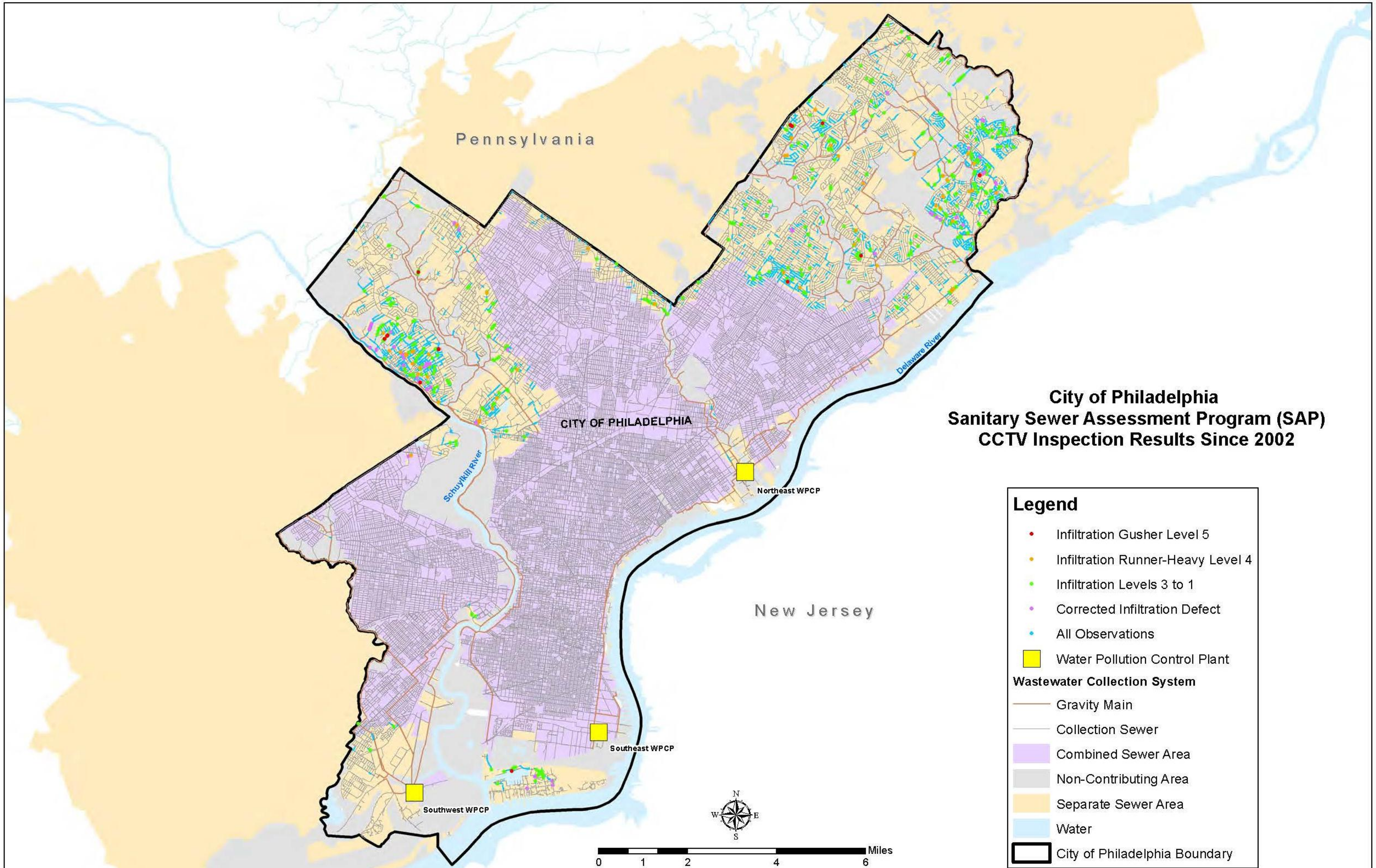


Figure 2-14: Sanitary Sewer Assessment Program (SAP) CCTV Inspection Results Since 2002

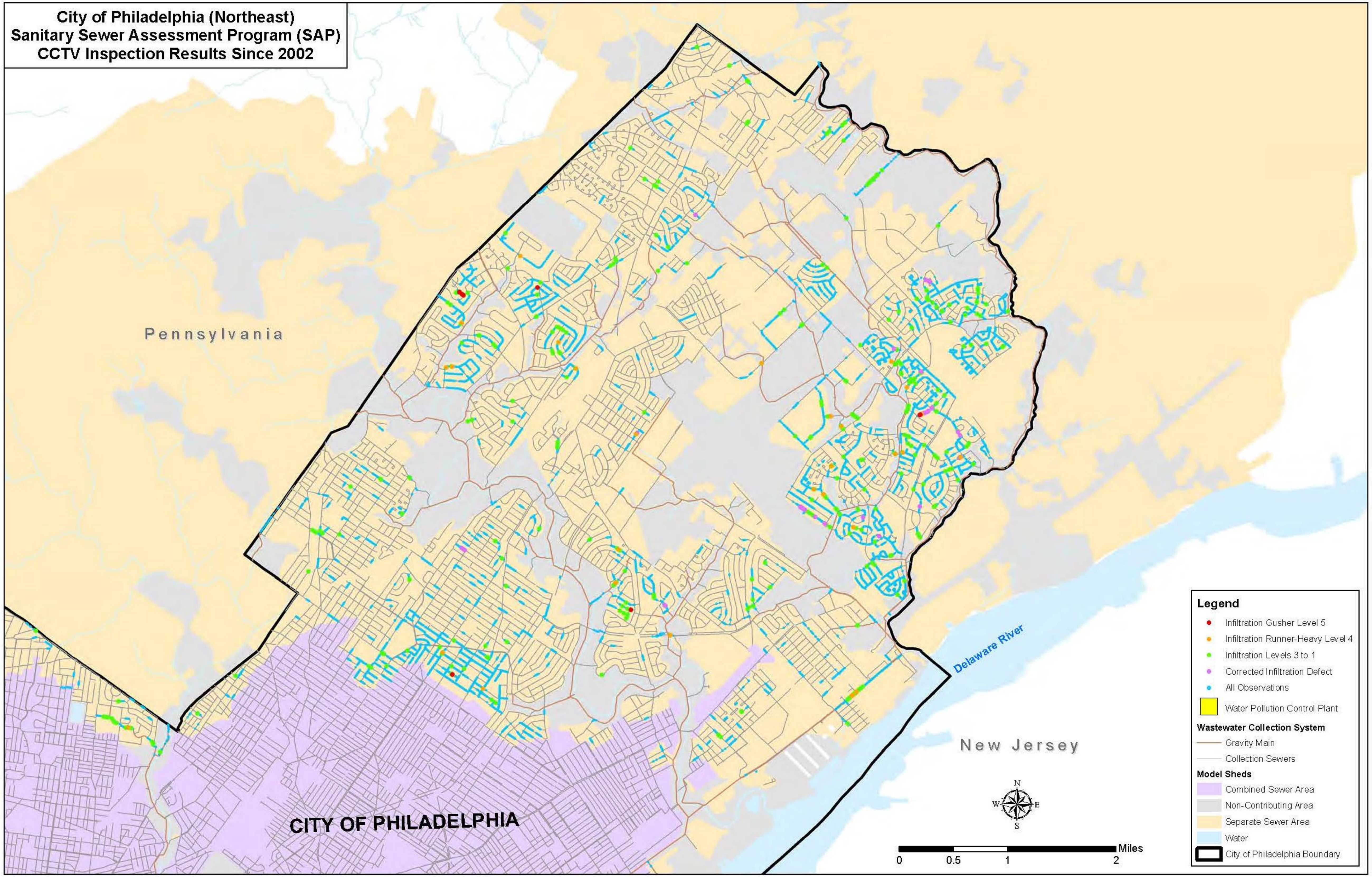


Figure 2-15: Sanitary Sewer Assessment Program (SAP) CCTV Inspection Results Since 2002 (Northeast Area)

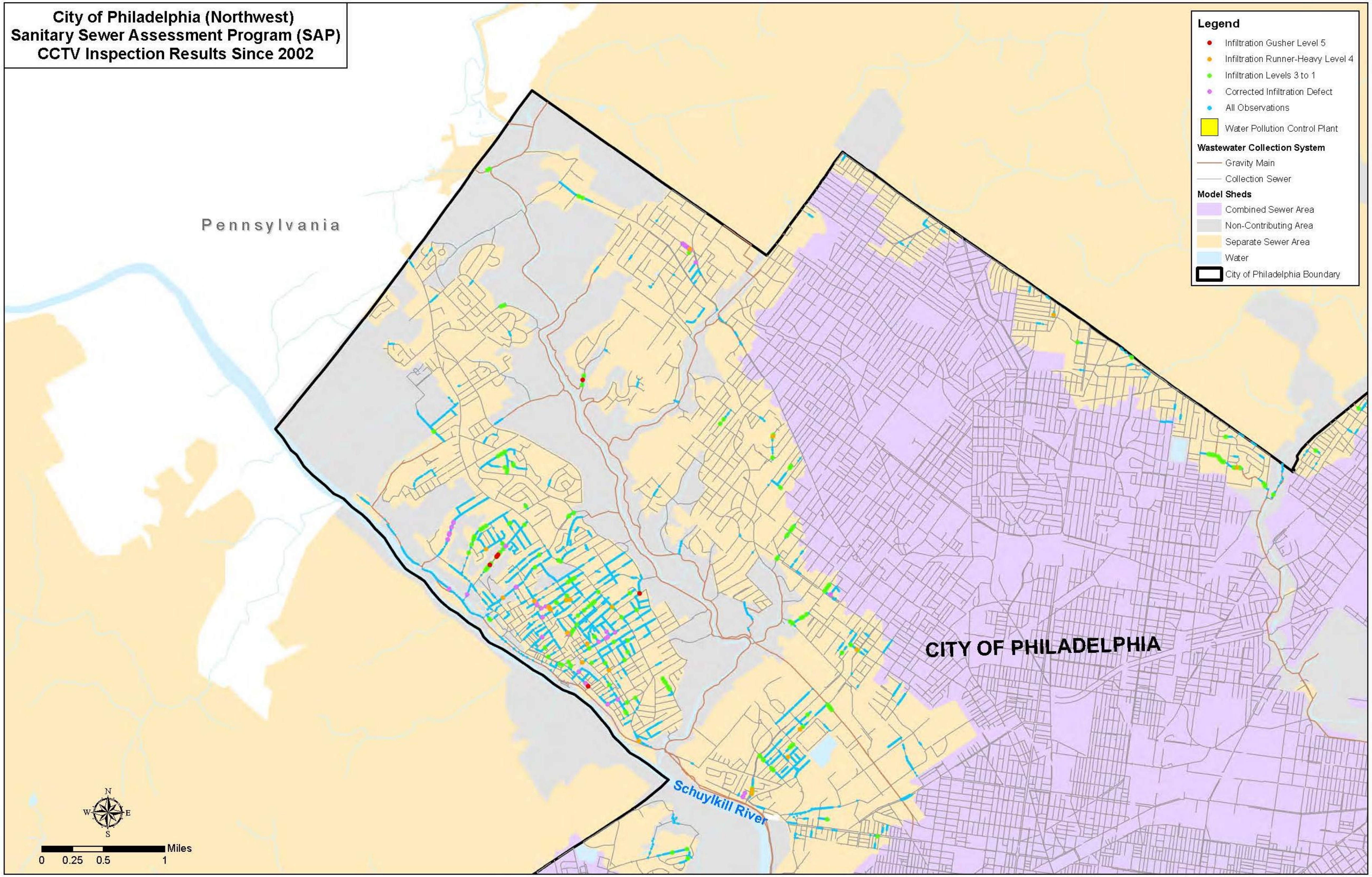


Figure 2-16: Sanitary Sewer Assessment Program (SAP) CCTV Inspection Results Since 2002(Northwest Area)

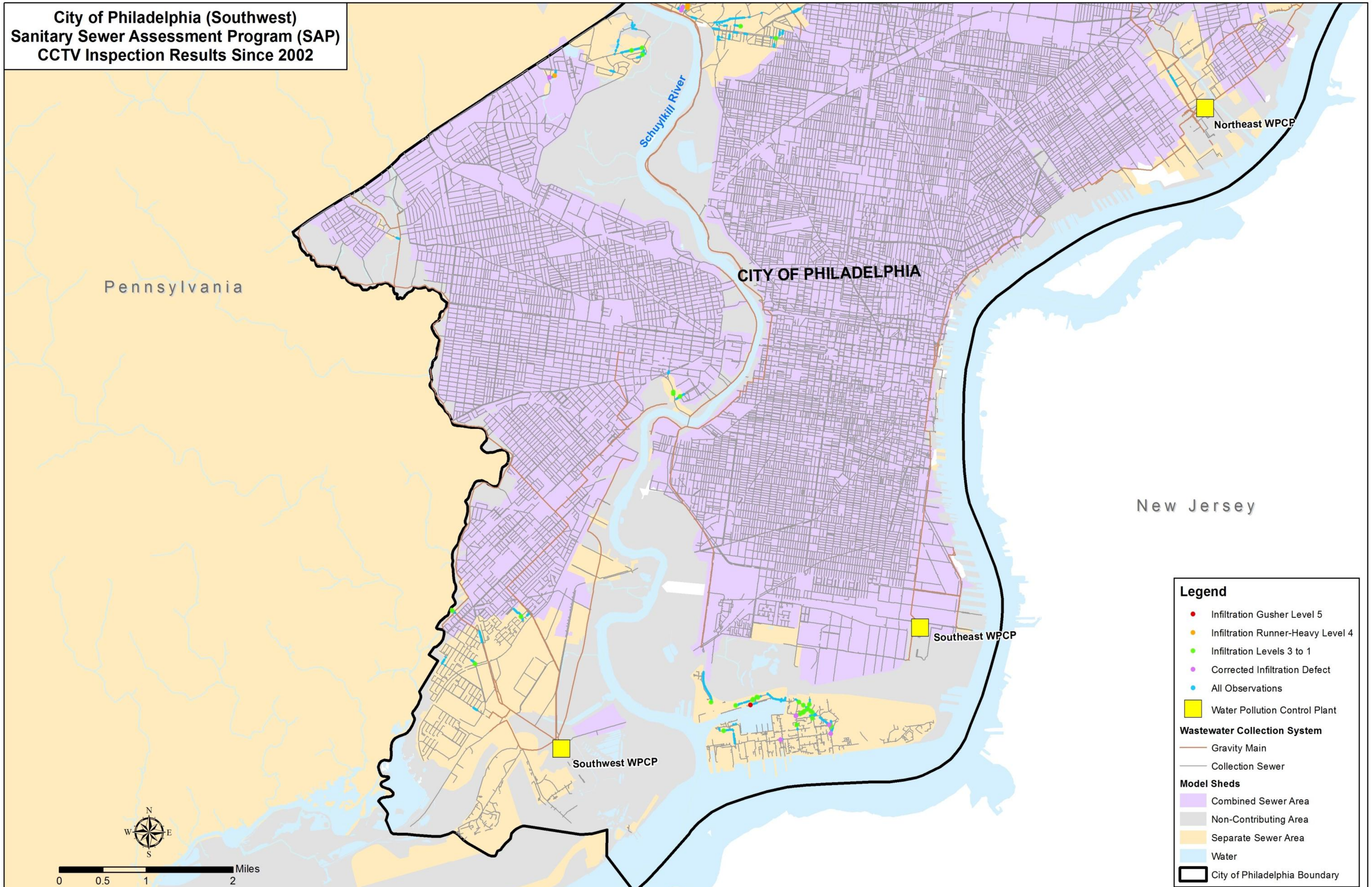


Figure 2-17: Sanitary Sewer Assessment Program (SAP) CCTV Inspection Results Since 2002(Southwest Area)

2.8 Sanitary Sewer Rehabilitation Projects Completed and Planned within the City

The Water Department's 2011 *Implementation and Adaptive Management Plan* (IAMP) indicated that the Phase 1 SSES should include an inventory and assessment of the sanitary sewer rehabilitation projects within the City that have been completed and those that are planned for future implementation. The IAMP also indicates that maps should be prepared indicating the location and extent of these sanitary sewer rehabilitation projects. The completed Phase 1 inventory indicated that between 2000 and 2013, the Water Department has implemented separate sanitary sewer rehabilitation projects totaling approximately 33.7 miles, and has plans to perform an additional 26.7 miles of rehabilitation projects.

2.8.1 Selection of Sewer Segments for Rehabilitation

There are a number of alternative means by which separate sanitary sewer segments were identified and scheduled for a planned sewer rehabilitation project. Many of the planned rehabilitation projects were initiated as a result of a closed circuit television (CCTV) inspection that was conducted under the Water Department's Sewer Assessment Program, previously described in Section 2.8. If the number, density, and severity of the observed defects were significant enough to warrant repair or replacement of an inspected sewer segment, the sewer was placed on the planned sewer rehabilitation project list. Two other means by which sanitary sewer segments were identified and scheduled for rehabilitation were through street paving and water main break repair activities. When a City street was scheduled for repaving, CCTV inspections were conducted for the sewer segments under that street, within the City block limits that were to be repaved. If the inspection results indicated that sewer segments should be replaced, the sewer segments were placed on the planned project list and rehabilitation construction was completed before the street was repaved. Similarly, when a water main break occurred and emergency repairs were made, the sewer segments in the vicinity of the break were inspected and any required sewer rehabilitation work was completed before the street was repaved. Hydraulic capacity restrictions could also initiate the need for sewer segments to be placed on the planned rehabilitation projects list. When the Water Department identified specific sewer segments with restricted hydraulic capacity that caused excessive surcharging, the associated sewer segments were scheduled for replacement. Similarly, if a water main was replaced for any reason such as capacity, age or condition, then the sanitary sewers in the vicinity of the planned water main construction were televised to determine if rehabilitation work was needed.

2.8.2 Extent and Magnitude of Sewer Rehabilitation Projects

There were two general categories of sewer rehabilitation projects that the Water Department implemented; remove and replace projects and sewer lining projects. The traditional remove and replace sewer replacement method was implemented with either a series of spot repairs, or replacing entire pipe segments from manhole to manhole with new pipes. This approach was used if a relatively large number of significant defects were observed within a relatively close spacing. It was one of the only ways to correct sags and humps due to soil settlement. However, this method of replacement can be disruptive at the surface. Utility crossings, and the vicinity of the trench lines, need to be carefully protected and traffic needs to be controlled around the construction site. Pipe lining is a method in which the existing pipe does not have to be removed. This procedure involves inserting a liner into the existing pipe, which renews the interior integrity of the surface and increases the structural capacity of the old pipeline. The most common types of lining are thermoplastic (fold and form) liners, thermoset (cured in place) liners, and slip liners. The extent of the rehabilitation projects was limited to public sewers and laterals located within the public right-of-way and did not encroach onto private property. Sanitary sewer lining rehabilitation projects were usually implemented using a cured-in-place lining system, although gunite lining systems were conducted in specific segments where the structural integrity of the pipe was a concern.

2.8.3 Summary of Completed and Planned Sewer Rehabilitation Projects

As a part of the completed Phase 1 SSES inventory activities, a list of completed and planned sewer rehabilitation projects was produced. Tables 2-5 and 2-6 provide a summary of the completed and planned sewer rehabilitation projects under the remove and replace category. The tables indicate the origin of the project, the number of project street segments, and the total length.

Table 2-5: Summary of Completed Remove and Replace Sewer Rehabilitation Projects

Project Status	Project Origination Type	Total Number of Project Street Segments	Total Project Street Segment Length (miles)
Completed	Sewer Condition	77	6.4
Completed	WaterBreak	27	1.8
Completed	Paving	19	1.5
Completed	Sewer - Hydraulic	7	0.7
Completed	Water - Hydraulic	4	0.3
Completed	Other	7	0.9
Total		**141**	**11.6**

Table 2-6: Summary of Planned Remove and Replace Sewer Rehabilitation Projects

Project Status	Project Origination Type	Total Number of Project Street Segments	Total Project Street Segment Length (miles)
Planned	Sewer Condition	22	2.2
Planned	Water Break	33	1.9
Planned	Paving	2	0.3
Planned	Water - Hydraulic	2	0.1
Planned	Sewer - Hydraulic	1	0.1
Planned	Other	4	0.3
Total		**64**	**4.9**

The completed Phase 1 inventory and assessment indicated that 8.6 miles of completed or planned sewer rehabilitation projects were the result of sewer defects identified through the CCTV inspection program. There were 4.1 miles of sewer rehabilitation projects that were completed or planned because the sewer segments were located in the vicinity of a water main break or a water main project to increase the size of the pipe. There were 1.8 miles of sewer rehabilitation projects completed or planned to coincide with street paving work. There were 0.8 miles of planned or completed sewer replacement projects that were the result of a localized pinch point and the need to increase the diameter of the sewer pipe. There was an additional 1.2 miles of sanitary sewer rehabilitation work that was conducted for other reasons. In total, there were 11.6 miles of completed projects where the selected rehabilitation method was to remove and replace the defective sewer line. There were a total of 4.9 miles of planned remove and replace sanitary sewer projects.

Table 2-7 provides a summarization of the completed and planned sewer rehabilitation projects using a lining method. Many of the lined sewer segment projects were located under streets, but some of the lined sewer segments were located along stream banks. These stream bank sewer lining projects were implemented to reduce groundwater infiltration into the sewer.

Table 2-7: Summary of Completed and Planned Sewer Lining Projects

Lining Project Status	Total Sewer Length for Off Street Lining Projects (miles)	Total Street Segment Length for Lining Projects Along Streets (miles)	Total Length (miles)
Completed	3.1	9.0	12.1
Planned	1.2	8.8	10.0
Total Length	**4.3**	**17.8**	**22.1**

The completed Phase 1 SSES inventory and assessment indicated that a total of 3.1 miles of completed sewer lining projects were implemented in the vicinity of streambeds and a total of 9.0 miles of completed sewer lining projects were implemented along or under streets. An additional 1.2 miles of sewer lining projects are planned for sewers in the vicinity of streambeds and an additional 8.8 miles of sewer lining projects are planned along or under streets. The table indicates that a total of 12.1 miles of sewer lining projects were completed within the City and a total of 10.0 additional miles of sewer lining projects are planned within the City.

2.8.4 GIS Maps Depicting the Locations of Sewer Rehabilitation Projects

Figure 2-18 provides a system-wide overview of the locations and extents of the completed and planned sewer rehabilitation projects within the City limits. Figures 2-19 through 2-21 depict the completed and planned sewer rehabilitation projects with a greater level of detail by dividing the City's separate sanitary sewer areas into northeast, northwest and southwest areas, respectively. Completed sewer rehabilitation project reaches that utilized the remove and replace method are shown with red lines. Planned remove and replace project reaches are shown with orange lines. Completed sewer lining project segments are shown with blue lines and planned sewer lining project locations are shown as green lines.

2.8.5 Rehabilitation Project Conclusions

The completed Phase 1 SSES activities and associated report includes an inventory and assessment of the sanitary sewer rehabilitation projects within the City that have been completed and those that are planned for future implementation. Completed and planned separate sanitary sewer rehabilitation projects were identified, and their locations and extents were depicted in GIS maps.

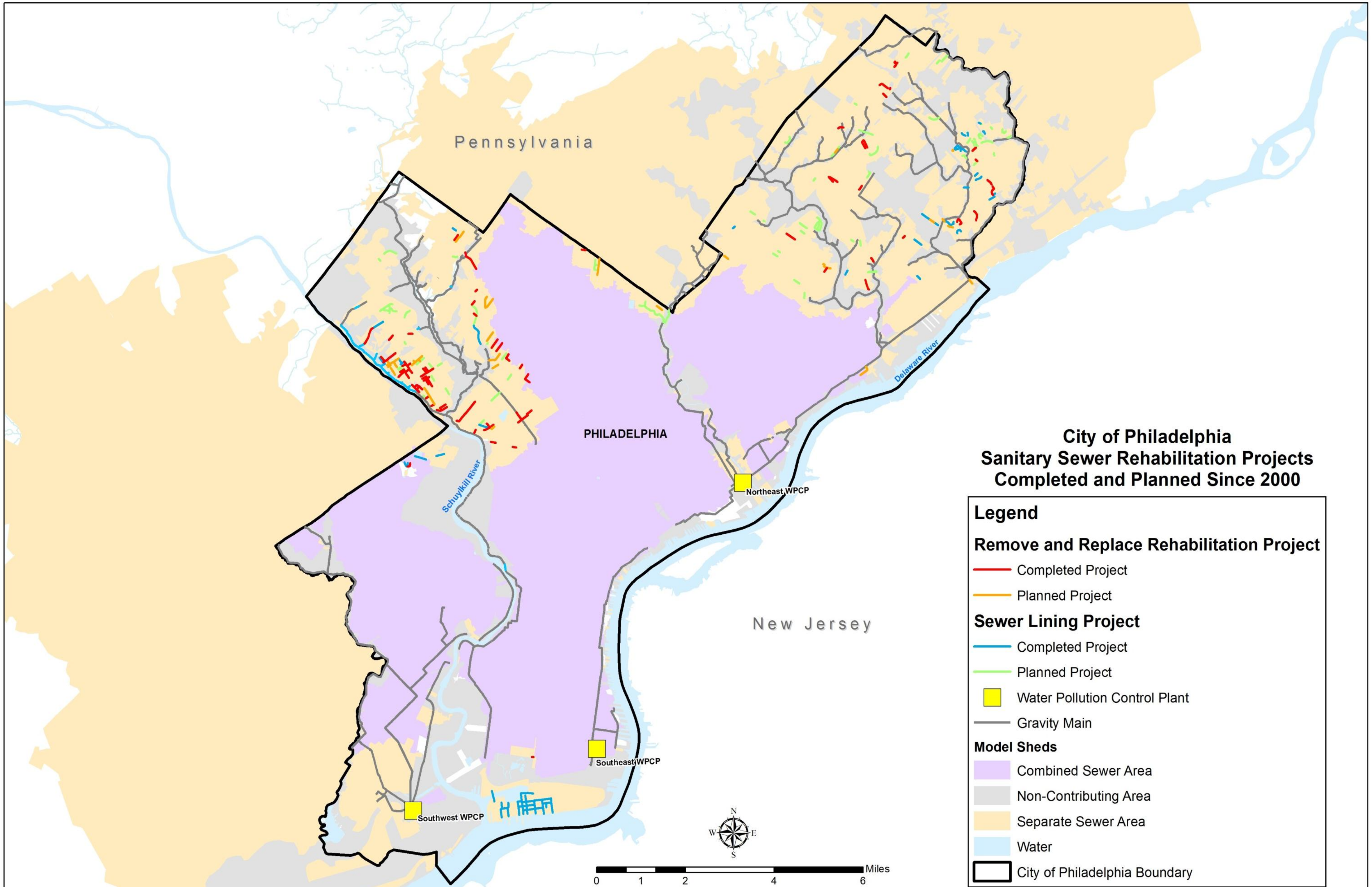


Figure 2-18: Locations of Completed and Planned Sanitary Sewer Rehabilitation Projects

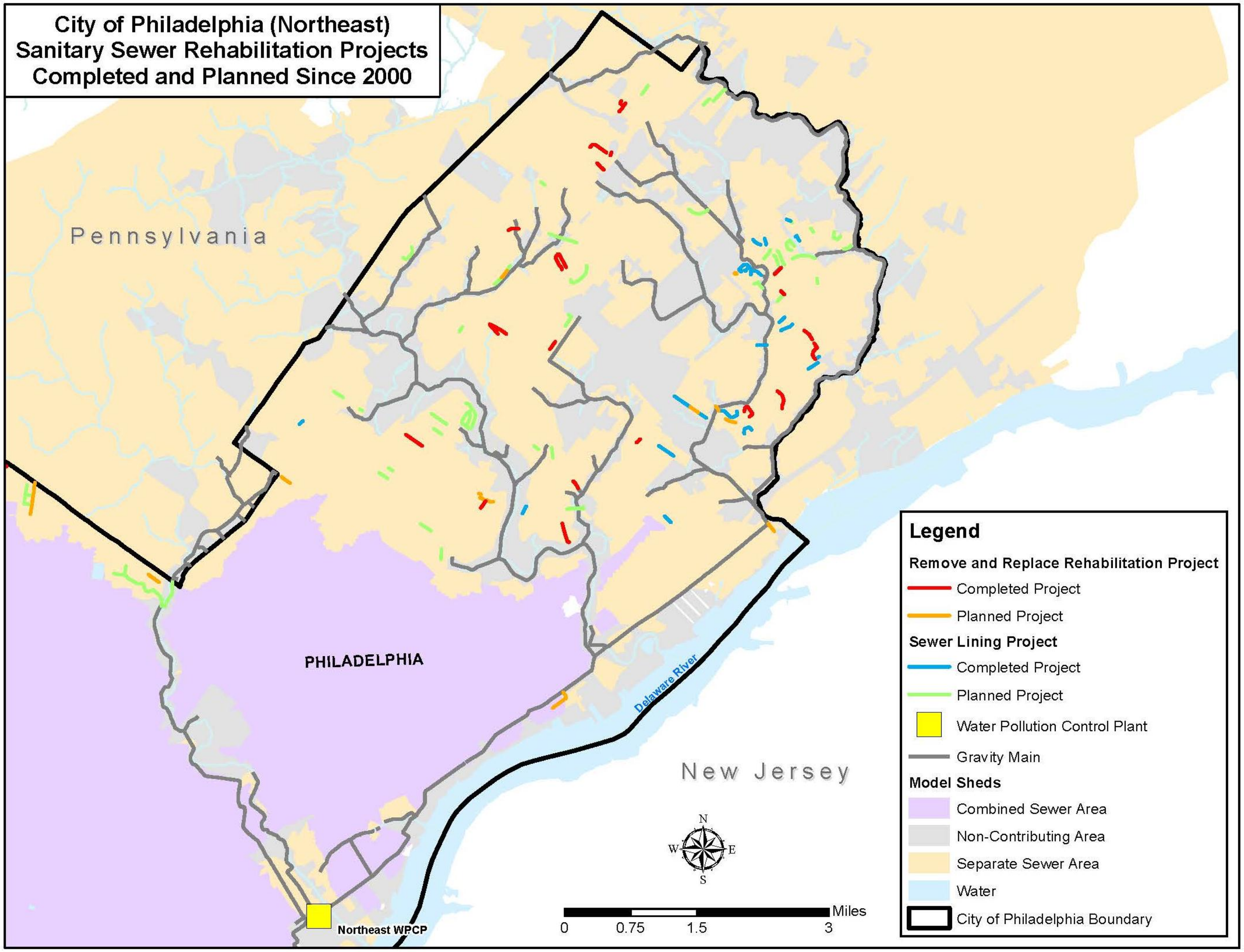


Figure 2-19:Locations of Completed and Planned Sanitary Sewer Rehabilitation Projects (Northeast Area)

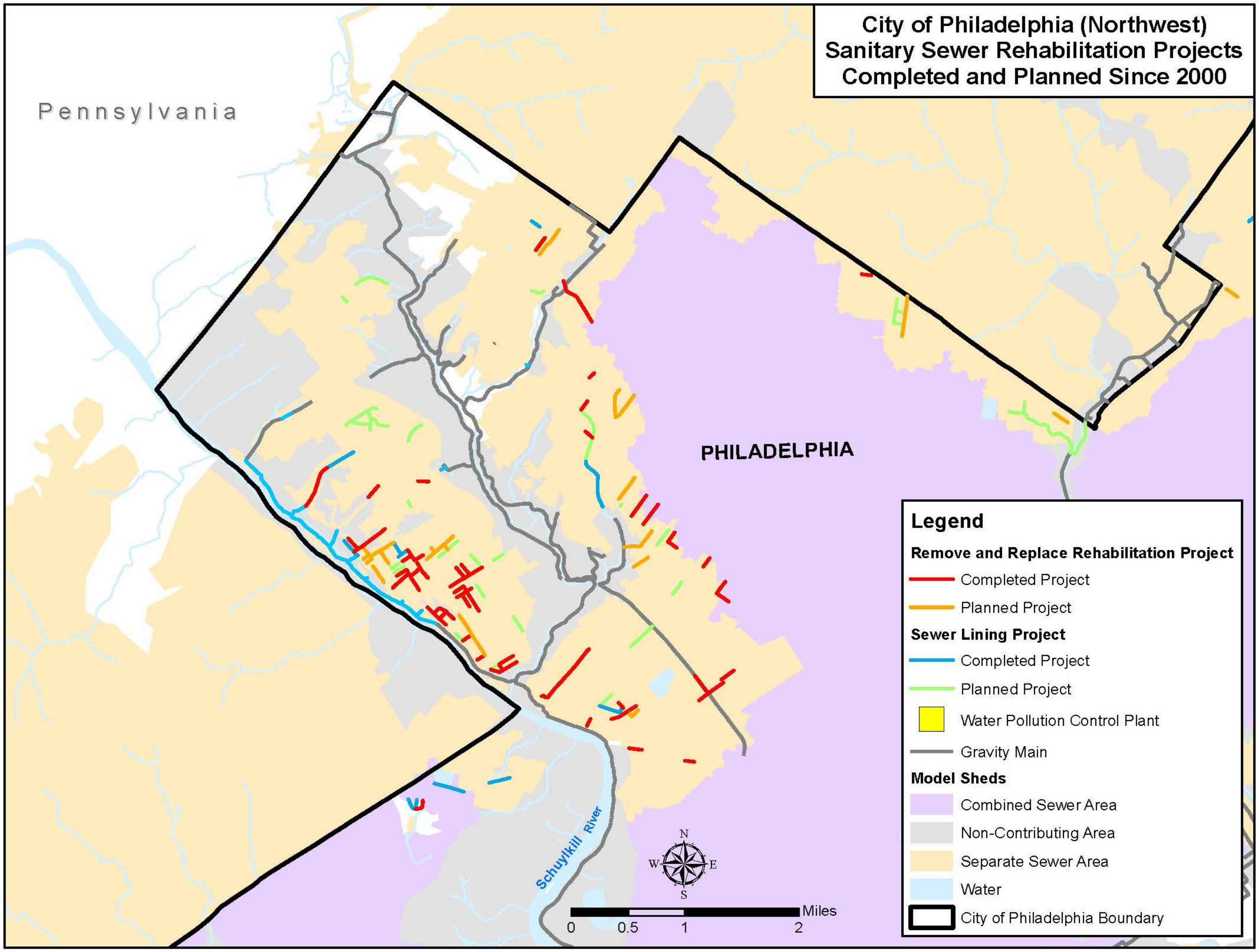


Figure 2-20:Locations of Completed and Planned Sanitary Sewer Rehabilitation Projects (Northwest Area)

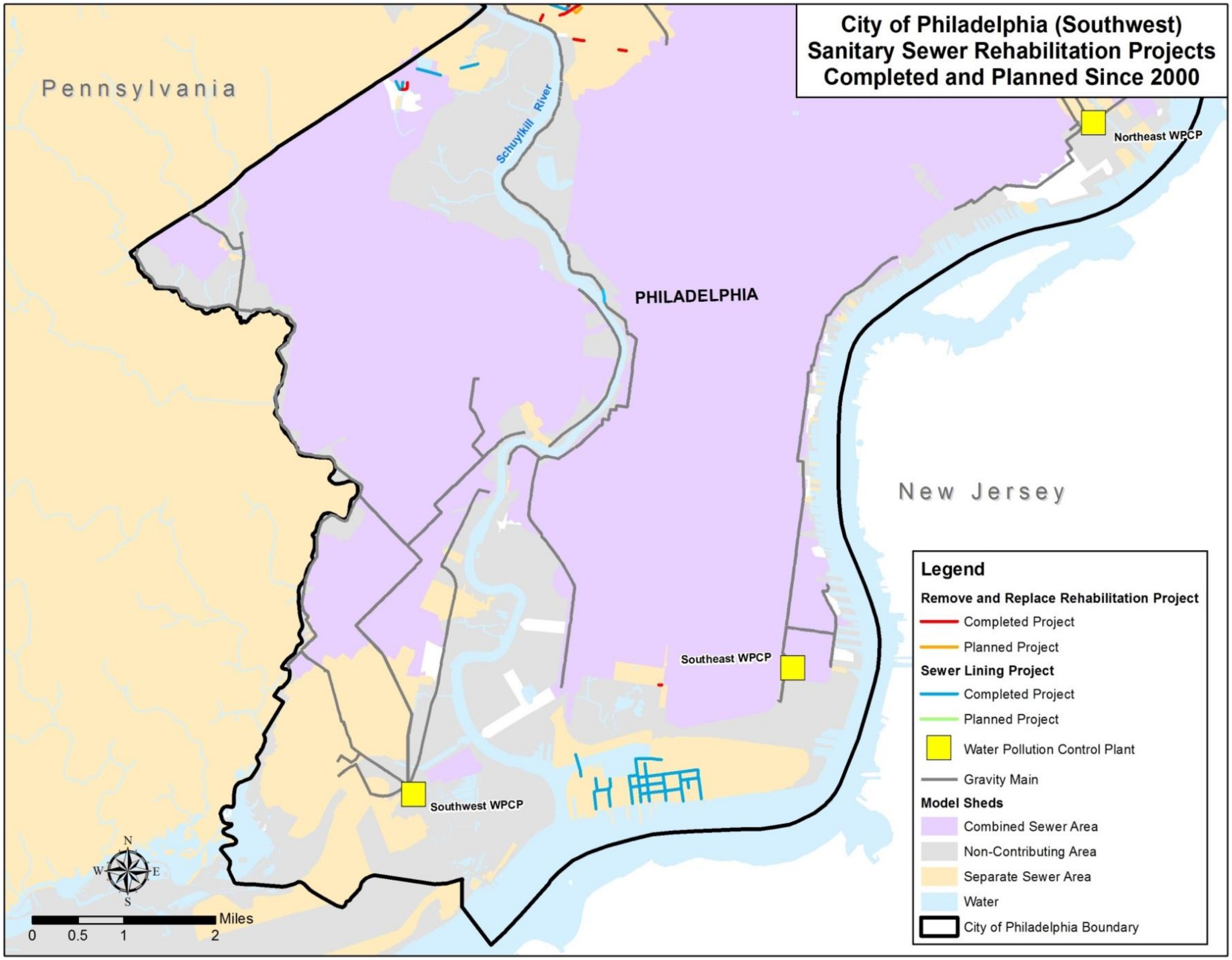


Figure 2-21:Locations of Completed and Planned Sanitary Sewer Rehabilitation Projects (Southwest Area)

2.9 Data Management Approach

One important aspect of the SSES is managing and organizing the large quantity of data utilized by the Philadelphia Water Department. This section documents the means and methods that were used to manage data. A proper data management approach is necessary to archive all of the data in a consistent and organized form. This allows for accurate and efficient reference when looking back through large amounts of data. Over the years, the Water Department has collected and obtained a multitude of data relevant to supporting the City's *Green City, Clean Waters* program. The data were stored with consistent formatting, labeling, and documentation, making the data readily accessible and straightforward for multiple users. The categories of Water Department data that needed to be managed and were pertinent to the SSES include the following.

- Regional and local precipitation data
- Sanitary sewer flow monitoring data
- Spatially referenced infrastructure data
- Closed circuit television (CCTV) inspection data
- Capital Program Integrated Tracking System (CAPIT) data

In addition to describing the various approaches used to manage these data sets, this section also identifies and describes the various software programs and analysis tools that were used in conducting the Phase 2 SSES analysis activities.

2.9.1 Data Management Software and Procedures

The Water Department utilized either a local network drive or Microsoft SQL Server databases in order to store and retrieve data. In this capacity, the data can be stored and retrieved by multiple users across the local system. The data on both systems were backed up to tape on a regular basis by the Water Department's Information Technology (IT) group. Since SQL Server has the ability to allow other software applications to retrieve data stored within it, the Water Department staff used Microsoft Access (MS Access) as an interface with an open database connection (ODBC) to the SQL Server. By doing this, they are able to query selected data from the database as necessary. Currently these servers house the raw flow monitoring data for the outlying community billing meters, the raw precipitation data collected by the city-wide rain gage network, the CCTV inspection data, and the CAPIT data. In addition, the SQL Server was also used to store the GIS geo-databases used for the SSES.

Management of Regional Precipitation Data

The Water Department has acquired several sources of precipitation data used as part of the Phase 1 activities. They are the Philadelphia International Airport (PHL) rain gage, the city-wide rain gage network, the gage adjusted radar rainfall system, and the area-weighted sewershed precipitation data. These data were previously described in Section 2.3 (Historical Precipitation Data within the City and Outlying Community areas).

The PHL rainfall data were collected from the rain gage located at the Philadelphia International Airport (WBAN ID 13739). The data were in 1 hour increments and were downloaded from the National Climatic Data Center (NCDC) and stored in a MS Access database stored on the Water Department server. The data used for the SSES analyses ranged from 1961 through the present.

The city-wide rain gage data utilized for this SSES extended from 1990 through the end of 2013. The raw 2.5-minute tipping bucket rain gage data were extracted from a link to the Water Department's Collector Systems real-time control unit (RTU) database which collected data directly via automatic telephone polling of the gages. The raw 2.5-minute data were then summed to fixed 15-minute intervals. Quality assurance and quality control (QA/QC) procedures were performed on this 15 minute data to identify and flag any suspect or missing data. The flagged data were subsequently removed and any gaps filled using an inverse distance weighting procedure that was applied to accepted data from surrounding gages so that a continuous precipitation record was available for each gage location. Copies of the precipitation data were stored in a MS Access database and loaded into MS Excel spreadsheets for use during the quality assurance reviews of the wastewater flow monitoring data.

The calibrated radar rainfall system data were available in 15-minute reporting periods from 2010 through the present. The data were stored in comma separated values (.csv) file format on the local network share drive.

The area-weighted sewershed precipitation data were generated using a GIS based program with the output data in the form of a text editor (.txt) file and a United States Environmental Protection Agency Storm Water Management Model (SWMM) input (.inp) file.

Management of Sanitary Sewer Flow Monitoring Data

The sanity sewer monitoring data collected for the SSES were described in Sections 2.1 and 2.2. Data management began in the field when the technicians downloaded the data from the wastewater flow meters and uploaded it to their laptop. Technicians interrogated or uploaded the data from the flow monitors according to equipment specifications, and at intervals that avoided data loss because of memory module overlap. The technicians also maintained field logs of flow monitoring measurements and equipment interrogations. The data from these field logs were then entered into MS Excel spreadsheets for storage.

After data were collected in the field, they were converted from the meter manufacturers' proprietary software to a comma separated values (.csv) file. These files were then uploaded into quarterly MS Excel spreadsheets for QA/QC analyses. These files were named and stored in a consistent and logical manner in order to identify the meter's location and the time period the data were collected. The MS Excel files contain the raw and quality-reviewed data within them.

When the MS Excel files were generated, the data were typically in 15-minute reporting increments and the quarterly site files would contain three months of data. Within the MS Excel files, there are worksheet tabs labeled as *Flow Data* which contain the raw interrogated data from the meter. This data include the date, time, monitored level(s), monitored velocity and corresponding calculated flow rate(s). In this same worksheet tab the quality-reviewed data were labeled as the corrected level, velocity, and flow. The quality-reviewed data also has a flag column that grades the data and communicates what form of data correction was used if applicable. Rainfall data, obtained from nearby rain gages or the region's calibrated radar rainfall network, were also added to this spreadsheet.

Any field documentation by the field technicians was also stored in each MS Excel file. A worksheet tab labeled *Site Info* contains site specific information such as sewershed name, pipe diameter, meter type, and installation and removal dates. This worksheet also includes any available field data information, such as dates of site visits, documentation of field measurements and adjustments, and documentation of any general observations made by the technicians.

Once these MS Excel files were created and finalized, they were saved on the local network server in a uniform directory so that the data can be accessed in a consistent fashion at anytime.

Management of Geographic Information Systems (GIS) Data

Another key set of data used during the Phase 1 and Phase 2 activities was GIS data. As described in Sections 2.5 and 2.6 (Available Sewer System Data and GIS Coverage within the City Limits and for Outlying Community Service Areas), all GIS infrastructure data were stored within databases. By doing this, the GIS databases can be updated on an as-needed basis as revisions to the data or improvements to the sewer system are implemented. Also, by storing the data in a database, Water Department users had one centralized location that housed all the files allowing the data to be more readily and easily maintained. The databases used for storage of the GIS data are called geodatabases. A geodatabase is simply a database that stores spatial data. Within the geodatabase there are feature classes which are stored as points, lines, polygons and annotations. Much of the Water Department's GIS data were stored in Esri ArcSDE geodatabases. The allowable size of ArcSDE geodatabases depends on the licensing agreements on SQL Server. With some licensing agreements there is a 4GB limit, but for those operating on an ArcGIS Server enterprise, the database size is unlimited. By using this type of database, users have the ability to extract the data to smaller personal geodatabases or separate shapefiles. These geodatabases are ultimately housed within a SQL Server for final storage.

Management of CCTV Inspection Data

The Water Department's comprehensive Sewer Assessment Program (SAP) was described in Section 2.8 (Sanitary Sewer Inspection Data within the City.) To facilitate an effective and efficient management system for CCTV inspection data, a systematic method was developed by the Water Department for identifying the sewer segments. Because the access points to and from the sewer for inspection activities are manholes, and because the crews inspect and report on the basis of manhole to manhole segments, a comprehensive methodology for manhole identification numbering was developed. Each manhole number is alphanumeric, containing both letters and numbers. The beginning designation identifies the sewer drainage system or sewershed area within which every manhole carrying that prefix resides. Following the prefix is an identification number containing up to six digits.

To provide standardization for the inspection methods that are employed and the digital inspection data that are collected, CCTV Inspection Group crews utilized the protocol standards and procedures of the Pipeline Assessment and Certification Program (PACP) of the National Association of Sewer Service Companies (NASSCO). The PACP is the U.S. industry standard for coding the nature and severity of sewer defects, maintenance conditions, and construction features from CCTV inspection videos.

The SAP data management system is a database that is viewable throughout Water Department offices via intranet using a web browser. The Water Department user has the ability to generate a series of standard and customized reports as described below.

- Debris Report – an organized list of inspected sewer segments sorted by the shape/size of pipe, the Water Department district where the pipe resides, and the accumulation of debris in cubic yards.
- Infiltration Report - allows the query of any inspected sewer segment that has infiltration observations associated with it, and is sorted from the most severe infiltration defect to the least.
- Roots Report - allows the query of any inspected sewer segment that has root defect observations associated with it, and is sorted from the most severe root defect to the least.

A myriad of queries and non-standard reports can also be performed through the data management system. Examples of these queries and non-standard reports include, but are not limited to, the following.

- Complete listing of structural scores
- Complete listing of debris scores
- Status of rehabilitation referrals
- Inspections by CCTV operator
- Defect occurrences by PACP/SAP code
- Defect occurrence by pilot/project areas
- Defect occurrence by street
- Inspections by sewer type
- Inspections by pipe size and/or sewer shape

2.9.2 Data Analysis Tools

The Water Department utilized several software programs and analysis tools for Phase 2 of the SSES. Specific programs and tools were selected to perform the required analyses for the precipitation and flow monitoring data, GIS sewershed data, sewer inspection data, and sewer rehabilitation data, to characterize dry and wet weather flow from sewershed areas and identify specific sewershed areas with relatively high rainfall dependent inflow and infiltration (RDII) volumes.

The US EPASanitary Sewer Overflow Analysis Program Toolbox

One of the keys tools used in the RDII quantification analyses conducted by the Water Department was the United States Environmental Protection Agency (US EPA) Sanitary Sewer Overflow Analysis Program (SSOAP) toolbox. The SSOAP toolbox is a collection of computer software tools used for the quantification of RDII and allow for capacity analysis and condition assessment of sanitary sewer systems. The RDII prediction methodology used in the SSOAP toolbox offers an effective means to design a focused sanitary sewer evaluation study. Further details regarding this methodology can be found in Section 3.6 (Wet Weather Flow Characterization) of this report.

The SSOAP toolbox also serves as a form of independent data storage. Flow monitoring and precipitation data are uploaded into a proprietary SSOAP database (.sdb) file. This file functions much as a MS Access database, providing storage capacity while at the same time enabling the toolbox the ability to analyze the uploaded data. It does not use a stand-alone database, instead giving the user the ability to specify the location of each .sdb database. The SSOAP toolbox also offers the user the ability to export the analysis results to either text editor (.txt) or comma separated values (.csv) file formats.

Esri ArcMap Geo-database Analysis Tools

Esri ArcMap software tools were used extensively for both displaying and analyzing geographic information as part of the SSES. The creation of a geometric network to represent the sewer collection system was a powerful tool that allowed the network to be traced upstream of a sewer monitoring location in order to identify the tributary collection system. The software allowed for the overlaying of orthophotography with sewer system maps and sewer network layers in order to facilitate more accurate delineation of tributary drainage areas. A geoprocessing tool that performed spatial intersections of two polygon layers was used for drainage area characterization in order to estimate population and characterize land use. In addition, spatial intersections of the monitor drainage area polygons with the gage adjusted radar rainfall (GARR) grid polygons were used to generate shed rainfall from GARR data.

Microsoft Access Analysis Tools

One of the main applications used for storing the city-wide rain gage precipitation data throughout the SSES was the MS Access database management system (DBMS). Choosing a relational database such as MS Access gave the Water Department the conveniences of adding, modifying or deleting tabular data from the database, while also providing the valuable tool of querying the data stored in the database. As new precipitation data were being collected, they were uploaded to the database for storage and then readily accessible when needed. As this database grew over time, the capacity of a stand-alone MS Access database was reached and this rain gage data was expanded to multiple databases with one central database providing the ability of linking to or querying data from the others.

In addition to the city-wide rain gage precipitation data, raw flow monitoring data from the outlying community billing meters was also managed via MS Access. As mentioned above, this data was stored in SQL Server; however the Water Department manages this data using a MS Access interface with an open database connection (ODBC). By using MS Access as an interface with the ODBC, the Water Department can directly upload, query, and manage the data on the SQL Server in an effective manner. The Office of Watersheds downloads these data from SQL Server and stores them in a MS Access database from which QA/QC reviews were performed and quality flagging of the data was conducted. The city-wide rain gage precipitation data and the raw flow monitoring data from the outlying community billing meters were queried or extracted from these databases for further analyses as part of the SSES.

Microsoft Excel Analysis Tools

The MS Excel software program was used in the SSES to conduct the QA/QC reviews for the flow monitoring data and for post-processing data from other software packages. As a QA/QC tool, MS Excel was used to generate the monthly time-series and scatter plots of the raw and corrected data as described in Section 3.4 (Quality Assurance Reviews for Flow Monitoring Data). These time-series and scatter plot tools facilitated the review of the raw data. They give a visual representation of the data that were collected by the meters and allowed the analysts to see and decide which data sets truly represented the site and which were errant. Scatter plots were generated for each month of data collected, displaying flow or velocity on the vertical axis versus monitored depth on the horizontal axis. Field measured data points were superimposed over the monitored data to ensure the equipment was properly calibrated. Time-series plots were generated for each month of data collected displaying flow, level and velocity on the vertical axis versus time on the horizontal axis. A secondary time-series plot was placed above the flow data plot displaying precipitation on the vertical axis versus time on the horizontal axis. This enabled the analyst to correlate the observed rainfall to the sanitary sewer responses.

In addition, MS Excel was used to post-process the analysis results from the SSOAP toolbox. Large quantities of data were extracted from the completed SSOAP analyses and loaded into spreadsheets where the data could be sorted and further dry and wet weather sewershed characterization analyses could be conducted. The post-processing included the development of cumulative distribution function (CDF) curves that were used in Section 4.3 (Wet Weather Flow Analysis Results) to rank the groundwater infiltration and rainfall dependent infiltration flow volumes and identify specific sewershed areas with relatively high wet weather flow volumes. The MS Excel program was also used to process GIS data and CCTV inspection data to compile the completed and planned rehabilitation projects documented in Section 2.8.

The MS Excel software program was also used to perform QA/QC of the Water Department's rain gage data. The Water Department's raw 2.5-minute rain gage data were summed into 15-minute increments and imported to a MS Excel workbook for performing QA/QC procedures. The QA/QC procedures identified and flagged questionable and missing data. The quality reviewed data were then imported into an MS Access database where flagged data were replaced with quality accepted data from surrounding gages using the inverse distance squared weighting method.

NetSTORM Analysis Tool

NetSTORM is a CDM Smith computer program for precipitation data assessment and rapid long-term urban runoff simulation. The software performs the following functions.

- Storage – Treatment – Overflow Runoff Modeling
- Precipitation intensity – duration – frequency (IDF) analysis
- Time series aggregation and synthetic disaggregation
- Data conversion from various US National Weather Service formats to tabular formats
- SWMM and MOUSE calibration and statistics tools

NetSTORM adapts selected algorithms originally included in the U.S. Army Corps of Engineers HEC-STORM program and extends the STORM methodology to simulate systems with multiple control structures. It has been used in CSO, SSO, industrial stormwater, and pump station planning studies worldwide. The IDF analysis module of NetSTORM was used to conduct the precipitation analyses conducted for this SSES, which are described and presented in Section 4.1 (Precipitation Data Analysis Results) of this report.

3.0 Summary of Analytical Assessment Approach

Section 3 provides summary documentation for the analytical and assessment methodologies used to conduct the Phase 2 Sewer System Evaluation Survey (SSES). The narrative explains how sewershed delineations and sewershed precipitation were refined and verified from the available historical data. Explanations are also provided for the quality assurance review procedures that were conducted for the monitored precipitation and wastewater flow data. The section concludes with descriptions of the analysis methods, tools, and procedures that were used to quantify and characterize dry and wet weather flow conveyed from the successfully monitored City separate sanitary sewershed areas.

3.1 Refinement and Verification of Sewershed Delineations and Information

The completed Phase 1 SSES inventories and assessments confirmed that the existing archived sets of sanitary sewer collection system maps and drawings, and the associated Geographic Information System (GIS) coverage, were sufficiently complete, up-to-date and reliable for sanitary sewershed areas within the City of Philadelphia. Phase 2 SSES activities included the verification and refinement of sewershed delineations and the corresponding sewershed areas and service populations.

As was previously described in Sections 2.4 and 2.5 (Available Sewer System Data and GIS Coverage within the City Limits and Outlying Community Service areas), the Philadelphia Water Department (Water Department) GIS includes tools that allow the analyst to check flow direction and the connectivity of the collection pipe network, and allow tracing the system upstream of a selected point of interest. This GIS tool was applied to each of the flow monitoring sites located within the City. The tool allowed the analyst to determine the collection sewer network tributary to each monitoring site, based upon the most up-to-date and reliable information. The analysts verified that the sewershed delineations were consistent with the indicated slopes of the pipes. Any apparent contradictions were examined and rectified. The analysts were thus able to refine and finalize the sewershed delineations for each City flow monitoring site, utilizing the updated sanitary sewer pipe network and pipe slope information.

Once the refined sewershed delineations were completed, the analysts utilized the GIS tools to directly compute the polygon area for each flow monitoring sewershed. The verified sewershed areas were subsequently used in the wet weather flow characterization analyses, and applied to the monitored precipitation depths, to quantify the precipitation volumes for each storm over each of the monitored separate sanitary sewershed areas (see Section 3.6). The updated and refined sewershed area polygons were also applied to 2010 U.S. census block information to determine the updated tributary service populations. Previously, service populations for sewershed areas had been computed using simple polygon intersects between delineated sewershed polygons and census block polygons. The assumption was made that the population distribution and density were uniform over the census block. For the Phase 2 SSES, a more complex and accurate analysis method was employed.

The GIS database information includes the footprint area and roof height for each building in the City. The volume was calculated for each residential building, to coincide with the residential population data provided by the census. Within each census block area, the total census population was divided by the total residential building volume. The resulting average unit value was applied to each building volume to calculate approximate building populations. Utilizing building volume helped to distinguish between and account for single family residences, apartment buildings, and multi-story condominium complexes. The building populations were subsequently applied to the building footprint areas. The refined polygon intersects were implemented between the refined sewershed delineation polygons and the residential building footprint area populations. The resulting GIS analysis results provided a more refined and accurate estimate of sewershed service populations. The refined and verified sewershed service populations were used in the dry weather flow characterization analyses to calculate per-capita sewer flows (see Section 4.2).

Conclusions

The completed Phase 2 SSES analysis activities were successful in verifying that the refined sewershed delineations were accurate and reliable, and that any apparent inconsistencies between the sewershed boundaries and the sewer collection system pipe network were adequately examined and rectified. The completed analysis activities were also successful in verifying that the corresponding sewershed areas and service populations were also accurate and reliable.

3.2 Refinement and Verification of Sewershed Precipitation

Phase 1 of the SSES included a review and assessment of the available precipitation data. As discussed in Section 2.3 (Historical Precipitation Data within the City and Outlying Community Areas), there are four primary sources of precipitation data used in the SSES. Section 2.3 describes in detail the Water Department's city-wide rain gage network and the calibrated radar rainfall system, while Section 4.1 (Precipitation Data Analysis Results) of this report provides an analysis of the historical data collected at the Philadelphia International Airport (PHL) rain gage and compares those results to the period of 1999 through 2013. The 1999 through 2013 analysis period coincides with the City flow monitoring activities supporting this SSES and the precipitation comparisons were used to determine if specific months or years were higher or lower than the historical norms.

The purpose of this section is to discuss the area-weighted sewershed precipitation data. Moreover, this section describes how the area-weighted sewershed precipitation was generated as well as the availability and usage of the data in subsequent analyses.

Generation of Area-Weighted Sewershed Precipitation Data

The generation of the area-weighted sewershed precipitation data for the SSES analyses was done using ArcGIS software. The ArcGIS software uses the ArcPy library which provides Python programming language access for all geoprocessing tools within ArcGIS. By using this library, a single Python program was written which imports the 15 minute calibrated radar rainfall data, the 1 km by 1 km radar rainfall pixel grid, and the flow monitors tributary sewershed polygon layers. The program then intersects the pixel grid and the shed polygons to determine the area from each pixel cell that falls within each shed polygon. Once these areas are derived, an area-weighted sewershed precipitation value is calculated for each time step. The weight for a given 1 km by 1 km pixel is calculated as the pixel area within the shed polygon divided by the total shed polygon area. The average or weighted rainfall is the sum of the product of the rainfall and the weight of each 1 km by 1 km pixel. The program then exports the output data in the form of a text (.txt) file and a United States Environmental Protection Agency Storm Water Management Model (SWMM) input (.inp) file.

Available Area-Weighted Sewershed Precipitation Data and Use in Wet Weather Flow Characterization Analyses

As discussed in Section 2.3 (Historical Precipitation Data within the City and Outlying Community Areas), the calibrated radar rainfall data is currently available from 2010 through the present. Since the area-weighted sewershed precipitation data is produced from the calibrated radar rainfall data, it is only available for the same time period. All wet weather flow characterization analyses (hydrograph deconstruction, total R-value, and unit hydrograph curve fitting) conducted on flow monitoring data collected from 2010 onward were completed using the area-weighted sewershed precipitation data, while analyses conducted prior to 2010 used the closest gage from the Water Department's city-wide rain gage network.

Conclusions

The completed Phase 2 SSES analysis activities were successful in utilizing the available archived gage and GARR data and the sewershed delineations to create area-weighted sewershed precipitation. The generated area-weighted sewershed precipitation was successfully used for rainfall characterization and wet weather analyses.

3.3 Quality Assurance Reviews for Precipitation Monitoring Data

The completed Phase 1 SSES data collection and assessment activities confirmed that the existing archived precipitation data were sufficiently complete, up-to-date, and reliable to quantify and characterize precipitation over the Philadelphia Water Department service area. The Water Department's *Implementation and Adaptive Management Plan* (IAMP) indicated that the SSES Phase 2 activities should include a quality assurance and quality control (QA/QC) review to verify that precipitation data quality is sufficient for use in performing hydraulic evaluations of wet weather flows in sanitary sewers. The QA/QC reviews extended to the two primary sources of precipitation data for the SSES: data from the Water Department's network of precipitation gages, and data from the gage adjusted radar rainfall (GARR) system.

3.3.1 Water Department Precipitation Data Processing and QA/QC

The Water Department's raw 2.5-minute data were summed to fixed 15-minute intervals. QA/QC review of this data was performed on a monthly basis by visual comparison of the individual gage data across the network in order to identify and flag missing or questionable data. Flagged data were then filled with coincident data from the six nearest gages using an inverse distance squared weighting method. In addition to the visual inspections conducted by the Water Department, automated QA/QC reviews of the gage data were also conducted by the GARR contractor as described below.

3.3.2 GARR Data Processing and QA/QC

The professional services contractor that provided the high-resolution gage adjusted radar rainfall (GARR) data conducted the comprehensive QA/QC reviews on a monthly basis before the GARR data were submitted to the Water Department. During each month, radar and rain gage data were segmented into qualified storm periods and then quality controlled (QC). The QA/QC process involved three steps.

- Initial QA/QC review of the raw precipitation gage data
- Adjustment of the raw radar reflection data to produce GARR
- Final QA/QC review of the GARR data

Initial QA/QC review of the Precipitation Data

Rainfall data from as many as 40 gages were used to adjust the next generation radio detection and ranging (NEXRAD) Doppler radar. The City of Philadelphia provided coordinate locations and 2.5-minute precipitation data for the 24 rain gages in the Water Department network. In addition, rain gage data were obtained from ten United States Geological Survey (USGS) stations and six National Weather Service Automated Surface Observing System (ASOS) stations. The collected rain gage data were systematically reviewed, utilizing software developed by the GARR contractor, to identify gages that were not consistent with the radar or surrounding gages during both the qualified storm and inter-event periods. Qualified rainfall events were defined based on a storm definition where, for any given hour, at least 50% of all working gages reported an accumulation of 0.05 inches.

Reasons for not using gages in rainfall analysis included clogs, significant under- or over-reporting of rainfall, gages that stop reporting during rainfall, or a combination of these reasons. A list of possible reasons for not using a gage based on the completed analyses is shown in Table 3-1.

Table 3-1: QA/QC Criteria for not using a Gage for Storm Quantification

Reason	Explanation
Clog(C)	Gage appeared to be clogged
Zero (Z)	Gage did not report any rainfall while radar rainfall estimates reported significant rainfall
Stop (S)	Gage appeared to stop reporting rainfall while radar rainfall estimates reported significant rainfall
Over (O)	Gage appeared to significantly over-report rainfall as compared to radar rainfall estimates and surrounding gages (e.g. anomalously high rainfall values caused by field calibration, data transmission error, or switch malfunctions)
Under (U)	Gage appeared to significantly under-report as compared to radar rainfall estimates and surrounding gages(e.g. half-tipper)
Sync (SY)	Gage appeared to be reporting out-of-sync with the radar rainfall estimates
Frozen (F)	Gage not reporting properly due to frozen precipitation
Melt (M)	Gage not reporting properly due to melting precipitation
Other (T)	Combination of multiple reasons
No Data (ND)	Gage reported "no data" for a significant amount of time

Radar Data Adjustment and Refinement Methodology

In the production of GARR, radar reflection data were bias corrected through comparison with rain gage accumulations. The first step in the data refinement process was to perform a local bias review to adjust the radar rainfall. The local bias method used the ratio of gage to radar accumulations from surrounding gages with the closest gage having the most weight. By statistical comparison between the radar and rain gage accumulations during a calibration interval, outliers were identified. The approach distributed the variation of bias over the entire Water Department service area, and the computed bias adjustments were applied within each storm period. The calculated bias correction factors were applied to the radar reflection data to enhance the accuracy of the GARR for any accumulation period.

The statistical QA/QC reviews of the data made the radar rainfall measurements more accurate. By adjusting the radar data with rain gage data, more accurate rainfall measurements were generated than either the radar or gages could produce alone. Though generally small, differences between rain gage and radar rainfall accumulations still exist due to sampling differences or local meteorological conditions. Radar measures above the ground, while rain gages measure close to the ground. Updrafts and downdrafts during storms can decrease or increase rainfall rates, respectively.

Final QA/QC Review Methodology for the GARR

As a final QA/QC review measure, cumulative distribution plots (CDPs) at each gage location showing gage, unadjusted radar, and GARR values were produced for each qualified rainfall event. Rain gages that were not performing consistently with the radar or surrounding gages were visually identified in the CDP graphs. Figure 3-1 shows a representative example of rainfall accumulation at a gage during a storm as measured by the gage (green), unadjusted radar (blue), and gage-adjusted radar (red). Final statistical reviews of the data provided an indication of data quality. Calibrated average difference (CAD) values for individual events less than 10% were considered excellent, 10 to 20% were considered good, and 20 to 30% were considered fair.

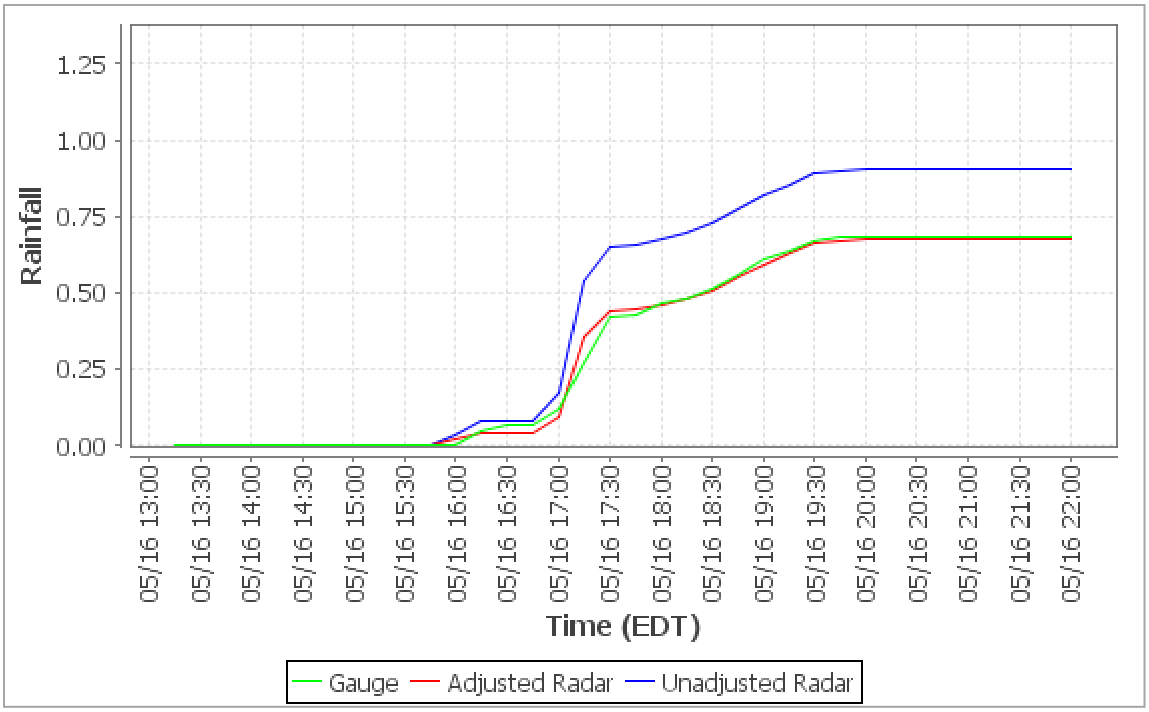


Figure 3-1: CDP Showing Rain Gage versus Unadjusted Radar versus GARR
(Source: Philadelphia Water Department (PWD) Radar Rainfall Analysis by Vieux, Inc.)

The final QA/QC process included an additional graphic comparison between the radar and gage data, called a Z-R relationship. A representative example of a scatter plot that shows the Z-R relationship for a representative storm is provided in Figure 3-2. The QA/QC linear regression analysis verified that the Z-R relationship had been properly adjusted, because the adjusted pairs formed a linear relationship.

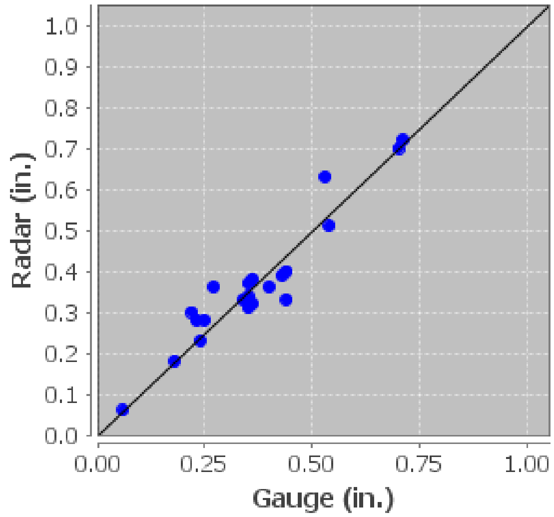


Figure 3-2: Scatter Plot of GARR versus Gage Pairs
(Source: PWD Radar Rainfall Analysis by Vieux, Inc.)

A representative example of a storm total plot for a storm where the GARR adjustment processes had been completed and the QA/QC reviews had been conducted is provided in Figure 3-3.

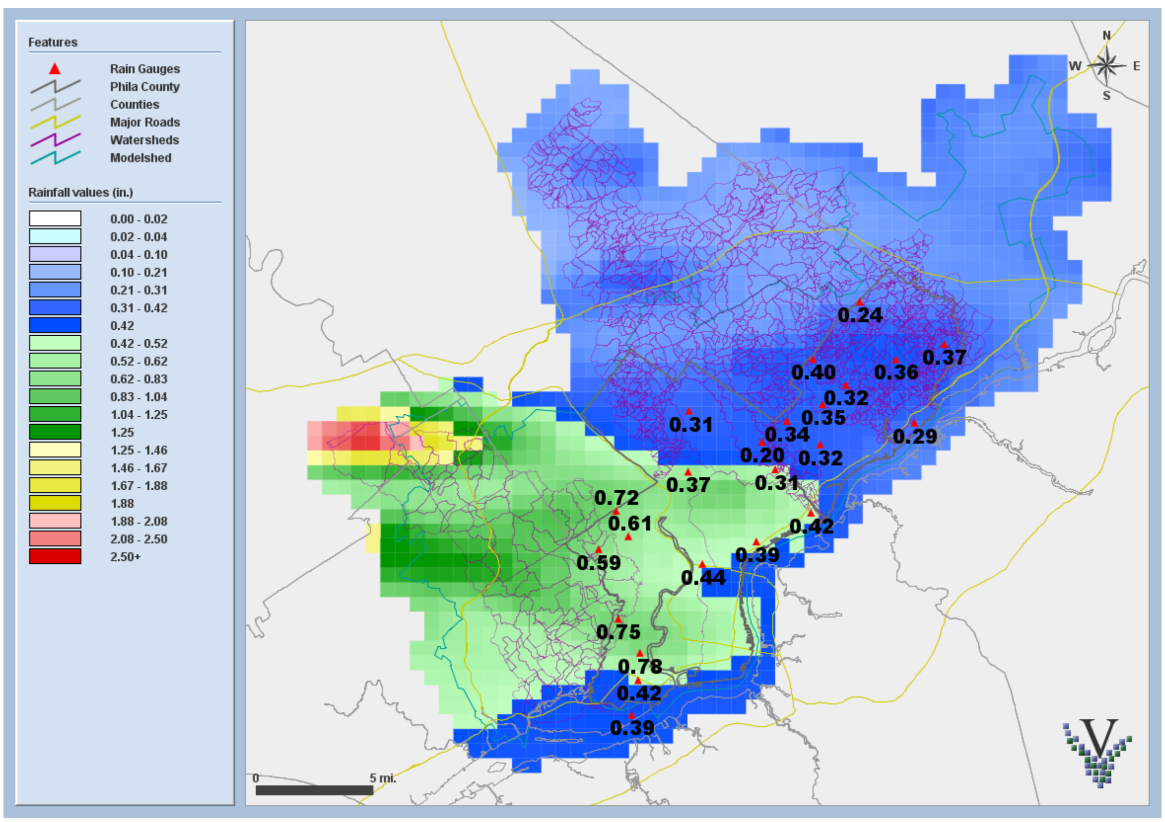


Figure 3-3: GARR Storm Total for an Example Event
(Source: PWD Radar Rainfall Analysis by Vieux, Inc.)

3.3.3 Precipitation Monitoring Conclusions

The completed QA/QC reviews for the collected precipitation data from the regional rain gage network and the GARR system were able to confirm and verify that the archived precipitation data used to conduct the SSES Phase 2 analyses were of sufficient quality and reliability. The completed QA/QC reviews were capable of detecting and identifying errant and unacceptable gage data and ensure that unreliable data were not incorporated into the SSES analyses. The existing available archived precipitation data was sufficient to quantify and characterize rainfall and snowfall over the City sewershed areas, quantify and characterize rainfall dependent infiltration and inflow (see report Section 3.6), and identify City sewershed areas that contribute excessive extraneous flow to the Water Department conveyance and treatment system (see Section 4.3).

3.4 Quality Assurance Reviews for Flow Monitoring Data

The Water Department's December 2011*Implementation and Adaptive Management Plan* (IAMP)indicates that the SSES should include a quality assurance and quality control (QA/QC) plan to ensure that the network of flow monitoring equipment provides representative, accurate, and reliable data. The June 2011 *Consent Order and Agreement* (COA) requires that the QA/QC plan ensure that the data quality is sufficient for use in the development and validation of a hydraulic and hydrologic (H&H) model of the Water Department's service area. QA refers to programmatic efforts to ensure the quality of monitored and field measured data. QA programs increase confidence in the validity of the reported analytical data. QC, a subset of quality assurance, refersto the application of procedures designed to obtain prescribed standards of performance in monitoring. The QA/QC plan that the Water Department implemented for this SSES is organized into two main categories: protocols for directing activities and procedures in the field, and protocols directing data verification in the office.

3.4.1 Protocols and Standards for Field Activities

Comprehensive protocols and standards for field activities are required elements to execute the flow monitoring program to maximize the collection of high quality data. Proposed monitoring sites were pre-screened, and field verification investigations were conducted to ensure conditions were conducive to accurate and reliable flow monitoring. A monitoring site naming convention was established. An effective inspection and assessment process ensured proper selection of monitoring sites and equipment. The physical and hydraulic characteristics of each site were matched with optimal technology selection and sensor placement that maximized the quality of collected data. All meter installations conformed to the flow monitoring equipment manufacturer's specifications. Qualified field technicians routinely interrogated the data, maintained the monitoring equipment, performed as-needed sensor calibrations, and documented field procedures and observations. These routine field visits consisted of the field technician obtaining physical measured levels and velocities, comparing these measurements to the real-time metered readings and calibrating and/or cleaning the sensors when needed. These field measurements and activities were documented in field logs and were used by the data analysts in the QA/QC process, in order to ensure the quality of the collected data.

3.4.2 Protocols and Standards for Office Activities

The second category of required activities within the QA/QC process is data verification in the office. A data QA/QC system was implemented to standardize the format and file names associated with collected data from the selected flow monitoring sites. This system included a comprehensive review of collected data, the identification of data gaps, and the conversion of raw flow data into final quality-reviewed data sets.

Individual site files were generated for each monitoring site which contain either one month or three months (organized on a quarterly basis) of data. Also, monthly time-series and scatter plots of the monitored data were included in the site file. These time-series and scatter plots were prepared to assist in the data review process and verify the reliability and accuracy of the collected flow monitoring data.

Time-series plots were used to flag any inconsistencies in the monitored diurnal cycles that could not be attributed to precipitation or seasonal changes in groundwater levels, and also to flag inconsistencies due to equipment failures. Figure 3-4 illustrates an example time-series plot of raw data used in the QA/QC process. These plots have the flow and velocity plotted on the primary y-axis, the levels plotted on the secondary y-axis, and the precipitation data plotted in a separate smaller graph above this data.

When redundant levels were utilized, they were compared to one another to determine if they were internally consistent, thus adding confidence to the accuracy of the monitored levels. More importantly, the monitored levels needed to be confirmed by comparing them to field measurements. If the field measured readings were within an acceptable range of the monitored data recorded at the time of the field visit, the data was considered to be reasonably reliable. When the redundant levels were not tracking one another, the field logs were used to confirm which level was more reliable by comparing which one was closest and within the acceptable range of the field measured readings at that time.

Precipitation data, obtained from a nearby rain gage or the region's calibrated radar rainfall network, was also added to the time-series plots. This aided in confirming that increases in level, velocity, and corresponding flow rates throughout the monitoring period were attributed to precipitation events and not errant data.

In addition to the time-series plots, scatter plots were generated for each month of data collected displaying flow and/or velocity on the vertical axis versus monitored depth on the horizontal axis. Field measured calibration points were superimposed over the monitored data to ensure the equipment was properly calibrated. Scatter plots were used to review the quality of the data collected and verify that the equipment was properly calibrated. A depth-flow relationship with a consistent envelope curve and a minimal degree of scatter in the data typically is indicative that the equipment was functioning properly and the data was reasonably reliable. Figure 3-5 provides an example scatter plot of raw data used in the QA/QC process.

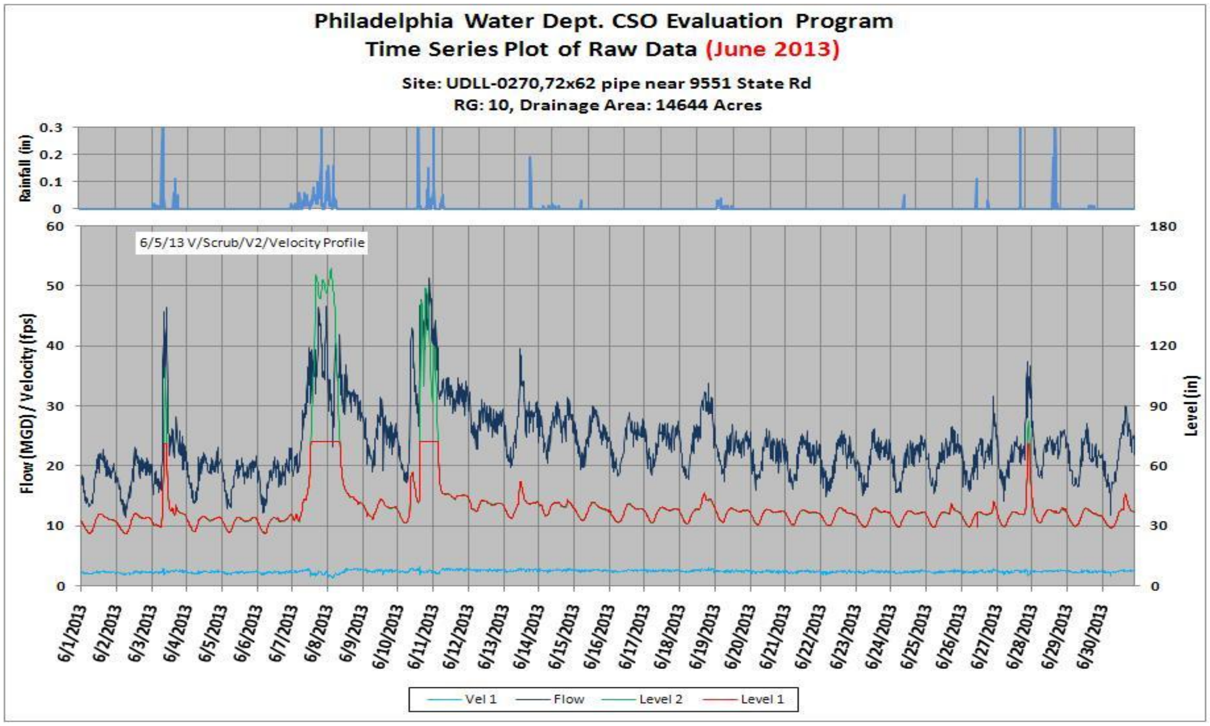


Figure 3-4:Example Time-Series Plot for Raw Data

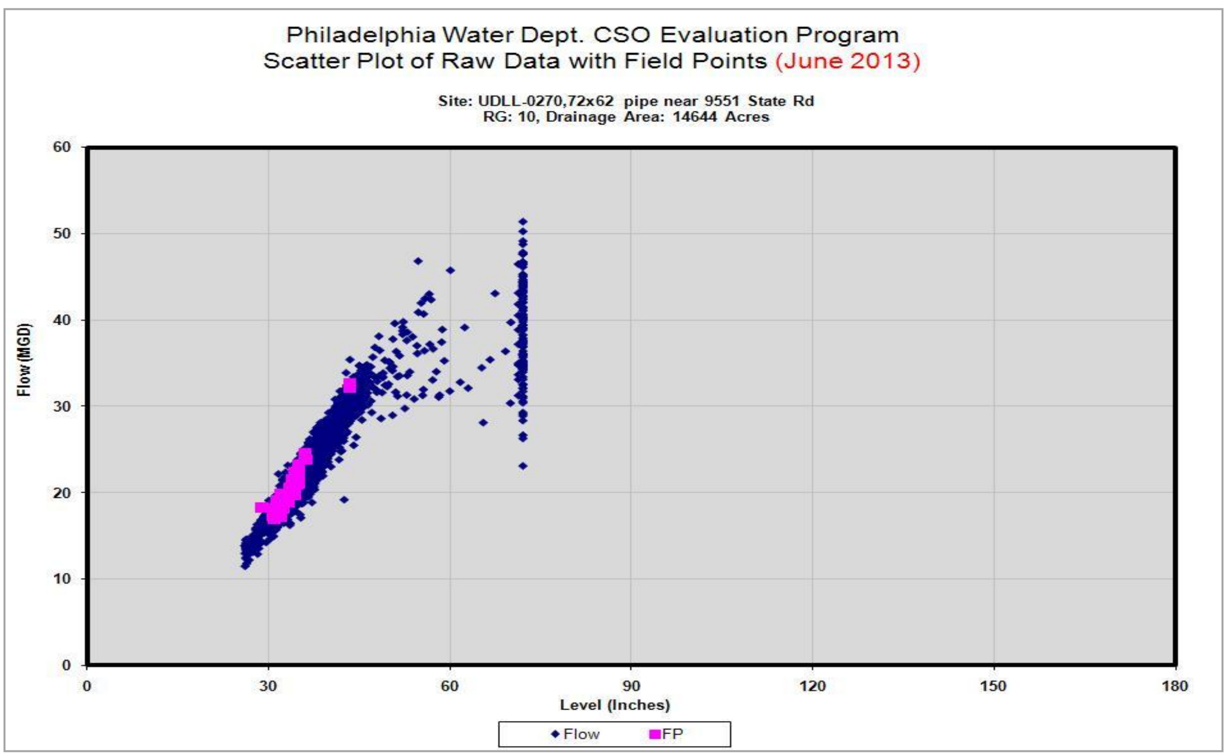


Figure 3-5:Example Scatter Plot for Raw Data

Two general categories of data errors were identified through the QA/QC process: short-term errors and long-term errors. Short-term errors are generally caused by temporary hydraulic conditions or intermittent sensor fouling and typically last for a brief duration. Since these brief periods of errant data are surrounded by reliable data points, both depth and velocity errors can usually be corrected by interpolating between adjacent points. Long-term errors, on the other hand, are caused by ongoing hydraulic conditions, extended sensor fouling, improper equipment calibration and/or equipment failures and can last from several hours to several weeks in extreme cases. Errant data identified through the review process was either flagged as unusable in subsequent analyses, or corrected using approved techniques such as a rating curve (established depth-flow relationship developed based on reasonably reliable monitored data) or interpolation between adjacent reliable data points as mentioned above.

The final step in the QA/QC process was to take the final quality-reviewed datasets and plot them on 'corrected' time-series and scatter plots. These plots show only the quality-reviewed data and any necessary data quality comments. Figure 3-6 illustrates an example final quality reviewed time-series plot resulting from the QA/QC process. It displays the corrected level as a red line and the corrected flow as a dark blue line. Figure 3-7 illustrates an example final quality reviewed scatter plot produced resulting from the QA/QC process. It displays the corrected flow as dark blue points with the field measured calibration points (in pink) superimposed over the 'corrected' monitored data.

The completed QA/QC reviews for the collected flow monitoring data were able to confirm and verify that the data used to conduct the detailed SSES Phase 2 analyses was of sufficient reliability. The completed QA/QC reviews were also able to identify errant or unacceptable data and ensure that unreliable data was not incorporated into the SSES Phase 2 analyses. The existing available wastewater flow monitoring information with acceptable data quality was sufficient to quantify and characterize dry and wet weather flow from City sewershed areas, quantify and characterize rainfall dependent infiltration and inflow, and identify City sewershed areas that convey relatively high wet weather flow to the Water Department conveyance system.

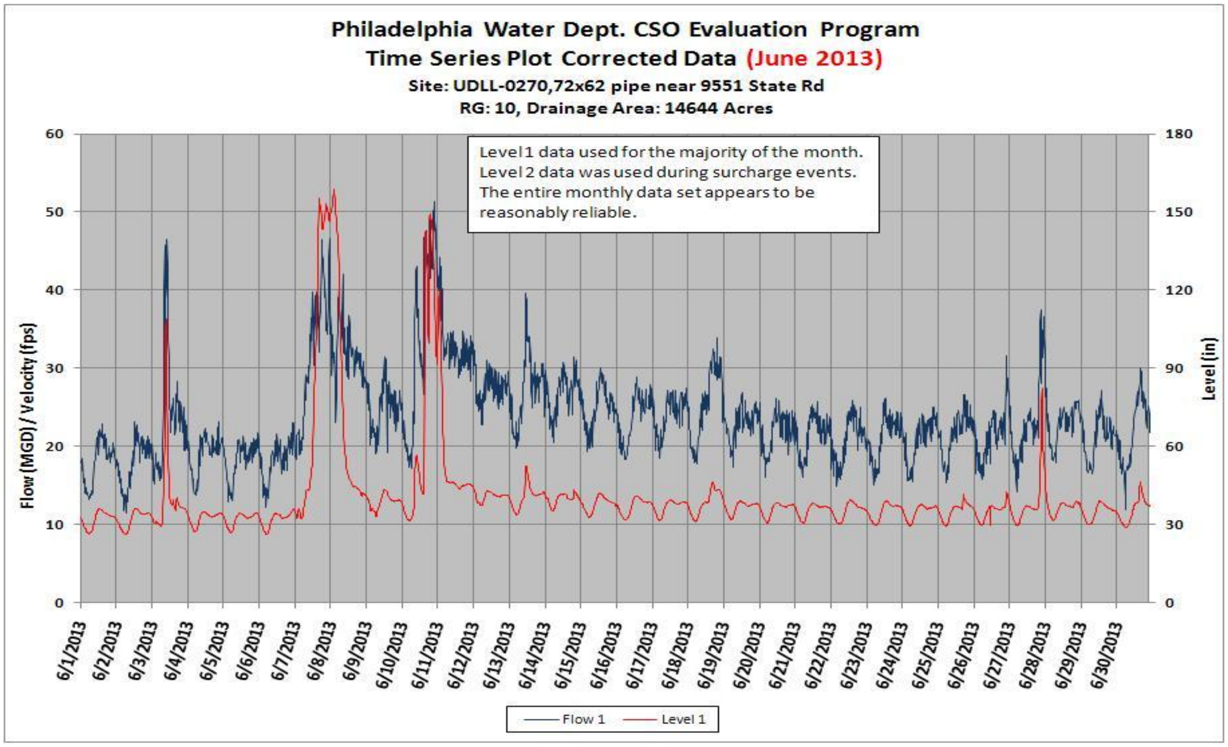


Figure 3-6:Example QA/QC'd Time-Series Plot

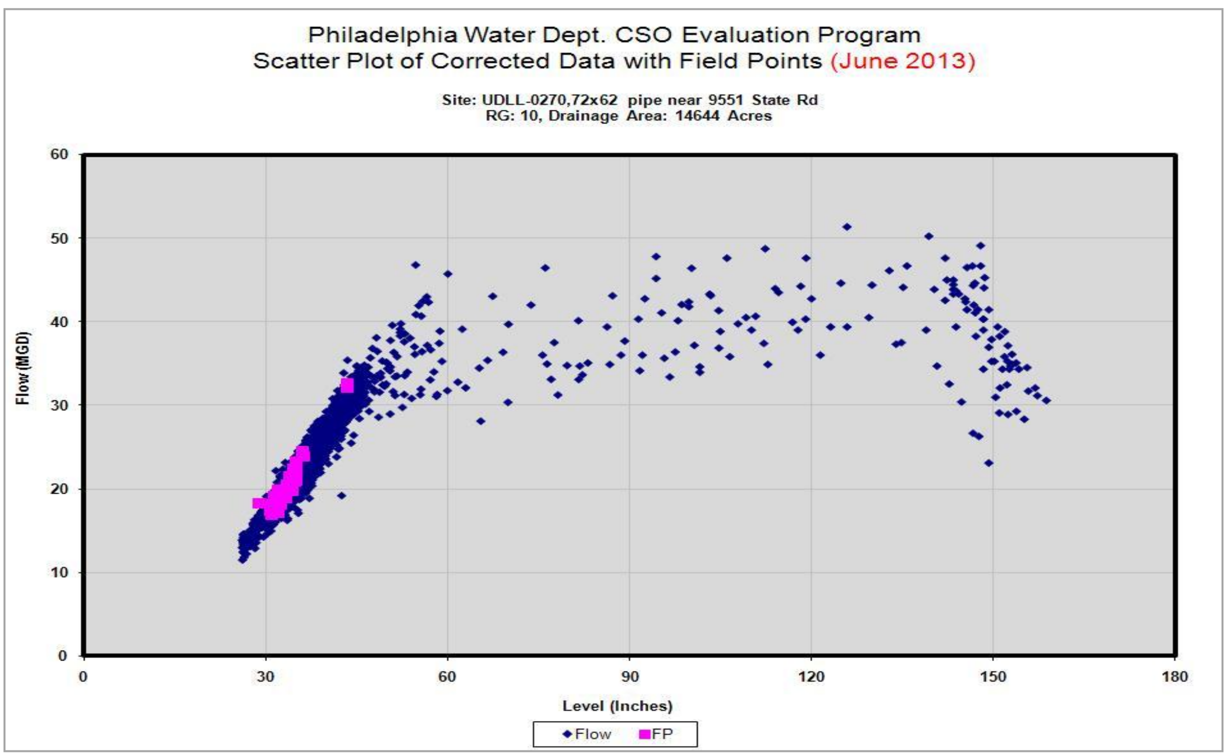


Figure 3-7: ExampleQA/QC'd Scatter Plot

3.5 Dry Weather Flow Characterization

The scope of work for Phase 2 of the SSES includes a series of analyses that were conducted to quantify and characterize dry weather flow (DWF). For each of the monitoring sites and corresponding sewershed areas located within the City of Philadelphia, dry weather flow periods were identified and corresponding monitored flows were analyzed to characterize dry weather hydrology. The dry weather flow analyses were conducted to quantify the total base wastewater flow (BWWF) and ground water infiltration (GWI) tributary to each of the monitoring sites. BWWF and GWI together comprise the DWF that occurs in a sanitary sewer system.

BWWF, often referred to as the base sanitary flow, represents the residential, commercial, institutional, and industrial flow that is discharged to a sanitary sewer system for collection and treatment. BWWF normally varies with water use patterns throughout a 24-hour period with higher flows occurring during the morning hours and lower flows during the night. GWI represents the infiltration of groundwater that enters the collection system through leaking pipes, pipe joints, and manhole walls. GWI varies throughout the year, often trending higher in late winter and spring as groundwater levels and soil moisture levels rise, and subsiding in late summer or after an extended dry period. For the Phase 2 SSES analyses, the assumption was made that all of the monitored minimum nighttime flow was GWI. While this assumption is admittedly conservative, as there is usually some sanitary BWWF being conveyed in the early morning hours, the consistent use of this assumption for all analyzed monitoring data should not significantly bias the analysis results. Figure 3-8 below depicts a typical DWF hydrograph. The orange shading represents the BWWF component of DWF, while the blue shading represents the GWI component.

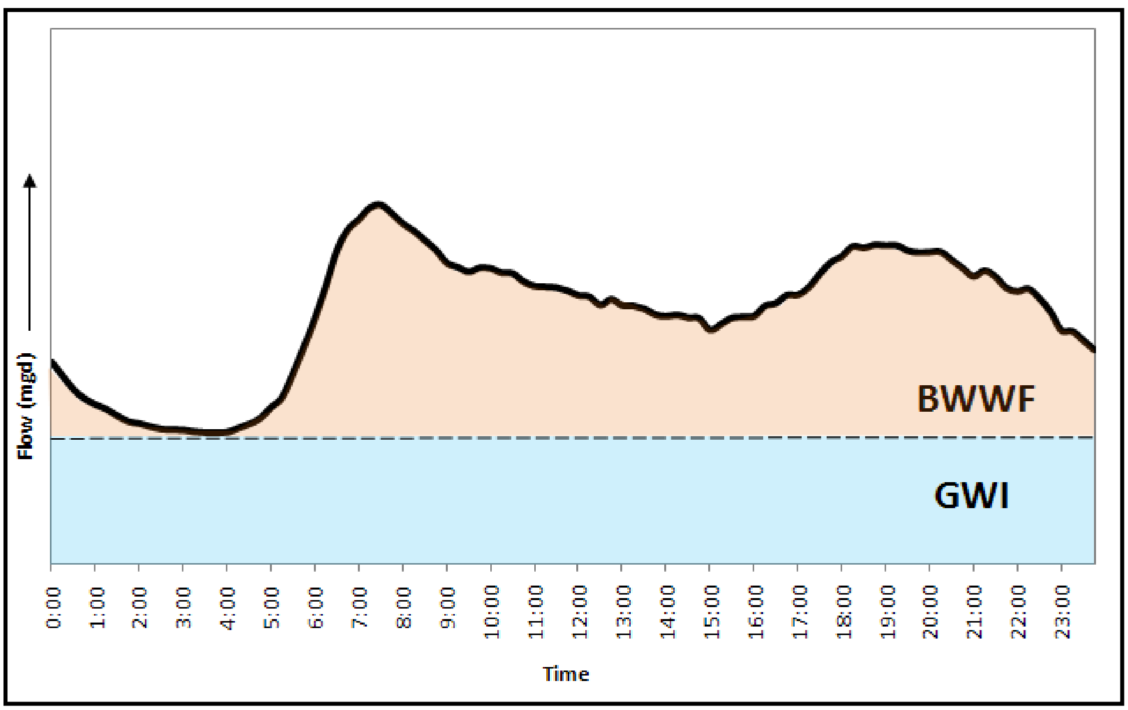


Figure 3-8: Components of Dry Weather Flow

3.5.1 Weekday and Weekend Dry Weather Hydrographs

As part of the dry weather flow characterization process, weekday and weekend average daily dry weather flow hydrographs and corresponding flow summaries were produced using the Environmental Protection Agency (US EPA) Sanitary Sewer Overflow Analysis Program (SSOAP). Using the program, periods of dry weather flow with no recorded precipitation, no influence from prior storms, and consistent diurnal patterns were manually selected by the analyst. A diurnal pattern is simply the observed flow pattern over a 24 hour period. After these periods of dry weather flow were selected, the incremental flow data points for these days were then averaged together by SSOAP to produce average weekday and weekend dry weather flow hydrographs for each monitoring site. Weekdays and weekend days were evaluated independently because weekdays and weekends typically exhibit their own unique, repeatable flow patterns. In predominantly residential areas, there usually is a lag between the weekday and weekend hydrographs due to residents starting their day earlier during the week. In non-residential areas, the weekday and weekend patterns can differ greatly due to almost non-existent weekend populations. Plots of these hydrographs were produced showing flow on the vertical axis versus time on the horizontal axis. Figure 3-9 illustrates the difference between weekday and weekend hydrographs in a primarily residential area, while Figure 3-10 shows the difference between weekday and weekend hydrographs in a commercial or industrial area.

These average dry weather flow hydrographs were then summarized and the resulting average daily dry weather flow (ADDWF) for each site and the average maximum and minimum dry weather flows were calculated and expressed in million gallons per day (mgd). The dry weather flow rates were also calculated in units of gallons per capita per day (gpcd). These average daily dry weather flow hydrograph plots, and corresponding dry weather flow summaries, can be found in Appendix B of this report. The appendix information is provided in digital format on the attached compact disc (CD).

3.5.2 Ground Water Infiltration Ratios

The computed average daily maximum and minimum dry weather flows characterize the fluctuation seen in the dry weather diurnal flow pattern, while the average daily minimum flow was calculated to approximate the rate of extraneous groundwater infiltration, or GWI, entering the upstream collection system. Also computed as part of the dry weather flow analyses are the GWI ratios for each site. Assuming BWWF during minimum flow nighttime hours is negligible in tributary areas that are predominately residential, a ratio can be calculated to approximate the percentage of GWI observed in the total dry weather flow. These GWI ratios were calculated by dividing the average minimum dry weather flow by the average daily dry weather flow. If the GWI ratio is high, then it can be assumed that the sewer is 'leaky', with a higher incidence of extraneous infiltration flow.

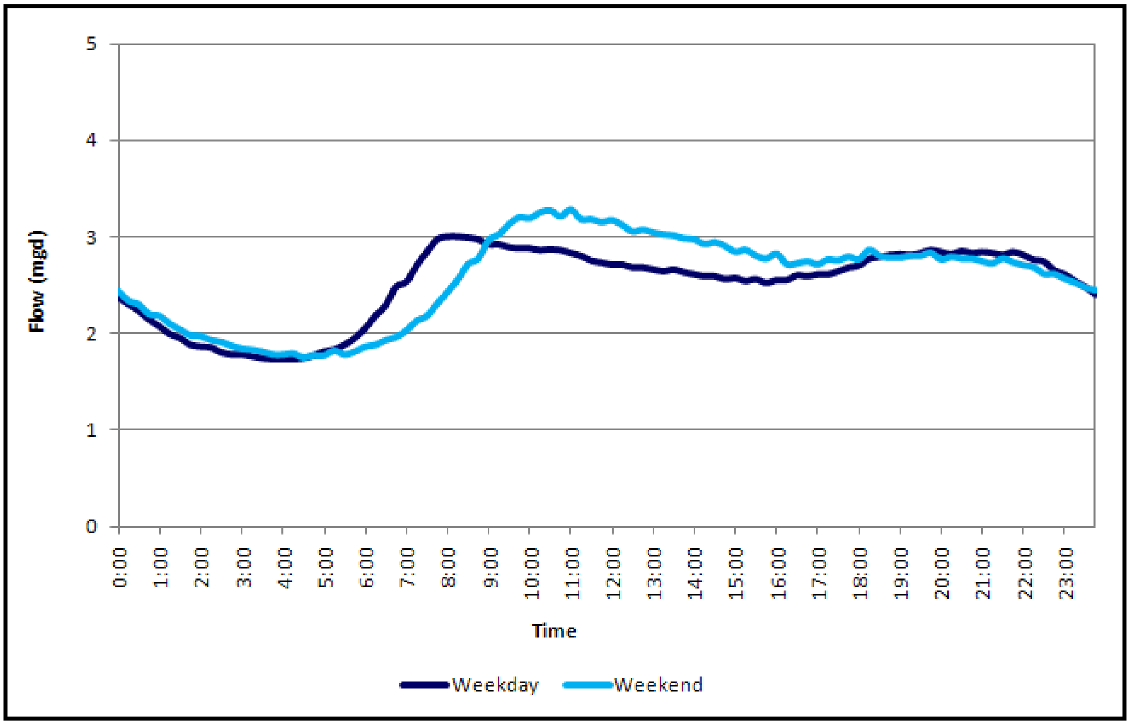


Figure 3-9: Example Weekday and Weekend Dry Weather Flow Hydrographs in a Residential Area

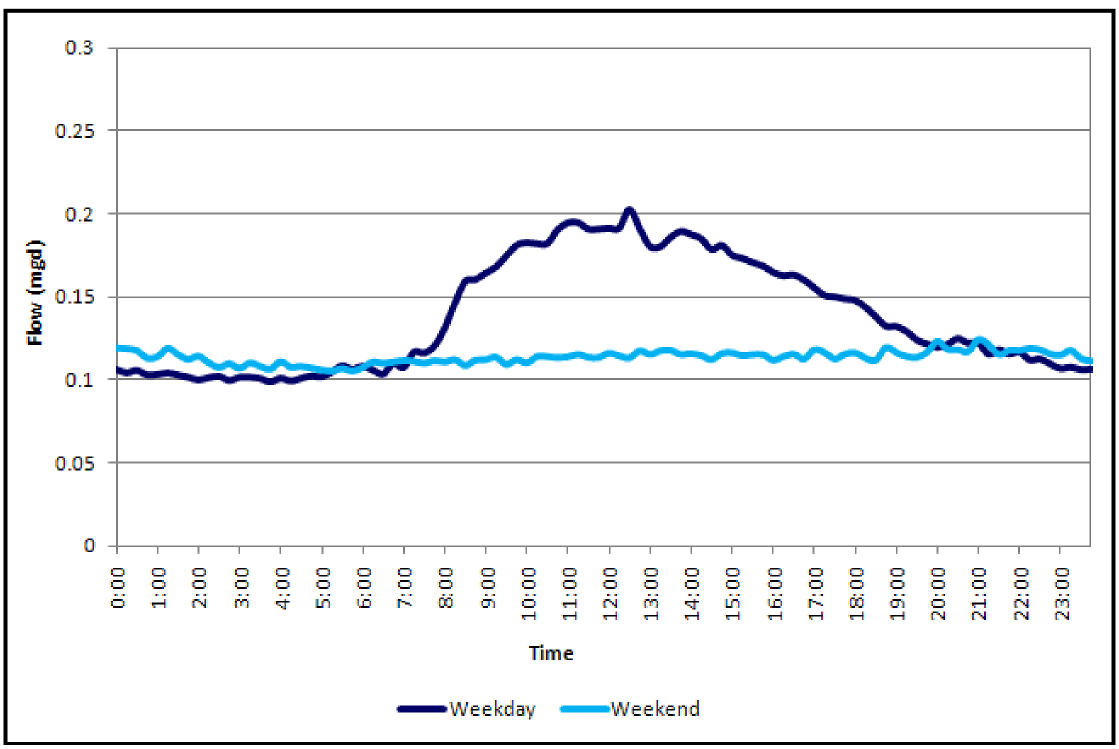


Figure 3-10: Example Weekday and Weekend Dry Weather Flow Hydrographs in a Commercial Area

3.5.3 Dry Weather Flow Analysis Results and Conclusions

The completed Phase 2 SSES analyses were successful in quantifying and characterizing dry weather flow from separate sanitary sewershed areas within the City of Philadelphia. Section 4.2 (Dry Weather Flow Data Analysis Results) provides various tables and graphics to depict illustrating the dry weather flow analyses results.

The dry weather flow analysis results for all sanitary sewer system monitors located within the City can be found in Appendix B of this SSES report. The appendix further details the following:

- The tributary drainage area and service population for each of the monitoring locations analyzed
- The resulting average weekday and weekend hydrographs for each site
- The average, maximum, and minimum dry weather flows
- The GWI ratio
- The number of days used in generating the dry weather flow statistics

3.6 Wet Weather Flow Characterization

After the dry weather flow analyses were completed, wet weather flow analyses were conducted as part of Phase 2 of the SSES. For each of the sanitary sewer flow monitoring sites located within the City of Philadelphia, wet weather flow periods were identified and corresponding monitored flows were analyzed to characterize wet weather hydrology. Analyses were conducted to quantify the total base wastewater flow(BWWF), ground water infiltration (GWI), and rainfall dependent inflow and infiltration (RDII) tributary to each of the monitoring locations. The understanding of each of these major flow components is essential to understanding the sources of flow into the sanitary sewer systems, the relative quantities of RDII in the systems, and whether the RDII is unreasonably high. Listed below are the analyses conducted as part of the wet weather flow characterization process. Each analysis will be explained throughout this section.

- Hydrograph Deconstruction
- Unit Hydrograph Curve Fitting
- Largest Monitored Events Summary Tables
- Peaking Factor

As described in Section 3.5, BWWF and GWI together comprise the dry weather flow that occurs in a sanitary sewer system. RDII is the rainfall-derived flow response in a sanitary system. In most systems, RDII is the major component of peak wastewater flows and is typically responsible for capacity issues, SSOs, and/or basement backups. Figure 3-11 depicts various pathways that RDII can enter into a sanitary sewer system.

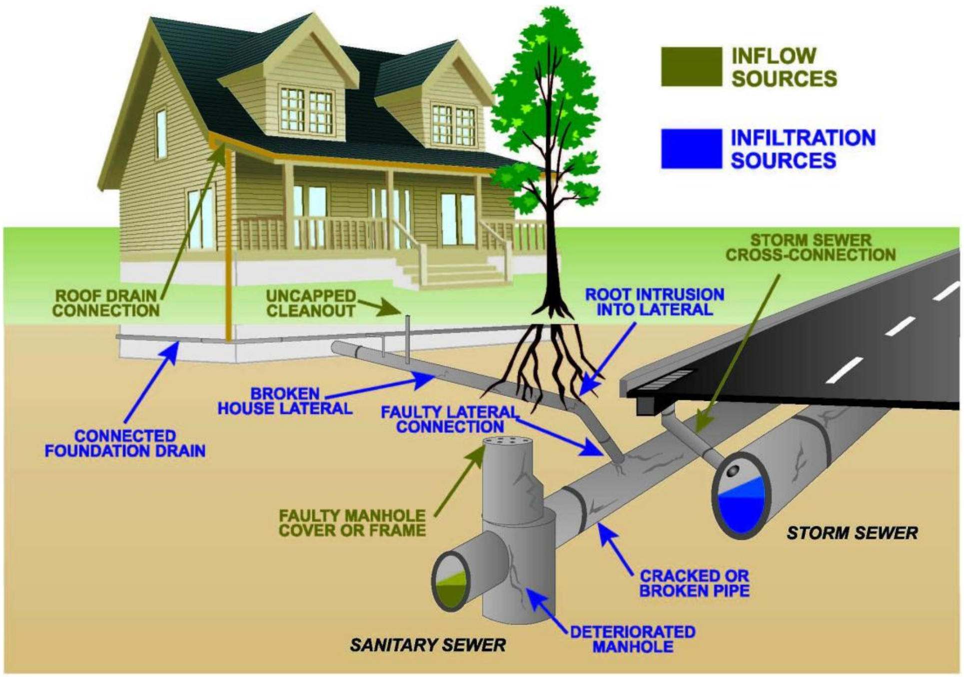


Figure 3-11:Causes for RDII in a Sanitary Sewer System
(Source: City of Oregon, OH)

Inflow is the water that enters the sanitary sewer system directly via leaky manhole lids and frames, roof drain connections, sump pumps, foundation drains, and cross-connections with storm sewers. Although direct connections such as downspouts, sump pumps, foundation drains, and areaway drains are no longer common design practices, they still exist and contribute to inflow in many older sanitary systems. Inflow typically occurs shortly after a rainfall event starts and is usually the major component of the peak RDII flow.

Rainfall-derived infiltration refers to rainfall runoff that filters through the soil before entering a sanitary sewer system through damaged pipe sections, leaky joints, etc. These defects can occur in both the public right-of-way portions of the sanitary sewer system or in individual service laterals on private property. Infiltration typically extends beyond the end of rainfall and takes some time to recede to zero after an event.

3.6.1 Hydrograph Deconstruction

The United States Environmental Protection Agency's Sanitary Sewer Overflow Analysis and Planning (SSOAP) toolbox was used to analyze the successfully collected and quality assurance-reviewed precipitation and flow monitoring data in order to develop an understanding of the system RDII characteristics. More specifically, the total monitored flows were deconstructed into their characteristic flow components of BWWF, GWI, and RDII. Figure 3-12 illustrates these components of the total monitored wastewater flow. The BWWF and GWI flows represent the dry weather flow component of the total flow, while the RDII component represents the rainfall-produced response in the sanitary sewer system.

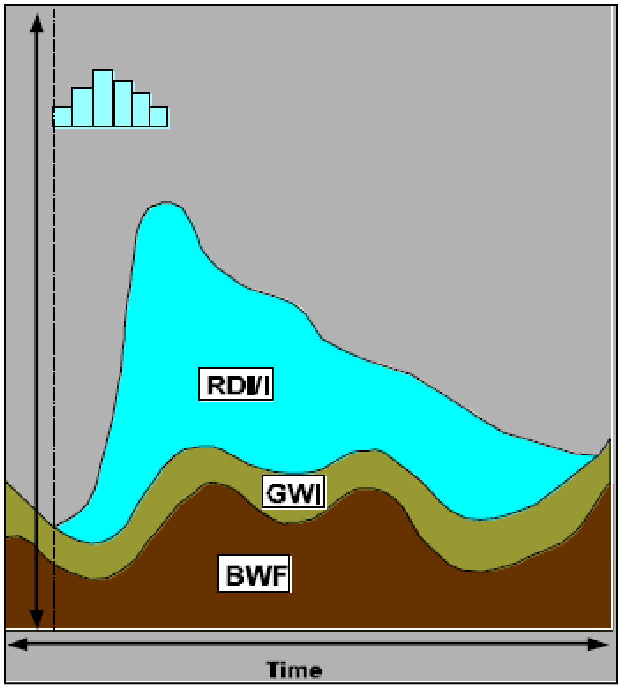


Figure 3-12:Components of Wet Weather Wastewater Flow
(Source: CDM SHAPE manual)

To conduct the SSOAP analyses, a graphical representation of the total monitored flow was generated for the entire monitoring duration. The analyst then took the typical weekday and weekend dry weather flow quantities and patterns, previously determined during the dry weather flow analyses, and superimposed them over the total monitored flow. The typical dry weather pattern of five weekdays and two weekend days was repeated as necessary to cover the entire duration of the monitoring period. For the hydrograph deconstruction process, SSOAP was used to address variability in the dry weather flow by accounting for the seasonal variations of GWI and ensure that the RDII flows were approximately equal to zero during dry periods not directly influenced by rainfall. This deconstruction of the total monitored flows was accomplished by adjusting the GWI flows to set the proper dry weather flow conditions prior to rainfall events to determine rainfall event specific RDII hydrographs.

After the GWI adjustments were made, the data analyst identified the start and end times of the individual RDII events during the period of record. Once individual events were defined, statistics were produced detailing each event’s RDII volume, rainfall volume, total-R value, and the deconstructed components of total monitored flow.

The calculated volume of RDII for each storm was divided by the corresponding volume of rainfall over the sewershed area and expressed as a percentage, or R-value. This R-value represents the fraction of the rainfall that fell over the tributary sewershed area that entered the sanitary sewer system. For example, a computed R-value of 0.045 would indicate that 4.5% of the measured rainfall over the sewershed area “leaked” into the sewer system as monitored RDII. Low values typically indicate a tight sewer system with minimal extraneous flow. On the contrary, high values indicate high quantities of extraneous flow originating from possible sources such as roof leader connections, foundation drain connections, connections with storm inlets or area drains, and leaking pipe joints. When the analysis was completed, the volume, duration and pattern of RDII flow were determined for each successfully monitored storm event.

An individual spreadsheet of results was prepared for each flow monitoring site that was analyzed and can be found in Appendix C of this report, provided in digital format in the enclosed compact disc (CD). These results allow for an understanding of the relative sewershed 'leakiness', and can be used to guide further investigation of RDII sources.

3.6.2 Unit Hydrograph Curve Fitting

As part of the Phase 2 SSES analyses, and in support of these H&H modeling efforts, unit hydrograph parameters were developed through a systematic analysis of the monitored flow and rainfall. The unit hydrograph method that was applied simulated RDII hydrographs from a specified unit hydrograph shape that relates RDII to unit precipitation volume, specified time duration, and sewershed characteristics. Each unit hydrograph is characterized by three parameters (R, T, and K). As described above, the R parameter represents the fraction of precipitation falling over a sewershed that enters the sanitary sewer system. The T parameter represents the time from the onset of rainfall to the peak of the RDII hydrograph (in hours), and the K parameter is the ratio of the time to recession of the RDII hydrograph to the time to peak. The first R-T-K hydrograph represents the fast response of the collection system, which generally tends to be more inflow driven. The second and third hydrographs simulate the intermediate and delayed responses of the sewer system, which generally tend to be more infiltration driven. These results allow for an understanding of the sources of flow in the system. Figure 3-13 illustrates RDII simulation using three triangular unit hydrographs.

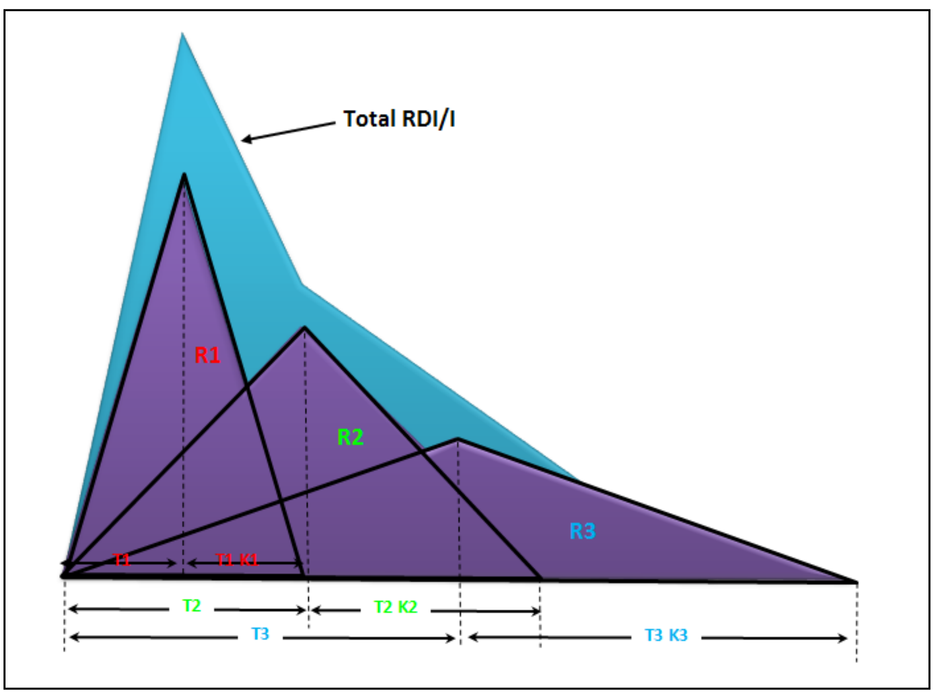


Figure 3-13:Characterization of RDII using Three Unit Hydrographs

The unit hydrograph curve fitting process included the distribution of the computed total-R value amongst the three unit hydrographs (R1, R2 and R3) used to simulate the RDII response in sanitary sewers. After the distribution of total-R into R1, R2 and R3, then the T and K parameters of the three hydrographs are also determined so that the simulated sewer system response formed by the three unit hydrographs closely matches the hydrograph of the monitored RDII flow.

During the curve fitting process, data analysts used SSOAP to determine the combination of R-T-K unit hydrograph parameters that successfully generated RDII hydrographs within 5% of the monitored RDII event peak flow and within 5% of the total monitored RDII event volume. Most but not all the events were analyzed. The most commonly encountered reasons for excluding an event were quality concerns with the available data, synchronization problems between the rainfall data and the RDII response of the sewershed, and/or considerable negative RDII during an event. The R-T-K parameters generated will be used as direct H&H model input for monitored areas, as well as for extrapolation to nearby unmonitored areas.

An individual spreadsheet of curve results was prepared for each flow monitoring site that was analyzed and can be found in Appendix D of this report, provided in digital format in the enclosed CD.

3.6.3 Largest Monitored Events and Peaking Factors

For each of the Water Department's City monitoring locations, additional wet weather analyses were conducted to provide an understanding of the hydraulic capacity and system response during wet weather. For these analyses, the five independent wet weather events that produced the largest monitored peak 15-minute flow rates were identified for each monitoring location.

Largest Monitored Events

Once the five independent wet weather events were identified, the corresponding monitored peak hourly flows were calculated. In addition, the monitored peak 15-minute and hourly levels were identified for each event. In conjunction with monitored flow rates and flow depths, monitored precipitation data were examined to determine the total precipitation volume during the duration of the event, and the monitored peak 15-minute precipitation volume within the defined event. The monitored data and the analysis results should reflect the total flow generated from the sewershed areas, as there are only two known locations with any significant upstream lost flows due to SSO discharges.

Peaking Factor

Along with the monitored flow rates, depths, and precipitation data that were examined for the five largest independent wet weather events, a flow rate peaking factor was also computed. The peaking factor was calculated by taking the monitored peak hourly flow during the event, and dividing it by the calculated average daily dry weather flow for the monitored sewershed area. This peaking factor represents the magnitude of the increase of RDII flow through the monitored sewer pipes during large storms, compared to the magnitude of flow during typical dry weather conditions.

These results from the five largest monitored wet weather events, and the peaking factor analyses were then compiled into summary tables that can be found in Appendix B, and are also provided in digital format on the enclosed CD. It is important to note that events with missing and/or errant data during any part of the storm were not included in the summaries.

For storms that resulted in pipe-full conditions and/or surcharging, these summary tables allow for the hydraulic capacity of the monitored sewers to be quantified and assessed. In addition, the peaking factors included in these summaries allow for an understanding of the relative quantities of RDII, as higher wet weather peaking factors are indicative of drainage areas that have relatively high wet weather flow.

An example wet weather summary is provided in Table 3-2: below. As the table illustrates; the 30” sewer surcharges during large storm events, with the hydraulic capacity ranging from 18 mgd to 20 mgd.

Table 3-2:Largest Monitored Storm Events and Peaking Factor Summary Table

Philadelphia Water Department - Sanitary Sewer Evaluation Program

Wet Weather Flow Analysis Results

PR-0060

General Information

Site:	PR-0060
Description of Location:	1015 Bloomfield Avenue
Data Range:	11/30/2011 to 12/6/2012
Pipe Diameter:	30"
Interceptor:	Paul's Run
Drainage Area (Acres):	1,421
Service Population:	23,030

Wet Weather Flow Summary

Storm Date	Total Event Rainfall	Monitored Peak 15 Minute Rainfall	Monitored Peak 15 Minute Flow	Monitored Peak 15 Minute Level	Peak Hourly Rainfall	Monitored Peak Hourly Flow	Monitored Peak Hourly Level	Peaking Factor (PHF/ ADDWF)
	(inches)	(inches/ 15 min)	(mgd)	(inches)	(inches/ hour)	(mgd)	(inches)	
9/4/2012	3.00	0.61	20.7	80.9	1.06	20.2	71.6	5.54
5/16/2012	2.50	0.26	19.1	68.6	0.78	18.5	49.0	5.07
9/3/2012	1.22	0.25	18.8	40.9	0.64	18.4	38.2	5.03
7/15/2012	1.08	0.44	18.4	44.5	0.88	16.6	33.0	4.55
8/1/2012	1.32	0.49	18.4	78.9	1.28	18.0	50.6	4.91
Five-Storm Average	**1.83**	**0.41**	**19.1**	**62.8**	**0.93**	**18.3**	**48.5**	**5.02**

3.6.4 Wet Weather Flow Analysis Results and Conclusions

The completed Phase 2 SSES analyses were successful in quantifying and characterizing wet weather flow from separate sanitary sewershed areas within the City of Philadelphia. Section 4.3 (Wet Weather Flow Analysis Results) of this report summarizes and characterizes the various wet weather flow analysis results described in this section.

The largest monitored events and peaking factor summary tables for all sanitary monitors located within the City can be found in Appendix B of this report. The RDII analysis results for all sanitary monitors located within the City can be found in Appendix C. The unit hydrograph curve fitting analysis results are located in Appendix D. The appendix information is provided in digital format on the enclosed CD.

4.0 Analysis Results

Section 4 provides a summary of the completed Phase 2 Sewer System Evaluation Survey (SSES) analysis results and conclusions. The results of the precipitation characterization analyses for the long-term record gage data are provided and compared to the annual precipitation over the Philadelphia Water Department (Water Department) service area for each of the years that were included in the period of record used for the SSES analysis. Dry weather flow characterization analysis results are presented using a series of summary tables, cumulative distribution function (CDF) curves, and color-coded geographic information system (GIS) maps. The analyses identified specific City sewershed areas where the quantity of ground water infiltration (GWI) was relatively high. Similarly, wet weather characterization analysis results for each of the analyzed City sewersheds are provided. The completed analyses allow for the Water Department to identify specific separate sanitary sewershed areas within the City where the quantity of extraneous rainfall dependent infiltration and inflow (RDII) was relatively high

4.1 Precipitation Data Analysis Results

Accurate and reliable precipitation data are a vital component of any SSES. The monitoring of the quantity, intensity, duration, and distribution of precipitation is necessary to analyze sanitary sewer system responses to wet weather, validate computer simulation models, and identify and prioritize sewer rehabilitation activities. Adequate precipitation data should include regional long-term precipitation records as well as spatially distributed data. Because precipitation conditions can vary over short distances, regional gage data needs to be supplemented with data from a distributed network of local precipitation monitoring stations. Available precipitation data for the SSES included long-term data from the airport gage, data from the regional gage network, and high resolution spatially distributed data from the calibrated radar-rainfall system.

Section 2.3 of this report provided a Phase 1 SSES summary of the available precipitation data within the City and outlying community areas, the various sources of these data, and how they were utilized in support of this SSES. Section 3.3 described the Phase 2 SSES quality assurance reviews conducted on these data. This section provides a characterization of the available precipitation data utilized in these SSES efforts. More specifically, this section includes an analysis of the historical regional data set in order to establish long-term characteristics of precipitation over the Water Department service area as well as analysis of individual years that coincide with the flow monitoring activities conducted to characterize dry and wet weather flow conveyed from monitored separate sanitary sewer areas.

4.1.1 Long-Term Historical Precipitation Analysis

The two criteria used in the Phase 2 SSES for establishing long-term precipitation characteristics over the Water Department service area were the total volume of precipitation and the total number of precipitation events occurring during each calendar year. Comparing a particular year's precipitation to the long-term average allows for determinations of wetter- and dryer- than-average years. Monthly totals and averages were also computed in the same way to examine seasonal differences. By examining these annual and monthly precipitation totals, the characteristics of precipitation over the service area for specific time periods could be evaluated.

Precipitation Volume Analysis Results

Figure 4-1 displays the annual precipitation volumes at the Philadelphia International Airport (PHL) from 1961 through 2013. The average annual precipitation volume of 41.71 inches is shown on the plot by a solid horizontal line and can be used as a bench mark for comparing a particular year's precipitation to the long-term annual average. The average annual precipitation volume plus and minus one standard deviation is shown as well (by dashed lines) and can be used to assess the range or extent of expected variability in the annual precipitation volumes. Figure 4-1 shows that the wettest and driest calendar years over the historical record were 2011 (64.33 in.) and 1965 (29.34 in.), respectively.

Figure 4-2 shows the average monthly precipitation volumes based upon the PHL historical record. Also depicted on the figure are the average monthly precipitation volumes plus and minus one standard deviation. The figure can be used to assess the variability in the monthly precipitation volumes and identify the typically wetter and drier seasonal periods of the year. The figure shows that, on average, the summer months of July and August are the months of the year with the greatest precipitation volume while February is the month with the lowest precipitation volume.

Precipitation Event Analysis Method and Results

In addition to the annual and monthly volumetric statistics produced for the long-term period of record, characteristics of individual precipitation events were developed. Each event in the historical record was characterized by its duration, volume, maximum intensity, and the time interval between successive events.

Prior to performing the event analysis, a minimum inter-event time (MIT) needed to be selected indicating the number of zero-rainfall hours that constitute an inter-event period. In other words, the number of consecutive dry hours encountered in the search must be equal to or greater than the MIT in order for the preceding wet period (made up of at least one non-zero precipitation value) to be considered a separate event. In order to be consistent with the MIT selected in the analysis included in Section 3.5 of the Philadelphia Long-Term Control Plan Update (LTCPU) and other precipitation analyses conducted by the Water Department, a MIT of 6 hours was selected for this analysis.

In addition to selecting a MIT, a minimum precipitation depth was needed to define an event. For this historical precipitation analysis, it was important to differentiate between event precipitation that would contribute to rainfall dependent inflow and infiltration (RDII), and event precipitation that would be intercepted by vegetation above the ground and depression storage on the ground and would not be a cause of RDII in the separate sanitary sewers.

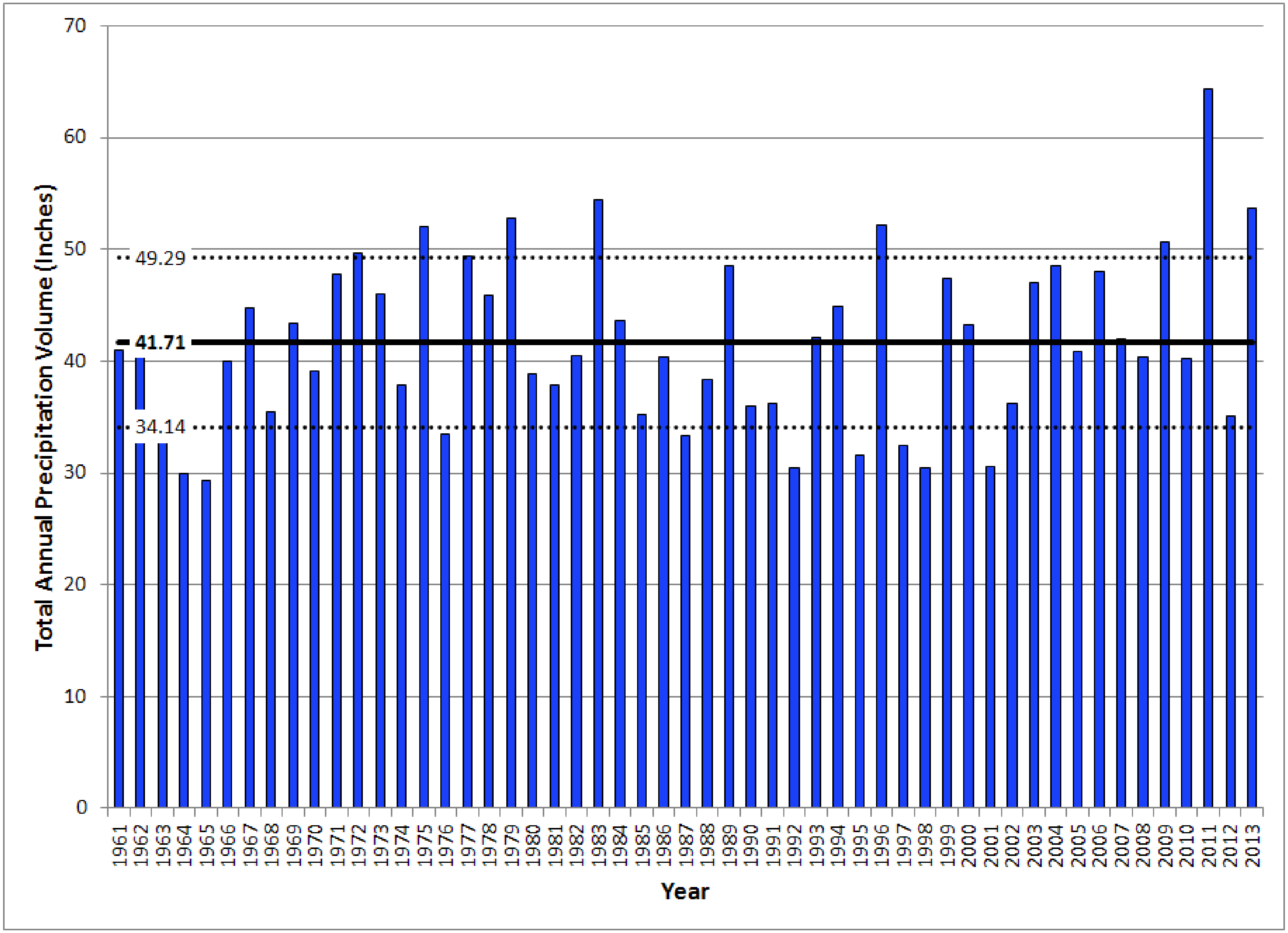
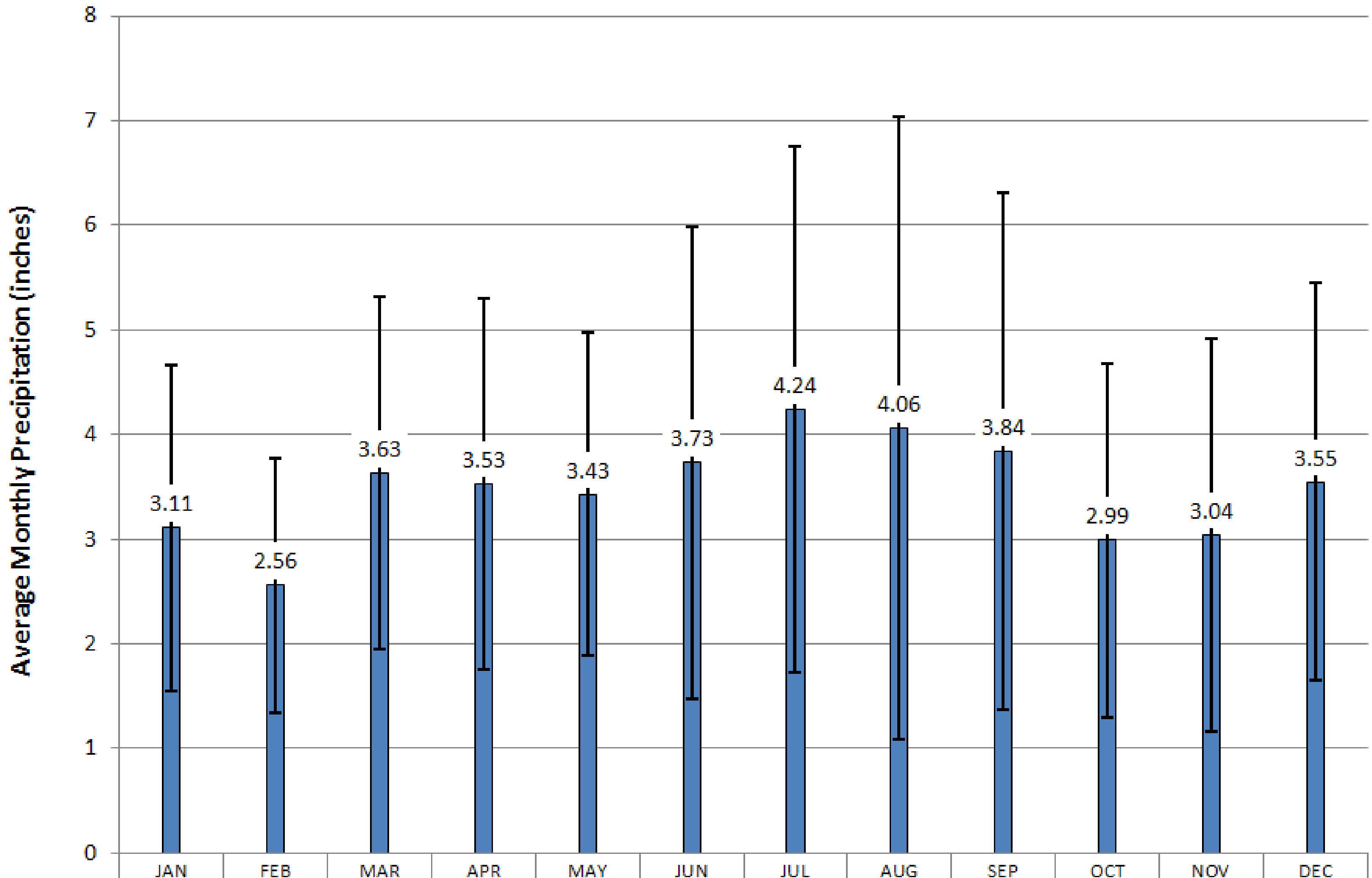


Figure 4-1: Annual Precipitation Volumes (PHL Historical Record)



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average	3.11	2.56	3.63	3.53	3.43	3.73	4.24	4.06	3.84	2.99	3.04	3.55
Avg+1STDEV	4.67	3.77	5.31	5.30	4.97	5.98	6.75	7.04	6.31	4.68	4.92	5.45
Avg-1STDEV	1.55	1.35	1.95	1.76	1.89	1.48	1.73	1.08	1.37	1.30	1.16	1.65

Figure 4-2: Average Monthly Precipitation Volumes (PHL Historical Record)

Per the wet weather flow analyses that were described in Section 3.6, and presented in Section 4.3, smaller event volumes of less than 0.10 inches were determined to have little to no impact on RDII entering into City separate sanitary sewers. As a result, event volumes greater than or equal to 0.10 inches were selected as the minimum precipitation depth for defining wet weather events.

Based on the wet weather event definition described above, information was developed on the characteristics of individual events from the PHL historical record. The sequence of hourly precipitation volumes was grouped into separate events and each storm was then characterized by its duration, volume, maximum intensity, and time interval between successive events. The event data were analyzed using standard statistical procedures to determine the mean and standard deviations for various event parameters. A rainfall characteristics summary table for the PHL historical record is shown on Table 4-1.

Based upon the minimum inter-event time (6 hours) and minimum event volume (0.10 inches) selected, the average annual number of wet weather events in the Water Department service area, based on the historical record, is 62.

Table 4-1: Mean Precipitation Event Characteristics for Philadelphia, PA [a]

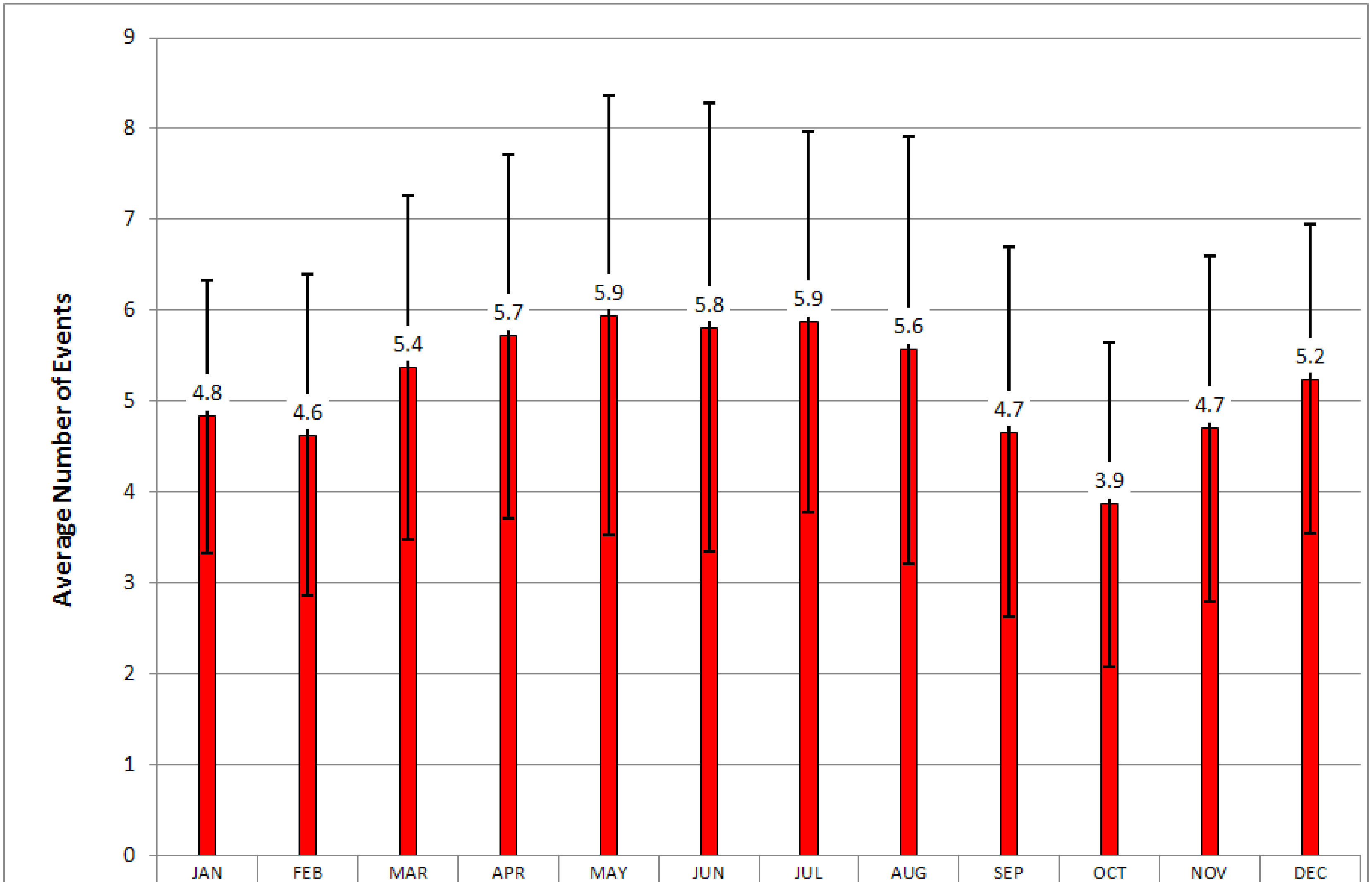
Total Number of Events [a]	Average Annual Number of Events [b]	Mean Event Rainfall Statistics [b]			
		Volume (inches)	Duration (hours)	Maximum Intensity (inches/hour)	Delta [c] (days)
3,297	62	0.65	10.4	0.23	5.9

[a] Based upon 53 years of records at the Philadelphia International Airport, from 1961 through 2013

[b] Events greater than or equal to 0.10 inches with a minimum of 6 dry hours to separate events

[c] Delta is the average interval between the midpoint of events

Figure 4-3 shows the average monthly number of events based upon the PHL historical record. Also depicted in the figure is the average monthly number of events plus and minus one standard deviation. The figure can be used to assess the variability in the number of events occurring during each month of the year. Figure 4-3 shows that, on average, more events tend to occur during the summer months of May, June, and July while the fewest occur during the month of October.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average	4.8	4.6	5.4	5.7	5.9	5.8	5.9	5.6	4.7	3.9	4.7	5.2
Avg+1STDEV	6.3	6.4	7.3	7.7	8.4	8.3	8.0	7.9	6.7	5.7	6.6	7.0
Avg-1STDEV	3.3	2.9	3.5	3.7	3.5	3.3	3.8	3.2	2.6	2.1	2.8	3.5

Figure 4-3: Average Monthly Number of Events (PHL Historical Record)

4.1.2 Precipitation Data Analysis (1999 through 2013)

As described in Section 2.1, the extent of City sanitary sewer monitoring activities in support of this SSES spans the period of 1999 through 2013. To gain an understanding of the hydrologic characteristics during this period, and interpret the dry and wet weather flow characterizations of the monitored City separate sewershed areas presented in Sections 4.2 and 4.3, comparisons were made between the precipitation statistics that occurred during this period and historic norms.

For the Phase 2 SSES, several steps were involved in analyzing the PHL rainfall that was collected during this time period. For each month during the 15-year analysis period, the total monthly volume of precipitation at the PHL was calculated. These monthly totals were computed to examine seasonal differences and were used as the basis for identifying atypical wet and dry periods coinciding with the City sanitary sewer flow monitoring activities. The frequency (i.e. the number) of events that occurred each month over the 15-year period of record was another parameter that was used to assess how the precipitation data collected from 1999 through 2013 compared to "typical" historic norms. For each month, the total number of wet weather events at the PHL was identified. It is important to note that the same event definition that was used in the historic data analysis was applied to the event analysis for the 1999-2013 period of record. To reiterate, an event was defined as having a minimum rainfall volume of 0.10 inches and a minimum inter-event period of 6 hours.

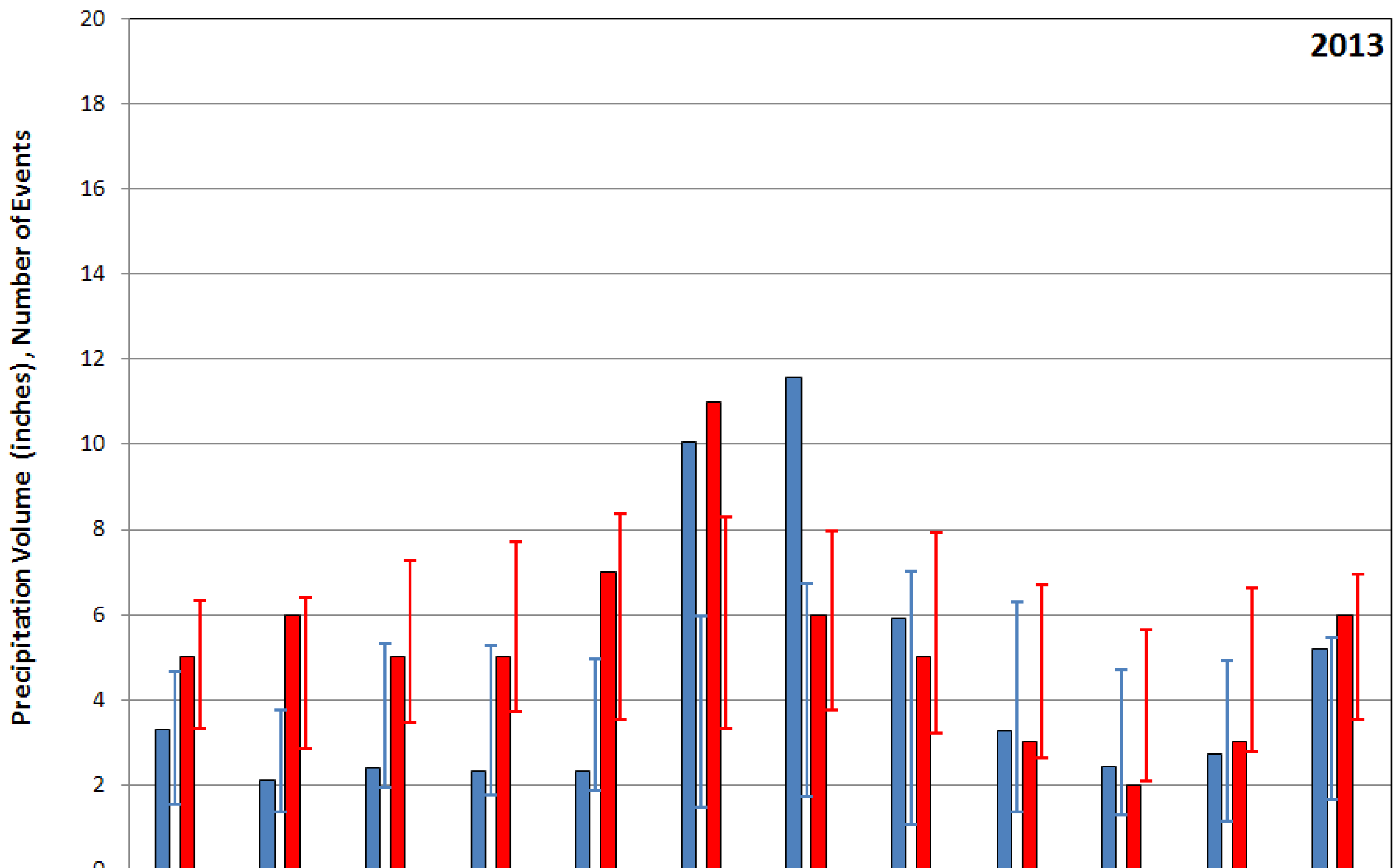
The precipitation volumes and number of events occurring during each month were calculated, displayed, and analyzed. Annual plots were produced for each year of the 15-year period of record. Shown on each are the monthly precipitation volume (in blue) and number of events (in red). These same monthly totals, as well as the monthly historic averages, are displayed on the table at the bottom of each plot. In order to assess the magnitude of these monthly values, the variability of the long-term historic averages was illustrated by plotting the historic average monthly volumes and event frequency plus and minus one standard deviation. These values are represented on the plot by typical range extent bars. These annual plots, for calendar years 1999 through 2013, can be found in Appendix A of this document. Figure 4-4, showing the monthly precipitation volume and number of events for 2013, provides an example of the plots included in Appendix A. The appendix is provided in digital format on the enclosed compact disc.

Table 4-2, which follows the figure, identifies atypical wet and dry months during the period of 1999 through 2013 coinciding with the City flow monitoring activities supporting this SSES. Months whereby the monthly precipitation volume was more than one standard deviation greater than the mean were identified as atypically wet (shown on the table as "Wet"). Months where the monthly precipitation volumes were more than one standard deviation less than the mean were identified as uncharacteristically dry (shown on the table as "Dry"). The wettest month during the 15-year period was August 2011 (19.31 inches) while the driest was September 2005 (0.21 inches).

While it is understood that various other factors influence responses in sanitary sewer systems (e.g. depth to groundwater, number and size of defects, soil characteristic, etc.), these summaries serve as a useful tool in understanding the hydrologic characteristics associated with the flow monitoring analysis results presented in Sections 4.2 and 4.3. The summaries provide the necessary precipitation characteristics in understanding the antecedent moisture conditions associated with the groundwater infiltration levels and RDII characteristics computed over the course of the monitoring periods and for individual events.

4.1.3 Precipitation Analysis Conclusions

The completed Phase 2 SSES was successful in utilizing the long term record data from the PHL gage to quantify and characterize typical monthly and annual precipitation volumes and event frequency over the Water Department service area. The analyses were successful in quantifying the extent of the expected range of variability in monthly precipitation volumes and the number of events. These precipitation volume and storm event ranges allowed the Water Department to identify drier and wetter than average months, based upon the long term record data. The completed analyses also demonstrated that during the analysis period from 1999 through 2013, monitored monthly and annual precipitation volumes and event frequencies varied from the historical norms. For some months the monthly total precipitation volume and/or the number of storms was slightly higher or lower than the historic norms. For other months the monthly precipitation was significantly more or less than the historic norms. When interpreting and utilizing wastewater flow monitoring data to characterize dry and wet weather flows from separate sanitary sewershed areas, it is important to know and understand if the precipitation associated with the monitored wastewater flows is more than or less than historic averages and patterns.



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2013 Volume	3.31	2.11	2.40	2.32	2.33	10.04	11.57	5.91	3.26	2.43	2.73	5.20
Avg Volume	3.11	2.56	3.63	3.53	3.43	3.73	4.24	4.06	3.84	2.99	3.04	3.55
2013 # Events	5	6	5	5	7	11	6	5	3	2	3	6
Avg # Events	4.8	4.6	5.4	5.7	5.9	5.8	5.9	5.6	4.7	3.9	4.7	5.2

Figure 4-4: 2013 Precipitation vs. Historical Long-Term Norms

Table 4-2: Identification of Wet and Dry Months (1999-2013)

YEAR	MONTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1999	Wet					Dry	Dry		Wet			
2000			Wet						Wet			
2001			Wet	Dry			Dry	Dry		Dry	Dry	
2002		Dry	Wet							Wet		
2003		Wet				Wet						
2004	Dry			Wet			Wet					
2005					Dry				Very Dry	Wet		
2006		Dry	Dry			Wet				Wet		
2007				Wet					Dry			
2008		Wet										Wet
2009		Dry	Dry					Wet		Wet		Wet
2010			Wet							Wet		
2011								VeryWet	Wet			
2012			Dry				Dry				Dry	
2013						Wet	Wet					

4.2 Dry Weather Flow Analysis Results

After the Phase 1 data collection process had been completed, and the data quality review process had been performed, SSES Phase 2 analyses were conducted on the monitored wastewater flows. Phase 2 analyses and results for this SSES report were focused on monitored sewershed areas located within the City. A separate SSES report documenting the analysis results for monitored sewershed areas within the Outlying Communities will be prepared and submitted by June 1, 2015. The analysis process was previously described in Section 3.5. This section provides and explains the results and observations from those completed analyses. The analyses enabled the Water Department to identify specific sewershed areas where the quantity of ground water infiltration (GWI) flow was relatively high. This could be an indication of a leaky wastewater collection system where sewer rehabilitation could potentially reduce the frequency, duration and volume of combined sewer overflow (CSO) discharges.

The results from the dry weather flow analyses completed for each successfully monitored City sewershed area are summarized in Table 4-3. The monitoring sites are identified by their manhole and site identification names and are grouped by the interceptor sewer which receives and conveys the monitored sewershed wastewater flow. The table provides the drainage area and service population for the sewershed areas tributary to the monitoring sites. It is important to note that the service populations were obtained from the U.S. census and would include only the people living in the sewershed areas and would not include the people who work in commercial and/or industrial facilities located within the sewershed. The monitoring period and duration are also provided for each site. The table provides the average, maximum and minimum average daily dry weather flows for the monitored sheds. These average values extend over the monitoring duration.

For the Phase 2 SSES, the monitored minimum average daily dry weather flow was assumed to be entirely GWI. This assumption is admittedly conservative because even in sewershed areas that have a predominately residential land use, there is almost always some sanitary base wastewater flow (BWWF) being conveyed in the early morning hours. In some sewershed areas, the minimum average daily flow may also contain commercial/industrial flows from any round-the-clock hospitals, factories and other facilities located within the monitored sewershed area. As part of the DWF analyses, the percentage of the monitored sewershed areas that had commercial and industrial land uses was calculated to assess the potential for bias from the use of this conservative assumption in the GWI analysis results.

The table also provides the magnitude of the average daily BWWF component of the total monitored flow. The BWWF component consists of the household residential wastes, commercial and industrial wastes, and the industrial process flows that are discharged by customers into the City sanitary sewer collection system. The remaining component is generally comprised mostly of GWI that enters the sewer system through cracks in the sewer pipes, open sewer pipe joints, and/or flow contributions from foundation drains. Additional dry weather flow characterization information, including average DWF hydrograph plots for each successfully monitored sewershed area, is provided in Appendix B.

Table 4-3: Summary of Dry Weather Flow (DWF) Analysis Results

MANHOLE ID	SITE ID	Interceptor	Tributary Drainage Area (acres)	Tributary Population	Data Start	Data End[1]	Duration (months)	Average Daily DWF (mgd)	Maximum Average Daily DWF (mgd)	Minimum Average Daily DWF (mgd)	Average Daily BWWF (mgd)	Per Capita Average Daily DWF (gpcd)	Per Capita Average Daily BWWF (gpcd)	Per Acre Average Daily GWI (gal/acre/d)	GWI Ratio[2]
BC-0010	BC-0010	Byberry Creek	3,271	40,961	7/26/08	1/31/10	18.2	7.74	9.03	5.43	2.31	189	56	1,660	0.70
BC-0055	BC-0055	Byberry Creek	2,715	33,648	11/30/11	12/31/12	13.1	5.94	6.84	4.24	1.70	177	51	1,562	0.71
BC-0055	BC-0055	Byberry Creek	2,715	33,648	1/1/13	9/30/13	8.9	5.87	6.70	4.45	1.42	175	42	1,639	0.76
BC-0200	43	Byberry Creek	2,326	23,909	11/3/99	2/14/00	3.4	4.93	5.87	3.52	1.41	206	59	1,513	0.71
BC-B0675	BC-B0675	Byberry Creek	230	2,374	1/1/09	12/31/09	12.0	0.464	0.593	0.286	0.178	195	75	1,243	0.62
BC-B0755	BC-B0755	Byberry Creek	275	4,752	12/11/12	10/16/13	10.2	0.549	0.674	0.353	0.196	116	41	1,284	0.64
BC-B1575	76	Byberry Creek	169	1,676	9/19/01	6/30/02	9.3	0.398	0.472	0.285	0.113	237	67	1,686	0.72
BC-B1575	76	Byberry Creek	169	1,676	5/18/01	9/18/01	4.0	0.551	0.698	0.401	0.150	329	89	2,373	0.73
Q101-03-S0020	Q101-03-S0020	Byberry Creek	112	1,773	10/21/11	12/4/12	13.5	0.184	0.257	0.102	0.0820	104	46	911	0.55
Q109-07-S0025	Q109-07-S0025	Byberry Creek	164	2,092	12/11/12	9/30/13	9.6	0.339	0.417	0.204	0.135	162	65	1,244	0.60
Q114-12-S0010	Q114-12-S0010	Byberry Creek	68	2,217	1/27/12	2/3/13	12.3	0.257	0.334	0.155	0.102	116	46	2,279	0.60
T089-04-S0055	T089-04-S0055	Cheltenham	98	1,819	12/1/11	4/4/12	4.1	0.319	0.400	0.194	0.125	175	69	1,980	0.61
THL-B0705	87	Cheltenham	200	1,942	4/15/03	6/24/03	2.3	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]
THL-B0705	THL-B0705	Cheltenham	200	1,942	12/11/12	9/30/13	9.6	0.543	0.666	0.400	0.143	280	74	2,000	0.74
CV-0145	CV-0145	Cresheim Valley	882	9,340	3/8/13	9/30/13	6.8	2.51	2.97	2.20	0.310	269	33	2,494	0.87
W077-02-S0060	W077-02-S0060	Cresheim Valley	225	1,810	1/8/10	1/11/11	12.1	0.361	0.455	0.281	0.0800	200	44	1,249	0.78
W086-01-S0060	W086-01-S0060	Cresheim Valley	225	2,546	1/30/12	2/29/12	1.0	0.765	0.950	0.625	0.140	300	55	2,778	0.82
IALL-B0355	IALL-B0355	Island Avenue Lower Level	214	1,308	7/1/12	9/30/13	15.0	0.331	0.371	0.288	0.0430	253	33	1,346	0.87
IALL-B0810	IALL-B0810	Island Avenue Lower Level	211	3,779	1/7/10	12/31/10	11.8	0.450	0.554	0.339	0.111	119	29	1,607	0.75
IALL-B0862	82	Island Avenue Lower Level	202	2,201	2/16/02	9/9/02	6.7	0.665	0.786	0.510	0.155	302	70	2,525	0.77
M-0045	48	Monoshone	868	15,682	6/1/13	9/30/13	4.0	3.31	3.84	2.72	0.590	211	38	3,134	0.82
W068-05-S0047	W068-05-S0047	Monoshone	520	8,863	11/30/11	12/3/12	12.1	1.87	2.35	1.44	0.430	211	49	2,769	0.77
W068-05-S0078	71	Monoshone	691	11,780	10/17/00	4/23/01	6.2	2.28	2.89	1.78	0.500	194	42	2,576	0.78
P108-17-S0010	P108-17-S0010	Paul's Run	79	675	9/24/10	9/29/11	12.2	0.110	0.164	0.0436	0.0664	162	98	552	0.40
P113-04-S0463	P113-04-S0463	Paul's Run	80	1,327	11/29/11	6/6/12	6.3	0.212	0.271	0.128	0.0840	160	63	1,600	0.60

MANHOLE ID	SITE ID	Interceptor	Tributary Drainage Area (acres)	Tributary Population	Data Start	Data End[1]	Duration (months)	Average Daily DWF (mgd)	Maximum Average Daily DWF (mgd)	Minimum Average Daily DWF (mgd)	Average Daily BWWF (mgd)	Per Capita Average Daily DWF (gpcd)	Per Capita Average Daily BWWF (gpcd)	Per Acre Average Daily GWI (gal/acre/d)	GWI Ratio[2]
PR-0060	PR-0060	Paul's Run	1,421	23,030	11/30/11	12/6/12	12.2	3.66	4.38	2.57	1.09	159	47	1,809	0.70
PR-0150	PR-0150	Paul's Run	1,069	19,728	10/20/11	12/6/12	13.6	2.53	3.09	1.74	0.790	128	40	1,628	0.69
PR-B0405	PR-B0405	Paul's Run	441	9,757	12/11/12	9/30/13	9.6	1.11	1.41	0.657	0.453	114	46	1,490	0.59
PR-B0455	23	Paul's Run	391	9,369	8/9/99	4/27/00	8.6	1.04	1.46	0.579	0.461	111	49	1,481	0.55
PR-B0540	77	Paul's Run	133	2,221	7/11/01	9/10/02	14.0	0.332	0.487	0.161	0.171	149	77	1,211	0.49
P104-09-S0025	P104-09-S0025	Pennypack Creek	50	993	1/1/11	6/30/12	18.0	0.165	0.194	0.128	0.0370	167	37	2,560	0.78
P105-06-S0035	P105-06-S0035	Pennypack Creek	184	3,174	6/11/10	6/13/11	12.1	0.394	0.546	0.196	0.198	124	62	1,065	0.50
PP-0215	PP-0215	Pennypack Creek	10,986	115,729	6/6/13	9/30/13	3.8	16.8	19.4	12.3	4.50	146	39	1,120	0.73
PP-B0650	14	Pennypack Creek	181	5,372	8/12/99	4/28/00	8.6	0.580	0.839	0.299	0.281	108	52	1,652	0.52
PP-B0790	15	Pennypack Creek	187	4,893	8/10/99	4/10/00	8.0	0.634	0.980	0.353	0.281	129	57	1,888	0.56
PP-B0790	15	Pennypack Creek	187	4,893	3/14/13	9/30/13	6.6	0.684	0.830	0.460	0.224	140	46	2,460	0.67
PP-B0840	18	Pennypack Creek	368	7,121	8/30/99	6/12/00	9.4	0.350	0.482	0.216	0.134	49	19	587	0.62
PP-B1035	19	Pennypack Creek	392	4,469	3/9/13	9/30/13	6.7	0.657	0.892	0.350	0.307	147	69	893	0.53
PP-B1080	PP-B1080	Pennypack Creek	2,549	11,596	1/27/12	3/19/12	1.7	2.16	2.68	1.58	0.580	186	50	620	0.73
PP-B1215	44	Pennypack Creek	2,225	9,181	11/3/99	6/12/00	7.3	1.54	2.00	1.08	0.460	168	50	485	0.70
PC-0010	PC-0010	Poquessing Creek	10,349	74,868	4/1/12	1/16/13	9.5	9.18	11.1	5.85	3.33	123	44	565	0.64
PC-0010	PC-0010	Poquessing Creek	10,349	74,868	7/29/08	1/31/10	18.1	11.1	13.3	7.65	3.45	148	46	739	0.69
PC-0045	PC-0045	Poquessing Creek	10,330	74,868	7/29/08	7/9/09	11.3	11.6	13.9	7.83	3.77	155	50	758	0.67
PC-0470	97	Poquessing Creek	145	849	9/30/04	5/4/05	7.1	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]
PC-1210	27	Poquessing Creek	732	6,745	8/12/99	4/27/00	8.5	0.802	1.22	0.383	0.419	119	62	523	0.48
PC-B1330	PC-B1330	Poquessing Creek	478	9,427	2/14/09	1/31/10	11.5	1.66	2.10	0.930	0.730	176	77	1,946	0.56
PC-B1360	29	Poquessing Creek	374	6,435	3/9/13	9/30/13	6.7	0.687	0.860	0.427	0.260	107	40	1,142	0.62
PC-B1440	92	Poquessing Creek	212	1,894	10/1/04	5/18/05	7.5	0.352	0.484	0.221	0.131	186	69	1,042	0.63
PC-B1530	Q119-01-S0015	Poquessing Creek	224	219	1/1/09	1/3/10	12.1	0.131	0.181	0.101	0.0300	599	137	451	0.78
Q107-02-S0025	75	Poquessing Creek	176	2,954	10/1/03	8/5/04	10.2	0.352	0.476	0.212	0.140	119	47	1,205	0.60
Q110-17-S0015	Q110-17-S0015	Poquessing Creek	59	709	5/31/13	9/30/13	4.0	0.100	0.128	0.0574	0.0426	141	60	973	0.57

MANHOLE ID	SITE ID	Interceptor	Tributary Drainage Area (acres)	Tributary Population	Data Start	Data End[1]	Duration (months)	Average Daily DWF (mgd)	Maximum Average Daily DWF (mgd)	Minimum Average Daily DWF (mgd)	Average Daily BWWF (mgd)	Per Capita Average Daily DWF (gpcd)	Per Capita Average Daily BWWF (gpcd)	Per Acre Average Daily GWI (gal/acre/d)	GWI Ratio[2]
Q120-02-S0010	Q120-02-S0010	Poquessing Creek	85	1,131	12/8/07	12/10/08	12.1	0.162	0.211	0.101	0.0610	144	54	1,188	0.62
Q120-08-S0010	Q120-08-S0010	Poquessing Creek	108	1,069	3/26/08	3/18/09	11.7	0.321	0.395	0.232	0.0890	301	83	2,148	0.72
Q120-10-S0010	Q120-10-S0010	Poquessing Creek	67	323	12/7/07	2/24/08	2.6	0.0304	0.0416	0.0216	0.00880	94	27	322	0.71
Q120-11-S0010	Q120-11-S0010	Poquessing Creek	81	932	12/6/07	12/9/08	12.1	0.249	0.287	0.197	0.0520	268	56	2,432	0.79
Q121-02-S0015	Q121-02-S0015	Poquessing Creek	73	1,076	12/11/07	12/9/08	12.0	0.162	0.229	0.0881	0.0739	150	69	1,207	0.54
P090-02-S0090	P090-02-S0090	Sandy Run	581	11,971	5/30/13	9/30/13	4.0	1.98	2.39	1.41	0.570	166	48	2,427	0.71
P090-02-S0590	P090-02-S0590	Sandy Run	635	9,971	12/11/12	9/30/13	9.6	1.35	1.57	0.990	0.360	135	36	1,559	0.74
P090-02-S0715	P090-02-S0715	Sandy Run	388	5,559	11/29/11	12/5/12	12.2	0.777	0.952	0.516	0.261	140	47	1,330	0.66
P090-02-S0865	P090-02-S0865	Sandy Run	148	1,537	12/11/12	9/30/13	9.6	0.330	0.385	0.249	0.0810	214	53	1,682	0.76
T088-01-S0050	T088-01-S0050	Tacony High Level	497	12,452	10/21/11	12/3/12	13.5	1.75	2.11	1.36	0.390	141	31	2,736	0.78
T088-01-S0155	31	Tacony High Level	380	9,816	8/10/99	6/12/00	10.1	1.37	1.86	0.960	0.410	140	42	2,526	0.70
T088-01-S0220	T088-01-S0220	Tacony High Level	62	3,044	12/11/12	9/30/13	9.6	0.464	0.526	0.392	0.0720	152	24	6,323	0.85
THL-B0375	THL-B0375	Tacony High Level	186	4,704	11/9/10	6/3/12	18.8	0.591	0.727	0.440	0.151	126	32	2,366	0.75
P083-03-S0050	P083-03-S0050	Upper Delaware Low Level	270	4,775	10/1/12	7/29/13	9.9	0.684	0.824	0.440	0.244	143	51	1,630	0.64
P083-03-S0050	P083-03-S0050	Upper Delaware Low Level	270	4,775	10/12/11	9/30/12	11.6	0.709	0.851	0.453	0.256	148	54	1,678	0.64
UDLL-0270	UDLL-0270	Upper Delaware Low Level	14,644	118,393	10/5/12	9/30/13	11.8	18.8	21.7	13.9	4.90	159	41	949	0.74
S051-05-S0020	74	Upper Schuylkill East Side	90	2,264	2/16/01	4/24/01	2.2	1.53	1.89	1.37	0.160	675	71	15,222	0.90
S051-08-S0012	55	Upper Schuylkill East Side	252	6,501	6/12/00	10/10/00	4.0	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]
S051-08-S0175	73	Upper Schuylkill East Side	68	2,092	2/13/01	9/10/01	6.9	0.171	0.270	0.0727	0.0983	82	47	1,069	0.42
S059-01-S0010	S059-01-S0010	Upper Schuylkill East Side	134	1,565	12/12/12	9/30/13	9.6	0.270	0.330	0.164	0.106	172	68	1,224	0.61
S059-02-S0010	58	Upper Schuylkill East Side	86	2,029	6/27/00	9/27/01	15.0	0.328	0.406	0.248	0.0800	162	39	2,884	0.76
S059-04-S0035	57	Upper Schuylkill East Side	141	3,734	6/13/00	9/10/01	14.9	0.410	0.526	0.333	0.0770	110	21	2,362	0.81
USE-0365	USE-0365	Upper Schuylkill East Side	773	13,233	5/1/10	8/23/10	3.8	2.59	3.10	2.07	0.520	195	39	2,678	0.80
USE-0365	USE-0365	Upper Schuylkill East Side	773	13,233	4/1/12	1/7/13	9.2	3.37	3.91	2.77	0.600	255	45	3,583	0.82
USE-0400	81	Upper Schuylkill East Side	637	9,351	11/8/01	11/21/01	0.4	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3]	NA[3])	NA[3]
USE-0500	USE-0500	Upper Schuylkill East Side	397	3,193	4/1/12	6/30/12	3.0	1.28	1.59	1.00	0.280	400	88	2,519	0.78

MANHOLE ID	SITE ID	Interceptor	Tributary Drainage Area (acres)	Tributary Population	Data Start	Data End(1)	Duration (months)	Average Daily DWF (mgd)	Maximum Average Daily DWF (mgd)	Minimum Average Daily DWF (mgd)	Average Daily BWWF (mgd)	Per Capita Average Daily DWF (gpcd)	Per Capita Average Daily BWWF (gpcd)	Per Acre Average Daily GWI (gal/acre/d)	GWI Ratio(2)
USE-0660	USE-0660	Upper Schuylkill East Side	246	1,627	7/12/12	8/4/13	12.8	0.402	0.502	0.292	0.110	247	68	1,187	0.72
USE-0760	47	Upper Schuylkill East Side	184	1,310	11/29/07	11/30/08	12.1	0.316	0.385	0.245	0.0710	241	54	1,332	0.78
USE-0855	46	Upper Schuylkill East Side	171	1,260	5/4/00	4/24/01	11.7	0.647	0.686	0.603	0.0440	513	35	3,526	0.93
W067-01-S0060	W067-01-S0060	Wissahickon High Level	257	3,990	6/1/13	9/30/13	4.0	0.589	0.709	0.450	0.139	148	35	1,751	0.76
W095-01-S0020	W095-01-S0020	Wissahickon High Level	57	93	6/6/13	7/18/13	1.4	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)
WHL-0110	49	Wissahickon High Level	1,834	13,706	1/18/01	3/31/02	14.4	3.23	4.19	2.46	0.770	235	56	1,341	0.76
WHL-0110	49	Wissahickon High Level	1,834	13,706	5/30/13	9/30/13	4.0	3.16	3.71	2.53	0.630	230	46	1,379	0.80
WHL-0265	52	Wissahickon High Level	269	831	5/3/00	9/14/00	4.4	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)	NA(3)
W075-01-S0018	W075-01-S0018	Wissahickon Low Level	141	1,185	5/31/13	7/9/13	1.3	0.0802	0.0929	0.0670	0.0132	68	11	475	0.84
W076-13-S0100	W076-13-S0100	Wissahickon Low Level	110	2,175	7/9/10	6/30/11	11.7	0.345	0.458	0.205	0.140	159	64	1,864	0.60
WLL-0028	WLL-0028	Wissahickon Low Level	5,639	37,760	8/11/10	8/11/11	12.0	7.20	8.50	5.20	2.00	191	53	922	0.72
WLL-0100	WLL-0100	Wissahickon Low Level	5,626	37,746	5/30/13	9/30/13	4.0	6.18	7.26	4.49	1.69	164	45	798	0.73
WLL-0105	41	Wissahickon Low Level	5,626	37,746	10/1/00	11/6/01	13.2	5.27	6.68	3.57	1.70	140	45	635	0.68
WLL-0332	51	Wissahickon Low Level	4,966	27,664	5/3/00	2/1/01	9.0	4.28	5.45	2.90	1.38	155	50	584	0.68
WLL-0565	40	Wissahickon Low Level	4,214	19,592	3/8/13	9/30/13	6.8	3.40	4.07	2.50	0.900	173	46	593	0.74
WBR-0375	72	Wooden Bridge Run	301	4,310	1/14/04	6/28/05	17.5	0.647	0.822	0.423	0.224	150	52	1,405	0.65
WBR-B0585	70	Wooden Bridge Run	278	3,693	1/1/04	9/9/04	8.3	0.526	0.655	0.324	0.202	142	55	1,165	0.62
WBR-B0585	70	Wooden Bridge Run	278	3,693	1/1/03	12/31/03	12.0	0.682	0.821	0.447	0.235	185	64	1,608	0.66

(1) As of September 30, 2013

(2) GWI ratios are calculated by dividing the average minimum dry weather flow by the average daily dry weather flow.The ratio signifies the approximate percentage of GWI observedin the total dry weather flow assuming the BWWF component during the minimum early morning flows is negligible.

(3) Sites marked as "NA" were determined to have unreliable data for the entire monitoring period.

4.2.1 Identification of Sewersheds with High Levels of Infiltration

Additional DWF quantification and characterization analyses were conducted to compare sewershed flows to each other and identify specific sanitary sewer collection systems where the quantity of GWI could be considered relatively high and potentially problematic. Special analyses are needed to make these comparisons because high monitored flow quantities do not necessarily indicate a GWI problem or leaky sewer system. Larger sewershed areas with larger populations are expected to generate more wastewater flow. Small sewershed areas would also be expected to contribute high flow quantities if the service population density is high. There are two analysis methods that are typically used to compare sewershed areas and identify relatively leaky sewershed areas: a GWI ratio approach and a per capita analysis approach.

The first analysis method used for the Phase 2 SSES was a GWI ratio approach where, for each successfully monitored City sewershed area, the average minimum dry weather flow was divided by the total average daily dry weather flow (ADDWF). The resulting ratio signifies the approximate percentage of GWI that was monitored as a component of the total flow, assuming the monitored BWWF component was negligible during the minimum early morning period. The GWI ratios are provided in Table 4-3 and allow sewershed areas of any size and/or service population to be compared. A cumulative distribution function (CDF) plot was prepared which includes each of the calculated GWI ratios. The GWI ratio values were placed in order from the lowest to the highest, and each sewershed area was assigned a cumulative percentile value. The percentile value was the percent of the sites with a GWI ratio value less than or equal to the value indicated on the horizontal axis. Sewershed areas with very high percentile values have sewer collection systems that are most leaky, and sewershed areas with low percentile values are the tightest. The CDF plot is provided in Figure 4-5 and was color-coded to facilitate interpretation of the results. Sewershed areas with very high monitored GWI ratio values (above0.83) were color-coded red. Sewershed areas with high values (from 0.80 to 0.83) were color-coded orange, and areas with moderately high values (0.77 to 0.79) were color-coded yellow. Sewershed areas with average and low GWI ratios, and relatively tight sewer collection systems, were color-coded green and blue, respectively. As a basis for comparison, the median or middle GWI ratio value for all the monitored City sheds was 0.71. Figure 4-6 provides the same data for sheds with GWI ratios greater than the median and provides the corresponding sewershed names for each point along the curve.

Another commonly used analysis method is to take the monitored flow and divide by the service population to derive percapita values by which sewersheds of differing size and population density can be directly compared. Per capita average daily DWF and per capita BWWF values were calculated for the Phase 2 SSES and are provided in Table 4-3 for each successfully monitored City sewershed area. A CDF plot was prepared which includes the per capita average daily DWFs calculated from each City sewershed area. The CDF plot is provided in Figure 4-7 below and was color-coded to facilitate easier interpretation of the results. Sewershed areas with very high monitored per capita ADDWF values (above 400 gallons percapita per day (gpcd)) were color-coded red. Sewershed areas with high values (from 280 to 400 gpcd) were color-coded orange, and areas with moderately high values (230 to 279 gpcd) were color-coded yellow. Sewershed areas with average and low per capita ADDWF values, and relatively tight sewer collection systems, were color-coded green and blue, respectively. As a basis for comparison, the median value for all the monitored City sewersheds was 163 gpcd.

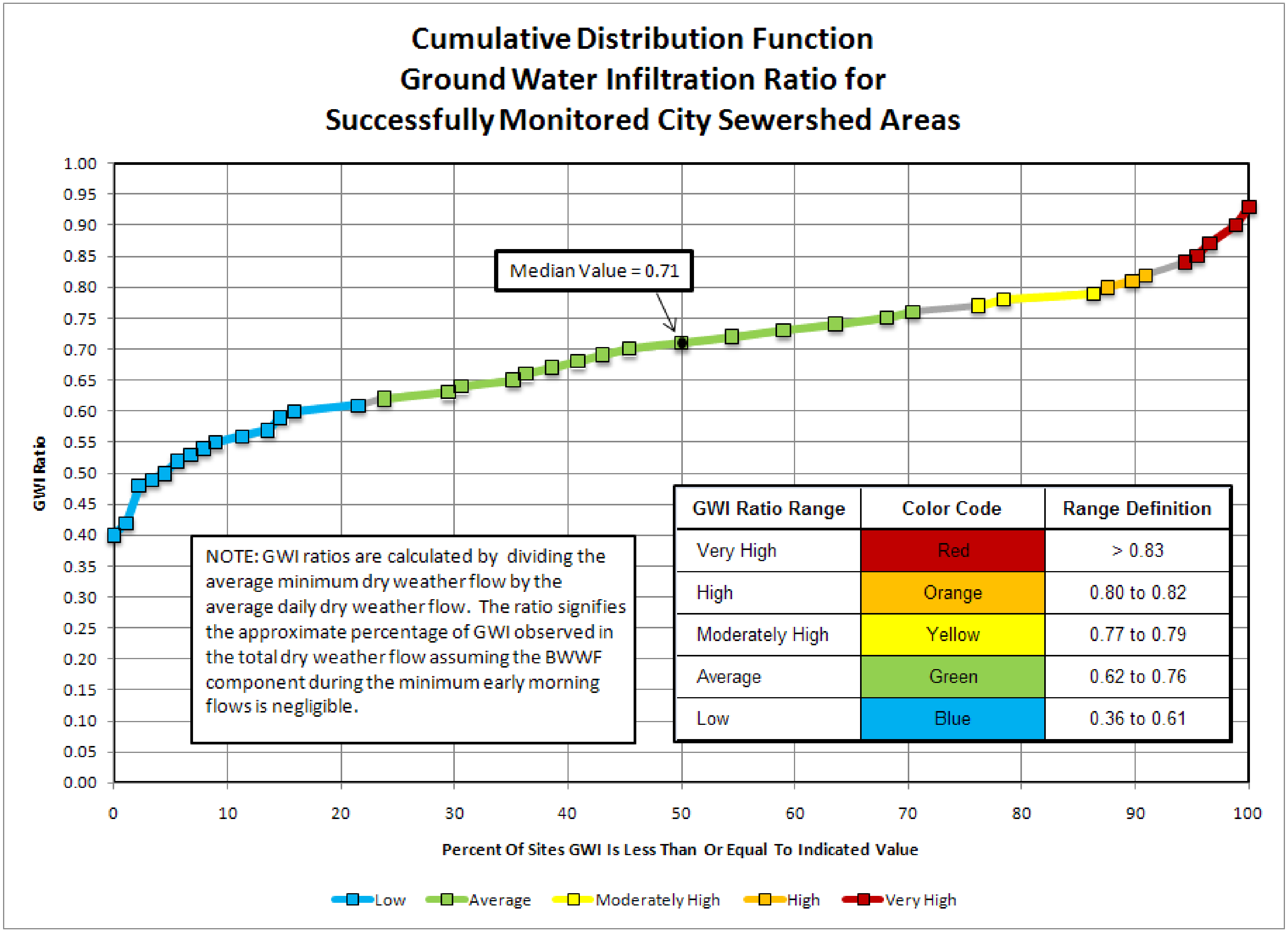


Figure 4-5: Cumulative Distribution Function for GWI Ratio

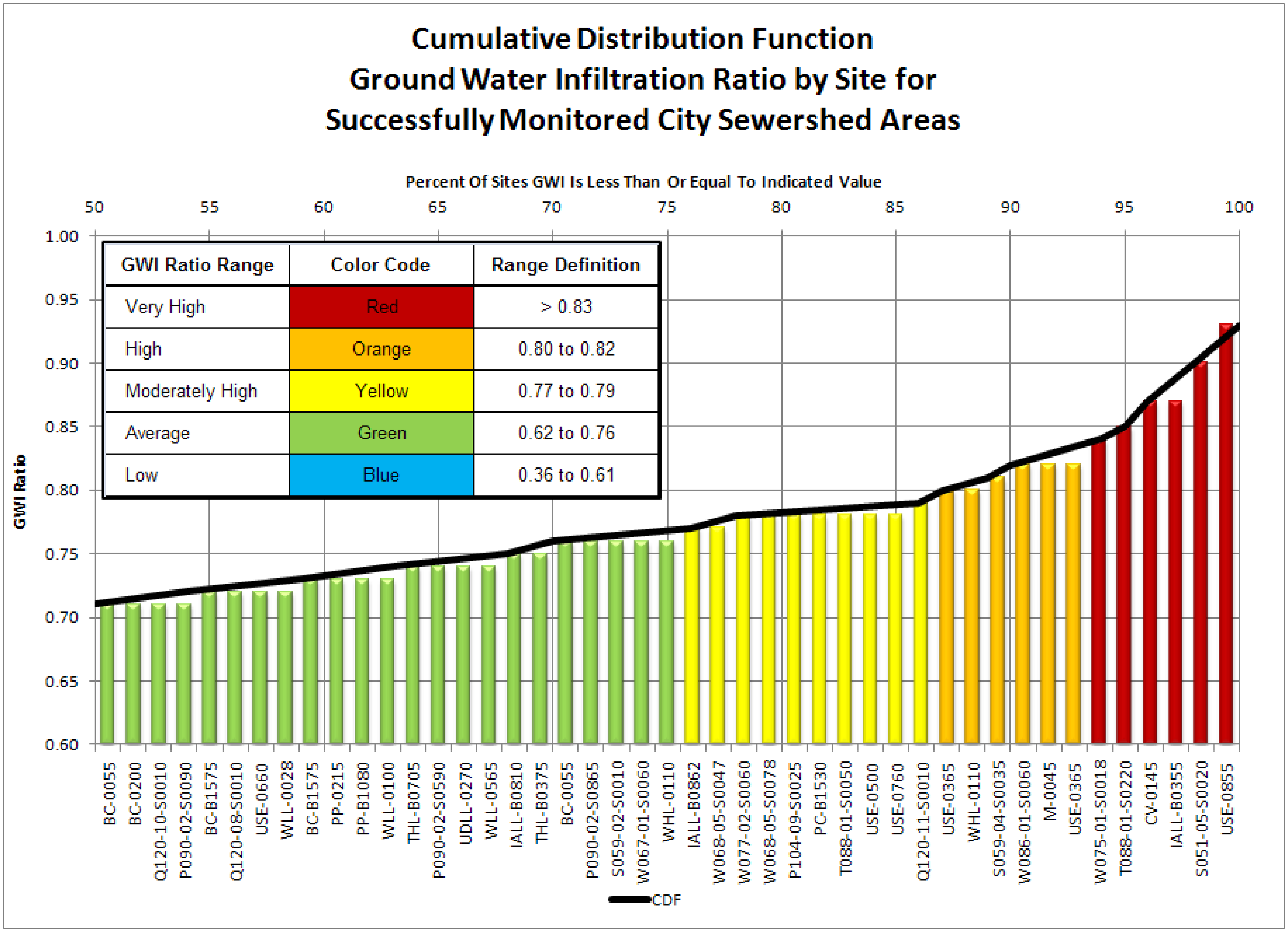


Figure 4-6: Cumulative Distribution Function for GWI Ratio with Site Locations

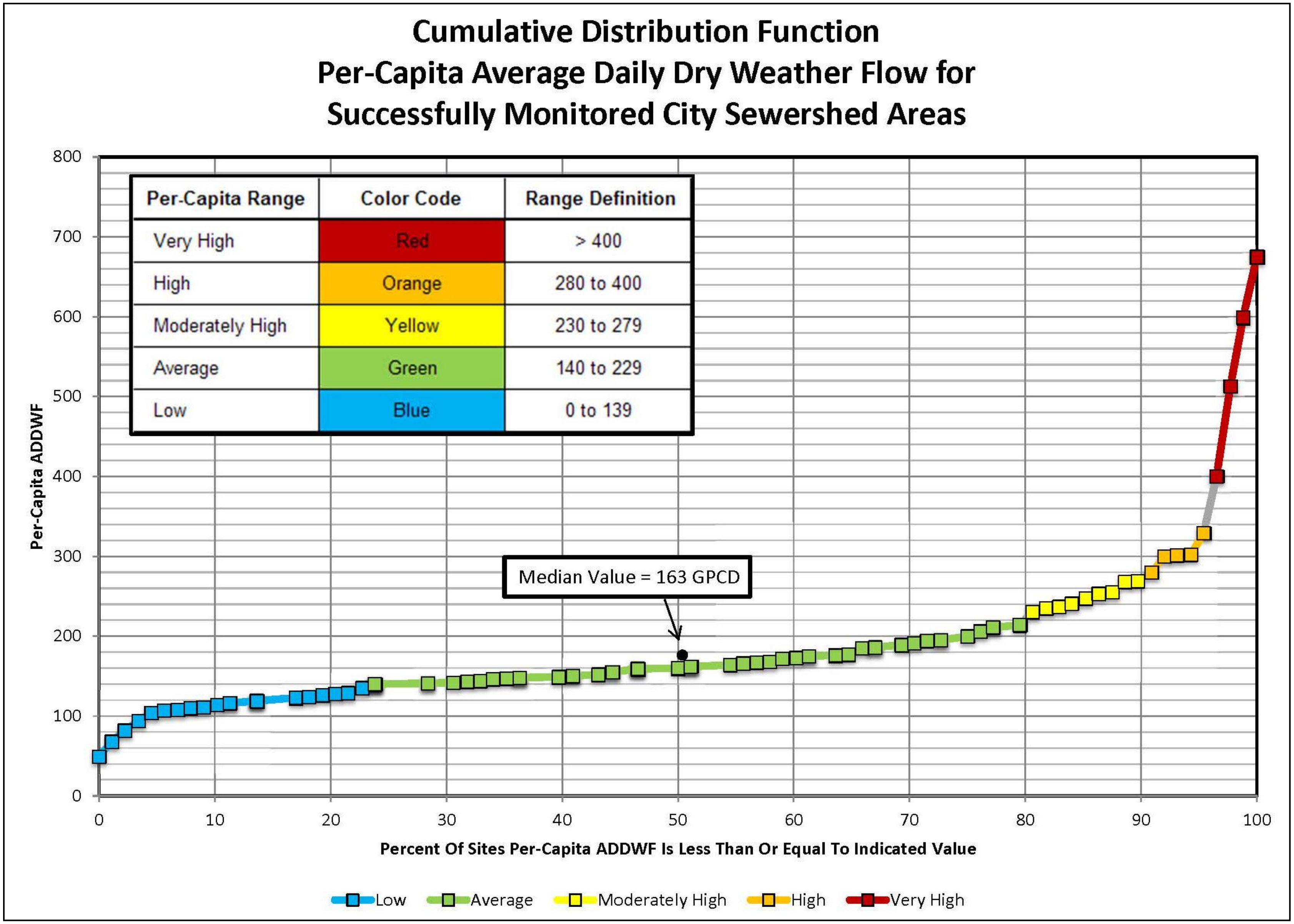


Figure 4-7: Cumulative Distribution Function for Per Capita Average Daily Dry Weather Flow

However, it must be understood that this analysis method needs to be limited to sewershed areas with a predominantly residential land use, and per capita ADDWF values can be misleading in areas with significant commercial and/or industrial land uses. Many of the City sewershed areas identified with high per capita ADDWF values also had significant portions of non-residential land uses, and the associated possibility for significant round the clock flow. For this reason, the GWI ratio analysis method was selected for providing the most reliable results for the SSES report.

4.2.2 Dry Weather Flow Analysis Conclusions

The completed Phase 2 SSES analysis was successful in identifying specific sewershed areas where the quantity of monitored GWI flow was relatively high. The GWI component of DWF varies gradually with seasonal changes in the elevation of the groundwater table and generally does not respond rapidly to a single storm. These higher GWI ratios could be an indication of a leaky wastewater collection system where the flow during dry weather conditions is relatively high and the elevation of the groundwater table is above the elevation of the sanitary sewer collection system for extended periods of time. For these sewershed areas, sewer rehabilitation could potentially reduce GWI flow and reduce the frequency, duration and volume of sewer surcharge conditions and combined sewer overflow (CSO) discharges. For these identified sewershed areas, the monitoring duration was taken into account to verify that there was sufficient data to examine seasonal variability. The monthly precipitation volumes and event frequencies during the monitoring periods were checked against the corresponding historical average values to see if there was potential bias (significantly wetter or drier than normal) that could impact the analysis results.

There were 6 sewershed areas within the City of Philadelphia where the GWI ratio, calculated from the monitored wastewater flow monitoring data, was greater than 0.83 and classified as very high (red range along the CDF curve.) When looking at the CDF curve in Figure 4-6, a clear inflection point or knee-of-the-curve can be seen. There was a wide range in the size of the identified sewershed areas, ranging from 62 acres up to 882 acres. The locations of these six City sewersheds are provided on the Figure 4-8 map.

- **Monitoring Site USE-0855** that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was approximately one year which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. During 9 of the 12 months in the monitoring period, the precipitation values were within the normal historical ranges (see Appendix A.) However it should be noted that for the month of May 2000, the monitored storm frequency was higher than normal and for the month of September 2000, the volume was higher than the historical norm. The storm volume during April 2001 was lower than average. Overall the precipitation volumes and frequencies during the monitoring duration were reasonably representative of historic norms.
- **Monitoring Site S051-05-S0020** that is tributary to the Upper Schuylkill East Side Interceptor. However, it should be noted that the monitoring duration was only two months which may not provide sufficient data to reliably characterize the sewershed

area. During the month of March 2001, the monitored storm volume and frequency were within the high side of the normal range. For the month of April, the monitored precipitation volume was lower than the historical norm, yet the calculated GWI volumes were still relatively high. Because of the short monitoring duration, the dry weather flow analysis results for this sewershed area should be used with caution.

- **Monitoring Site IALL-B0355** that is tributary to the Island Avenue Low Level Interceptor. The monitoring duration was 15 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The monitored precipitation volumes and frequencies were within the normal historical ranges for 13 of the 15 months in the monitoring duration. For the month of July 2012, the monitored precipitation volume was lower than the normal historical range, yet the calculated GWI volume was still relatively high. For the month of September 2012, the monitored storm frequency was higher than the historical norm. Overall, the precipitation volumes and frequencies during the monitoring duration should be reasonably representative.
- **Monitoring Site CV-0145** that is tributary to the Cresheim Valley Interceptor. The tributary sewershed includes areas both within and outside the City limits. The monitoring duration was approximately seven months, including the typically wetter spring season, which should provide sufficient data to characterize the sewershed area flow. For five of the seven months during the monitoring duration, the monitored volumes and frequencies were within the historic norms. However, for June 2013, the monitored storm volumes and frequencies were both higher than the historical norm and the monitored volume for the following July was higher than average. The biased precipitation for these two months could potentially make the sewershed appear to have a higher average GWI volume than it should under normal precipitation conditions.
- **Monitoring Site T088-01-S0220** that is tributary to the Tacony High Level Interceptor. The monitoring duration was approximately nine and one half months, including the typically wetter winter and spring seasons, which should provide sufficient data to characterize the sewershed area flow. The monitored storm volumes and frequencies during the monitoring period were within the typical ranges of the historical values except for two months. As was explained for Site CV-0145 above, the months of June and July 2013 had monitored storm values that were higher than the historical norms. However, the calculated GWI values from the other seven and one half months should balance out the potential upward bias from these two months.
- **Monitoring Site W075-01-S0018** that is tributary to the Wissahickon Low Level Interceptor. However, it should be noted that the monitoring duration was only two months which may not provide sufficient data to reliably characterize the sewershed area. The only available monitoring data for this site was collected during June and July of 2013. As was explained for the two sewershed areas above, these months had monitored storm values that were higher than the historical norms. The biased precipitation for these two months could potentially make the sewershed appear to have a higher average GWI volume than it would under normal precipitation conditions.

Therefore the dry weather analysis results for this sewershed area should be considered to be unrepresentative and potentially misleading.

There were 5 sewershed areas within the City of Philadelphia where the GWI ratio was between 0.80 and 0.83 and was classified as high (orange range along the CDF curve.) When looking at the CDF curve in Figure 4-6, a clear inflection point or knee-of-the-curve can be seen. The locations of these five City sewersheds are provided on the Figure 4-9 map.

- **Monitoring Site USE-365** that is tributary to the Upper Schuylkill East Side Interceptor. However, it should be noted that the monitoring duration was four months, which may or may not provide sufficient data to reliably characterize the sewershed area. For the months of May and June 2010, the monitored storm precipitation volume and frequency were both lower than the normal historical range of values. During the month of August 2010, the monitored storm frequency was below the historical average value. The biased precipitation for three of the four months in the monitoring duration could potentially make the sewershed appear to have a lower average GWI volume than it would under normal precipitation conditions.
- **Monitoring Site M-0045** that is tributary to the Monoshone Interceptor. However, it should be noted that the monitoring duration was four months, which may or may not provide sufficient data to reliably characterize the sewershed area. For half the monitoring period, the monitored precipitation was higher than the historic norms. For June 2013, the monitored storm volumes and frequencies were both higher than the historical norm and the monitored volume for the following July was higher than average. The biased precipitation for these two months could potentially make the sewershed appear to have a higher average GWI volume than it should under normal precipitation conditions. Because of the short monitoring duration and the biased precipitation, the dry weather flow analysis results for this sewershed area should be used with caution.
- **Monitoring Site W086-01-S0060** that is tributary to the Cresheim Valley Interceptor. However, it should be noted that the monitoring duration was only for one month, which may not provide sufficient data to reliably characterize the sewershed area. The monitored precipitation volume and storm frequency for February 2012 was within the normal historical range. However, because of the short monitoring duration, the dry weather flow analysis results for this sewershed area should be used with caution.
- **Monitoring Site S-059-04-S0035** that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was 15 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The monitored precipitation volume during September 2000 was higher than the historical average range. However 2001 was a drought year with the monitored April precipitation volume being lower than historical norms and the both rainfall volume and storm frequency being lower than normal for the months of April, July and August. The biased precipitation during 2001 could potentially make the sewershed appear to have a lower average GWI volume than it should under normal precipitation conditions.

- **Monitoring Site WHL-0110** that is tributary to the Wissahickon High Level Interceptor. The tributary sewershed includes areas both within and outside the City limits. The monitoring duration was 18 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The sewershed had two monitoring periods; one during 2013 and another during 2000 and 2001. During the 5-month monitoring period in 2013, the monitored precipitation was higher than normal for two months. For June 2013, the monitored precipitation volume and storm frequency were both higher than the normal historical range and the monitored storm volume was higher than average for the following month. Monitoring activities during 2001 were biased from the drought conditions. Monitored precipitation volume during April 2001 was lower than the normal range, and monitored rainfall volume and storm frequency were both lower than the historic normal range for the months of July, August, October and November. The precipitation during 2001 could potentially bias the GWI analysis and make the sewershed appear to have a lower average GWI volume than it should under normal precipitation conditions.

It is important to note that just because a sewershed area was identified as having a relatively high GWI value does **not** indicate that sewer rehabilitation is recommended. Wet weather analysis methods to quantify and characterize rainfall dependent infiltration and inflow (RDII) also need to be considered as explained in Section 4.3 (Wet Weather Analysis Results) when selecting candidate sewershed sites. It also needs to be understood that if a sewershed is identified as having a relatively high GWI value, it does **not** indicate that all the collection sewers within the entire sewershed area tributary to the monitoring site would need to be rehabilitated. Especially for larger sewershed areas, there may be a combination of some very leaky areas along with some acceptably tighter areas.

Figure 4-8: Identification of City Sewershed Areas with Very High GWI

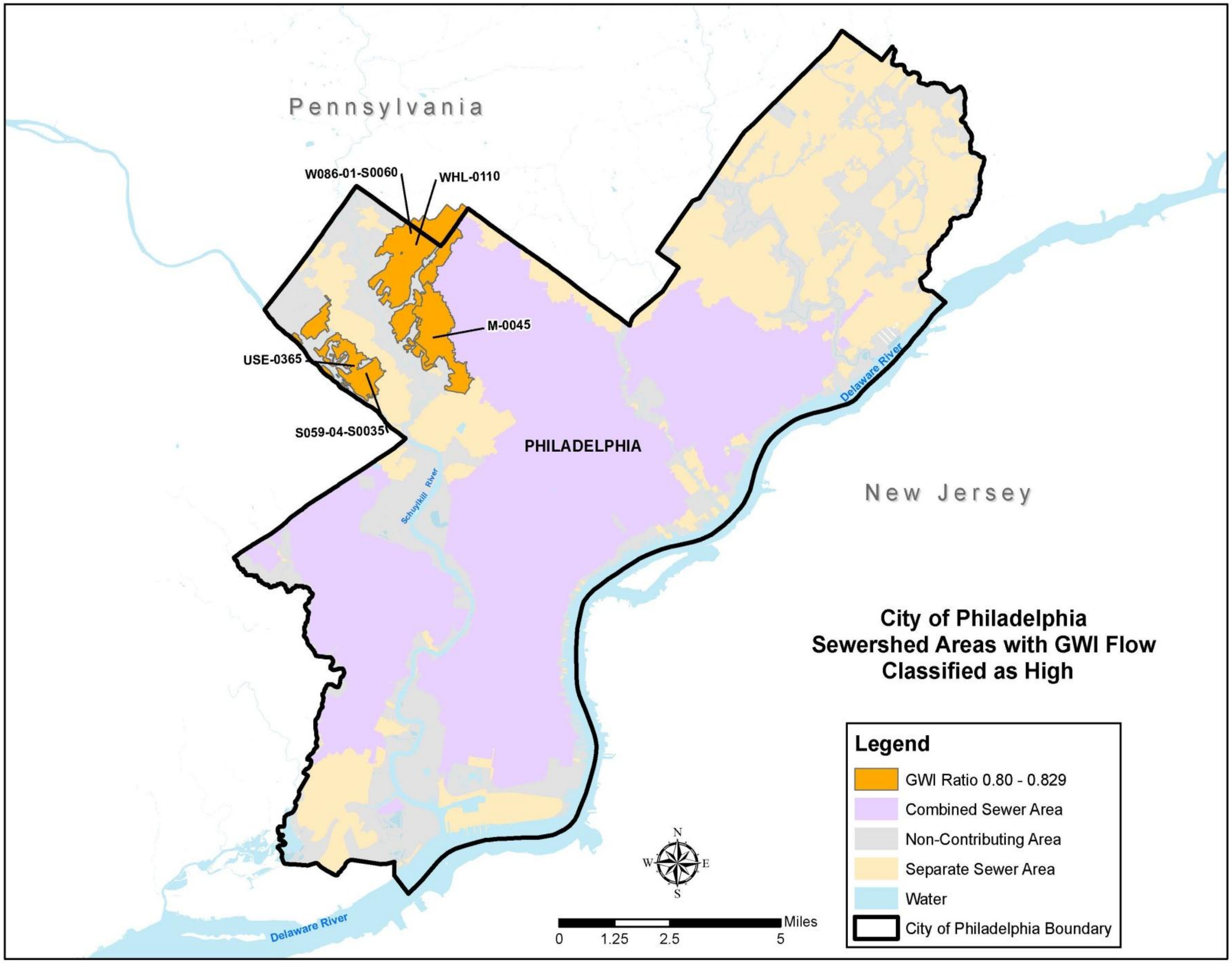


Figure 4-9: Identification of City Sewershed Areas with High GWI

4.3 Wet Weather Flow Analysis Results

After the Phase 1 data gathering process had been completed, the data quality review procedures had been performed, and the dry weather flow analyses were finished, SSES Phase 2 analyses were conducted to quantify and characterize wet weather wastewater flows. The completed Phase 2 analyses were successful in quantifying and characterizing the wet weather flow (WWF) from monitored City sewershed areas. The WWF analysis process was previously described in Section 3.6. This section provides and explains the results and observations from those completed analyses. The analyses enabled the Water Department to identify specific sewershed areas within the City where the quantity of rainfall dependent infiltration and inflow (RDII) flow was relatively high. This could be an indication of a leaky wastewater collection system, or illicit connections which could be tracked down and corrected, where the flow is relatively high and sewer rehabilitation could potentially reduce the frequency, duration, and volume of combined sewer overflow (CSO) discharges. The Phase 2 analyses and documentation of results for this SSES report were focused on monitored sewershed areas located within the City. A separate SSES report documenting the analysis results for monitored sewershed areas within the Outlying Communities is scheduled to be prepared and submitted by June 1, 2015.

4.3.1 Overall Wet Weather Analyses Results

The results from the completed SSES Phase 2 WWF analyses, and background information for the monitoring sites, are summarized in Table 4-4, below. The monitoring sites are grouped by the interceptor sewer which receives and conveys the monitored sewershed wastewater flow. The summary results provided in the table include 81 successfully monitored City sanitary sewershed areas. The table provides relevant context information for each monitoring site, including the pipe size and the associated drainage area and service population for the tributary sewershed areas. It is important to note that the service populations were obtained from the US census and therefore include only the people living in the sewershed areas and would not include those who work in commercial and/or industrial facilities located within the sewershed. The table provides the duration of the available monitoring data in months, the number of successfully monitored storms that were analyzed, and the number of seasons that could be characterized. A minimum of 4 successfully monitored and analyzed storms were required to characterize a season. Monitoring sites with more than 4 analyzed seasons had more than a year of available monitoring data. The remaining columns in the table provide the summary results of the completed wet weather analyses and will be explained later in the narrative.

Additional wet weather flow characterization information, including the results of the wet weather hydrograph deconstruction analyses, is included in Appendix C. This additional hydrograph characterization information will be incorporated into the hydrologic and hydraulic (H&H) models to further refine and improve the model simulations that are used to guide the implementation of the Water Department's Green City, Clean Waters program.

Table 4-4: Summary of RDII Quantification Analysis Results

Interceptor System / Monitoring Site Identification	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Service Population	Monitoring Data Duration (months)	Number of Storms Analyzed	Number of Seasons Analyzed	Maximum 5 Storm Average Total R	Maximum Seasonal-Average Total R	Annual Average Total R	Maximum 5 Storm Average Peaking Factor
Byberry Creek Interceptor										
BC_0010	48	3,271	40,961	18	95	6	0.103	0.061	0.044	4.46
BC-0055 (2012)	51h x 48w	2,715	33,648	13	61	5	0.074	0.051	0.036	5.03
BC-0055 (2013)	51h x 48w	2,715	33,648	9	55	3	0.048	0.038	0.029	4.52
BC-0200	42	2,326	23,909	3	9	1	0.030	0.023	0.023	1.96
BC-0675	20	230	2,374	12	59	4	0.277	0.123	0.088	11.6
BC-0755	18	275	4,752	10	31	2	0.083	0.062	0.056	10.7
BC-1575 (1st Location)	24	169	1,676	4	22	2	0.111	0.056	0.050	4.40
BC-1575 (2nd Location)	24	169	1,676	9	34	3	0.089	0.060	0.047	3.93
Q101-03-S0020	15	112	1,773	14	56	5	0.123	0.094	0.062	14.6
Q109-07-S0025	15	164	2,090	10	64	4	0.081	0.063	0.034	5.70
Q114-12-S0010	12	68	2,217	12	78	5	0.221	0.139	0.108	11.2
Cheltenham Intercepting Sewer										
T089-04-S0055	15	98	1,819	4	14	2	0.096	0.059	0.058	3.32
THL-B0705	12	200	1,942	10	43	3	0.020	0.012	0.010	2.75
Cresheim Valley Interceptor										
CV-0145	27h x 18w	882	9,340	7	42	3	0.105	0.068	0.057	5.09
W077-02-S0060	15	225	1,810	12	40	4	0.025	0.014	0.011	3.94
W086-01-S0060	18	225	2,546	1	4	1	N/A	0.033	0.033	1.50
Island Avenue Low Level Interceptor										
IALL-B0355	24	214	1,308	15	88	5	0.070	0.033	0.021	8.53
IALL-B0810	20	211	3,779	12	49	4	0.046	0.032	0.017	3.36
IALL-B0862	24	202	2,201	7	17	3	0.018	0.014	0.011	2.25

Interceptor System / Monitoring Site Identification	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Service Population	Monitoring Data Duration (months)	Number of Storms Analyzed	Number of Seasons Analyzed	Maximum 5 Storm Average Total R	Maximum Seasonal-Average Total R	Annual Average Total R	Maximum 5 Storm Average Peaking Factor
Monoshone Interceptor										
M-0045	30	868	15,682	4	22	2	0.108	0.069	0.067	7.31
W068-05-S0047	30	520	8,863	12	75	5	0.119	0.076	0.059	4.38
W068-05-S0078	30	691	11,780	6	22	2	0.080	0.060	0.056	2.35
Paul's Run Interceptor										
P108-17-S0010	12	79	675	12	56	4	0.092	0.056	0.043	20.6
P113-04-S0463	12	80	1,327	6	37	3	0.078	0.048	0.039	3.29
PR-0060	30	1,421	23,030	12	71	5	0.079	0.046	0.037	5.02
PR-0150	27	1,069	19,728	14	76	5	0.085	0.060	0.040	5.61
PR-B0405	24	441	9,757	10	59	4	0.151	0.079	0.069	6.60
PR-B0455	24	391	9,369	9	36	4	0.100	0.078	0.062	4.99
PR-B0540	15	133	2,221	14	64	5	0.091	0.060	0.041	4.56
Pennypack Interceptor										
P104-09-S0025	10	50	993	18	82	6	0.096	0.060	0.034	6.09
P105-06-S0035	18	184	3,174	12	51	4	0.035	0.019	0.015	2.88
PP-0215	63h x 54w	10,986	115,729	4	25	2	0.040	0.027	0.026	3.97
PP-B0650	15	181	5,372	9	35	4	0.163	0.121	0.100	4.87
PP-B0790 (1999)	15	187	4,893	8	27	3	0.157	0.086	0.081	5.15
PP-B0790 (2013)	15	187	4,893	7	43	3	0.083	0.084	0.047	4.76
PP-B0840	24	368	7,121	9	51	4	0.076	0.044	0.037	9.78
PP-B1035	15	392	4,469	7	53	3	0.036	0.021	0.014	3.25
PP-B1080	24	2,549	11,596	2	6	1	0.016	0.015	0.015	1.53
PP-B1215	21	2,225	9,181	7	23	3	0.040	0.026	0.023	2.40
Poquessing Creek Interceptor										
PC-0100 (2009)	60	10,349	74,868	18	86	6	0.047	0.031	0.021	4.51
PC-0100 (2013)	60	10,349	74,868	10	55	3	0.024	0.015	0.013	3.21
PC-0045	60	10,330	74,868	11	42	4	0.030	0.021	0.013	2.65

Interceptor System / Monitoring Site Identification	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Service Population	Monitoring Data Duration (months)	Number of Storms Analyzed	Number of Seasons Analyzed	Maximum 5 Storm Average Total R	Maximum Seasonal-Average Total R	Annual Average Total R	Maximum 5 Storm Average Peaking Factor
PC-1210	24	732	6,745	9	34	4	0.040	0.028	0.021	5.07
PC-B1330	18	478	9,427	12	78	4	0.224	0.131	0.083	4.28
PC-B1360	18	374	6,435	7	45	3	0.114	0.070	0.054	5.08
PC-B1440	12	212	1,894	8	21	2	0.118	0.082	0.071	6.47
PC-B1530	18	224	219	12	76	4	0.089	0.039	0.030	8.80
Q107-02-S0025	15	176	2,954	10	39	4	0.125	0.097	0.073	9.14
Q110-17-S0015	12	59	709	4	32	2	0.046	0.032	0.028	9.57
Q120-02-S0010	12	85	1,131	12	24	3	0.118	0.067	0.058	7.38
Q120-08-S0010	12	108	1,069	12	63	4	0.155	0.078	0.049	3.19
Q120-10-S0010	10	67	323	3	21	2	0.036	0.022	0.017	1.47
Q120-11-S0010	12	81	932	12	65	5	0.545	0.426	0.228	5.37
Q121-02-S0015	10	73	1,076	12	70	5	0.067	0.041	0.028	4.13
Sandy Run Interceptor										
P90-02-S0090	27	581	11,971	4	22	2	0.052	0.041	0.038	5.65
P90-02-S0590	24	635	9,971	10	64	4	0.054	0.041	0.032	6.65
P90-02-S0715	24	388	5,559	12	67	5	0.117	0.078	0.060	8.41
P90-02-S0865	24	148	1,537	10	71	4	0.106	0.061	0.053	6.42
Tacony High Level Interceptor										
T088-01-S0050	24	497	12,452	13	71	5	0.181	0.113	0.072	3.55
T088-01-S0155	18	380	9,816	10	40	4	0.054	0.034	0.030	3.01
T088-01-S0220	15	62	3,044	10	67	4	0.450	0.323	0.235	4.41
THL-B0375	15	186	4,704	19	96	7	0.097	0.058	0.038	8.50
Upper Delaware Low Level Interceptor										
P083-03-S0050 (2011)	24	270	4,775	12	57	4	0.119	0.077	0.067	6.20
P083-03-S0050 (2013)	24	270	4,775	12	68	4	0.092	0.063	0.051	6.35
UDLL-0270	72h X 62w	14,644	118,393	12	71	4	0.031	0.020	0.016	2.56

Interceptor System / Monitoring Site Identification	Pipe Size (inches)	Tributary Drainage Area (acres)	Tributary Service Population	Monitoring Data Duration (months)	Number of Storms Analyzed	Number of Seasons Analyzed	Maximum 5 Storm Average Total R	Maximum Seasonal-Average Total R	Annual Average Total R	Maximum 5 Storm Average Peaking Factor
Upper Schuylkill East Side Interceptor										
S051-05-S0020	15	90	2,264	2	17	2	0.128	0.099	0.083	0.77
S051-08-S0175	12	68	2,092	7	30	3	0.370	0.268	0.139	9.98
S059-01-S0010	15	134	1,565	10	59	3	0.023	0.011	0.010	2.14
S059-02-S0010	10	86	2,029	15	69	5	0.134	0.066	0.054	4.08
S059-04-S0035	15	141	3,734	15	62	5	0.145	0.100	0.089	11.1
USE-0365 (2010)	48	773	13,233	4	16	2	0.066	0.058	0.046	4.95
USE-0365 (2012)	48	773	13,233	9	50	3	0.160	0.089	0.084	5.46
USE-0500	43h X 34w	397	3,193	3	17	1	0.052	0.033	0.033	3.70
USE-0660	31	246	1,627	13	46	4	0.074	0.041	0.032	15.3
USE-0760	32	184	1,310	12	52	5	0.272	0.173	0.069	14.3
USE-0855	15	171	1,260	12	66	5	0.150	0.068	0.043	4.40
Wissahickon High Level Interceptor										
W067-01-S0060	15	257	3,990	4	24	2	0.061	0.036	0.034	4.76
W075-01-S0018	12	141	1,185	1	11	1	0.006	0.004	0.004	11.2
W076-13-S0100	12	110	2,175	12	49	4	0.060	0.035	0.023	4.45
WHL-0110 (2001)	52	1,834	13,706	14	61	5	0.038	0.025	0.021	3.46
WHL-0110 (2013)	52	1,834	13,706	4	25	2	0.045	0.032	0.031	4.93
Wissahickon High Level Interceptor										
WLL-0028	42h x 28w	5,639	37,760	12	55	5	0.054	0.030	0.021	2.54
WLL-0100	36.5	5,626	37,746	4	25	2	0.021	0.014	0.013	2.65
WLL-0105	36	5,626	37,746	13	24	2	0.039	0.027	0.019	2.45
WLL-0332	36	4,966	27,664	9	34	2	0.024	0.011	0.011	1.89
WLL-0565	27.5	4,214	19,592	7	38	3	0.021	0.012	0.011	2.56
Wooden Bridge Run Interceptor										
WBR-0375	24	301	4,310	17	43	4	0.079	0.044	0.037	4.78
WBR-B0585 - 2003	18	278	3,693	12	48	4	0.062	0.053	0.032	3.41
WBR-B0585 - 2004	18	278	3,693	8	25	2	0.063	0.038	0.032	3.77

4.3.2 Selected Analysis Parameters and Indicator Values

The primary analysis parameter utilized to conduct the Phase 2 SSES wet weather assessment was rainfall dependent infiltration and inflow (RDII). RDII is the rainfall-derived flow response in a sanitary sewer system. In most systems, RDII is the major component of peak wastewater flows and is typically responsible for capacity issues, SSOs, and/or basement backups. Rainfall-derived infiltration refers to rainfall runoff that filters through the soil before entering a sanitary sewer system through damaged pipe sections, leaky joints, etc. Rainfall-derived inflow is the storm water that enters the sanitary sewer system directly via leaky manhole lids and frames. Other inflow sources include illicit roof drain connections, sump pumps, foundation drains, and cross connections with storm sewers and/or storm inlets. These defects can occur in both the public right-of-way portions of the sanitary sewer system or in individual service laterals on private property. Inflow typically occurs shortly after the start of a rainfall event. Infiltration typically extends beyond the end of rainfall and takes some time to recede to zero after an event. The methodology used to calculate the RDII component of the monitored wastewater flow is explained in Section 3.6 (Wet Weather Flow Characterization).

There were two categories of indicator values that were utilized in the SSES to represent the RDII flow for the analyzed sewershed areas: the total R-value and the peaking factor. Explanations for both of these indicator values and how they were calculated are provided in Section 3.6. To quantify the total R-value, the calculated RDII volume for each storm was divided by the corresponding rainfall volume over the sewershed area and expressed as a percentage. This R-value represents the fraction of the rainfall that occurred over the tributary sewershed area and entered the sanitary sewer system. For example, a computed R-value of 0.035 would indicate that 3.5% of the monitored rainfall over the sewershed area “leaked”or entered into the separate sanitary sewers as monitored RDII. Low R-values typically indicate a tight sewer system with minimal extraneous flow and high values indicate a leaky sewer system with high quantities of extraneous flow. The peaking factor was calculated by taking the maximum hourly monitored flow during the storm event, and dividing it by the calculated average daily dry weather flow for the monitored sewershed area. This peaking factor represents the magnitude of the increase of RDII flow through the monitored sewer pipes during large storms, compared to the magnitude of flow occurring during typical dry weather conditions.

4.3.3 Four Alternative Analysis Approaches

Maximum 5 Storm Average Total R-Value by Site

The first RDII analysis approach was to calculate the average for the five monitored storms with the largest total R-value for each of the 81 successfully monitored and analyzed City sanitary sewershed areas. This analysis alternative characterizes the sewershed areas under a worst case scenario; during the five storms with the largest magnitude of monitored flow. This approach assumes that usually, the flows during smaller and medium-sized storm flows are safely conveyed through the sewers to a treatment plant, but flows during the largest storms could be potentially problematic. Table 4-4 provides the maximum 5 storm average total R-value for each of the successfully monitored City sanitary sewershed areas.

Maximum Seasonal Average Total R-Value by Site

The second alternative analysis approach was to calculate the average total R-value for all the storms over each of the four seasons of the year. This approach was used to quantify and characterize the RDII flow from sewershed areas not only for a worst case scenario during the largest storms, but extending over an entire 3 month period. Table 4-4 provides the seasonal-average total R-value for the season with the highest monitored RDII flow. Most of the City sewershed areas (63 out of the 81 analyzed sites) were seen to experience their largest monitored total R-values either during the winter season or during the end of the fall season, from December 1 through December 20. This is expected because the rainfall interception and evapotranspiration losses provided by trees and other vegetation were lowest during these months.

Average Monitoring Duration Total R-Value by Site

The third analysis approach was to calculate the average total R-value for all storms over the entire monitoring period. For many of the monitoring sites, the monitoring duration was sufficient to quantify and characterize RDII flow over all four seasons. For monitoring sites where less than a year of monitoring data were available, the average included all the available storm events occurring over all the available seasons. The arithmetic mean was calculated for all successfully monitored storms observed at each of the 81 analyzed City sewershed sites. Table 4-4 provides the average total R-value for the sewershed areas tributary to each of the reported monitoring sites.

Site Average Five Largest Storm Peaking Factor

The last alternative analysis approach was to determine the average of the calculated peaking factors for the five storms with the largest monitored hourly-peak flows. This analysis alternative characterizes the sewershed areas under a worst case scenario, during the five storms with the largest magnitude of peak wet weather flow. Table 4-4 provides the maximum five storm average peaking factor for each of the successfully monitored City sewersheds.

4.3.4 Identification of Sewersheds with Relatively High RDII

Additional WWF quantification and characterization analyses were conducted to compare sewershed flows to each other and identify specific City sanitary sewer collection systems where the quantity of extraneous RDII could be considered being too high and RDII reduction rehabilitation measures may be beneficial. A cumulative distribution function (CDF) plot was prepared for each of the alternative analysis approaches which included each of the calculated R-values and the peaking factor. The R-values or peaking factors were placed in order from the lowest to the highest, and each sewershed area is assigned a cumulative percentile value. The percentile value is the percent of the sewershed monitoring sites with an R-value or peaking factor less than or equal to the values indicated on the vertical axis. Sewershed areas with very high percentile values have sewer collection systems that are most “leaky”, and sewershed areas with low percentile value are the tightest with the lowest wet weather flow contribution.

Total R-Value for all Individual Storm Events

To provide an overall context from which to interpret the results from each of the alternative analysis methods, a CDF analysis was prepared for each of the 4,174 individual storm events for which RDII analyses were conducted for the Phase 2 SSES. The total R-values for each storm were placed in order, from the lowest value to the highest, irrespective of the sewershed area over which the storm occurred. The resulting CDF plot is provided in Figure 4-10 and was color-coded to facilitate interpretation of the results. Individual storm events with very high monitored total R-values (above 0.18, where 18% of the sewershed rainfall entered the sanitary sewer collection system) were color-coded red. Sewershed areas with high values (from 0.10 to 0.179) were color-coded orange, and areas with moderately high values (0.060 to 0.099) were color-coded yellow. Sewershed areas with average and low R-values, indicating relatively tight sewer collection systems, were color-coded green and blue, respectively. The median or 50th percentile total R-value over all the analyzed storm events was 0.035. A clear inflection point, or knee-of-the-curve along the CDF line, can be observed at the 0.10 total R-value. This inflection point indicates that individual storm events that produce a sewershed wet weather response with an R-value of 0.10 or higher (the designated orange and red ranges) would be considered to have the highest relative volume of monitored RDII flow.

Maximum 5 Storm Average Total R-Value by Site

The CDF analyses were repeated for each of the alternative analysis methods, but this time the monitored storms and calculated R-values were grouped together over each of the individual City sewershed areas. For this first alternative RDII analysis approach, a CDF analysis and plot were prepared for the average of the five monitored storms with the largest total R-value. Each of the 81 successfully monitored and analyzed City sewershed areas was represented by a point along the CDF curve, from the sewershed with the lowest average R-value (corresponding to the tightest sewer collection system) to the sewershed with the highest average R-value (corresponding to the "leakiest" sewer system.) The CDF plot for the first RDII analysis approach is provided in Figure 4-11 and was color-coded to facilitate interpretation of the results. Individual City sewershed areas with very high monitored five-storm average total R-values (above 0.26, where 26% of the sewershed rainfall entered the sanitary sewer collection system) were color-coded red. Sewershed areas with high values (from 0.17 to 0.259) were color-coded orange, and areas with moderately high values (0.12 to 0.169) were color-coded yellow. Sewershed areas with average and low R-values, and relatively tight sewer collection systems, were color-coded green and blue, respectively. Figure 4-12 provides the upper ranges from the same CDF curve and indicates the corresponding sewershed names for each point along the CDF curve. The median or 50th percentile maximum five storm average total R-value over all the analyzed City sewershed areas was 0.080. A clear inflection point, or knee-of-the-curve along the CDF line, can be observed at the 0.16 total R-value. The CDF inflection point indicates that under a worst case scenario, considering only the five storms with the largest magnitude of monitored extraneous flow, the City sewershed areas that produce a sewershed wet weather response with a maximum five storm average total R-value of 0.16 or higher (the designated orange and red ranges) would be considered to have the highest relative volume of monitored RDII flow.

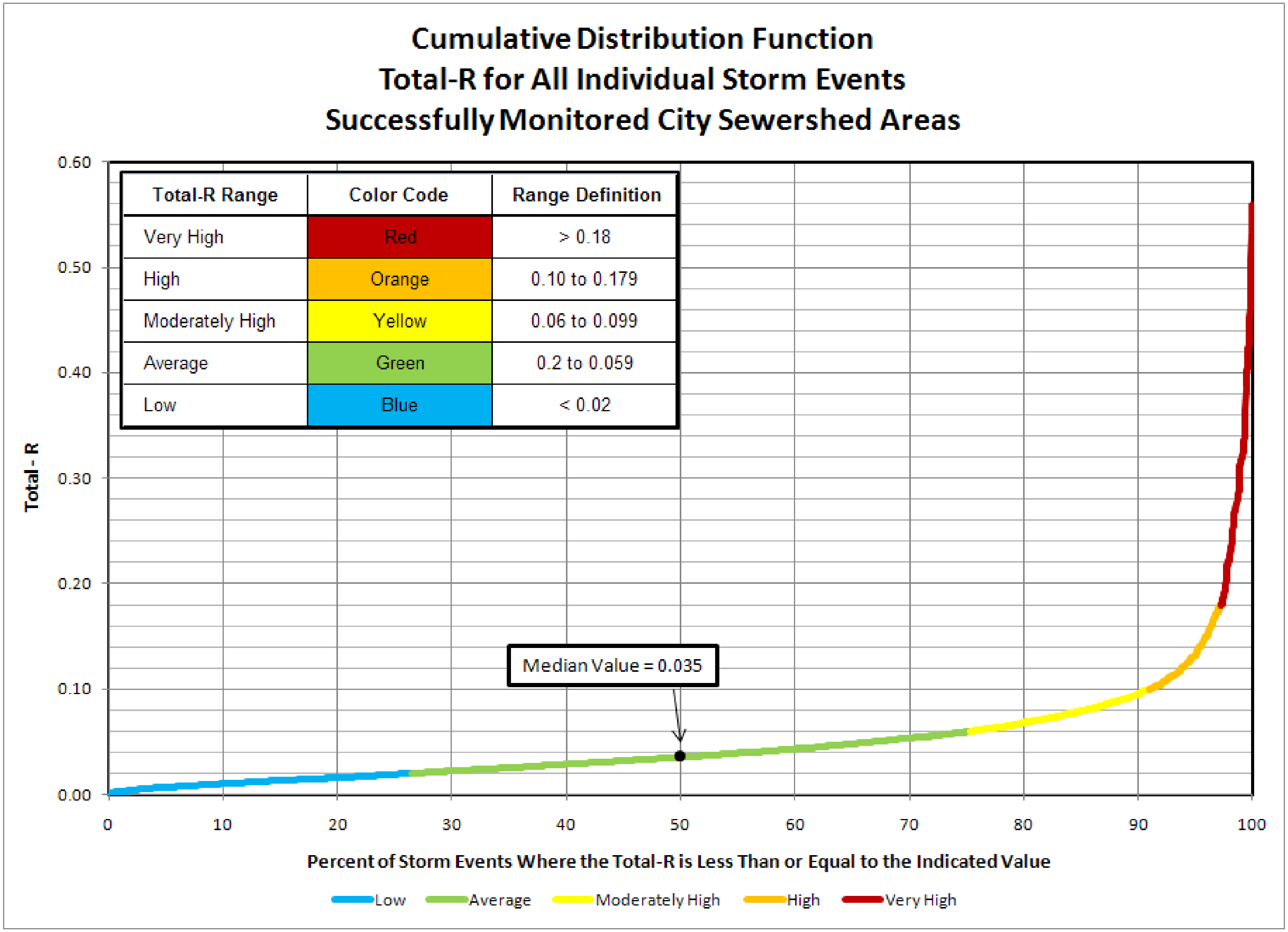


Figure 4-10: CDF of Total-R for all Individual Storm Events

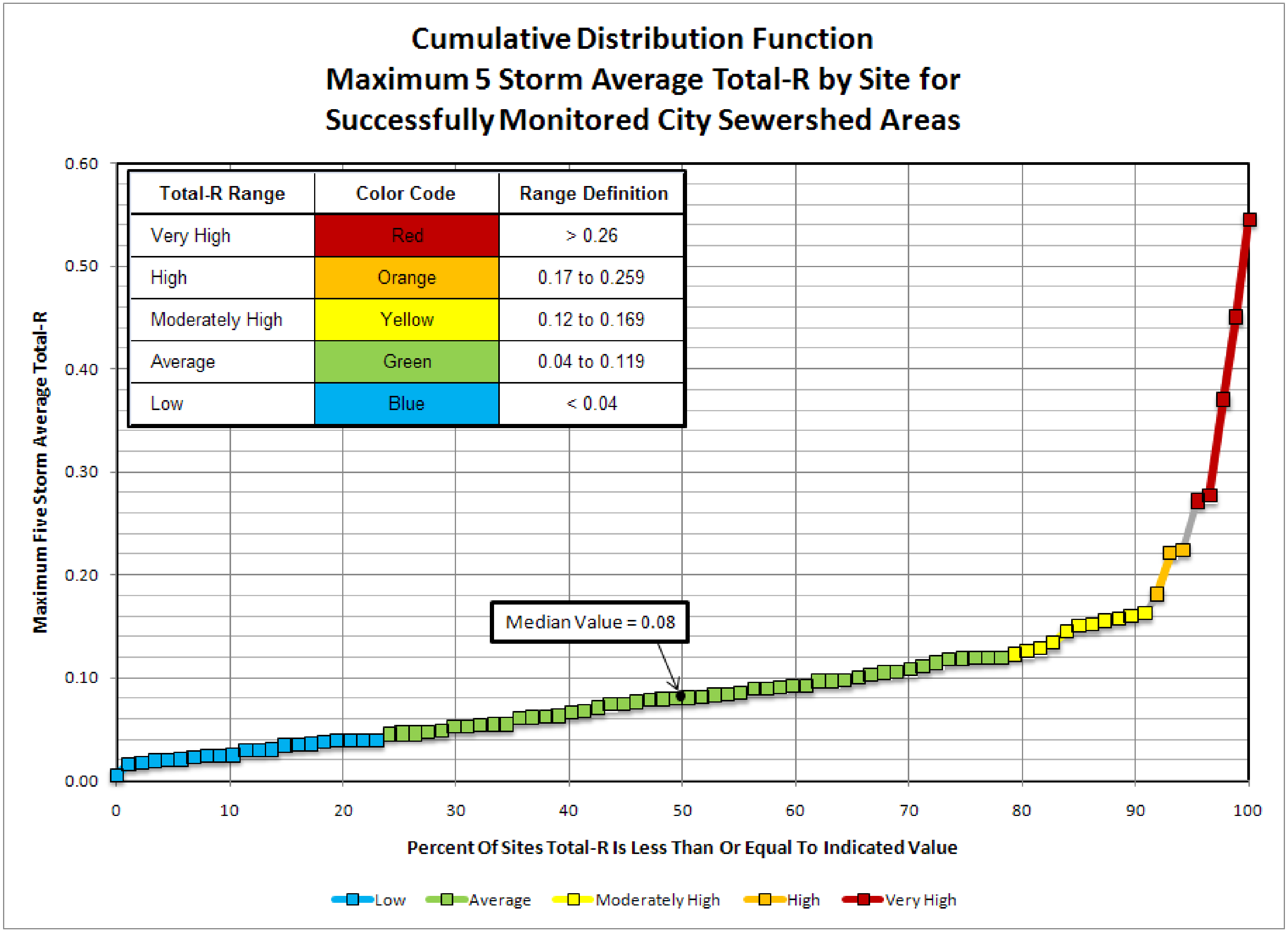


Figure 4-11: CDF of Maximum Five Storm Average Total-R by Site

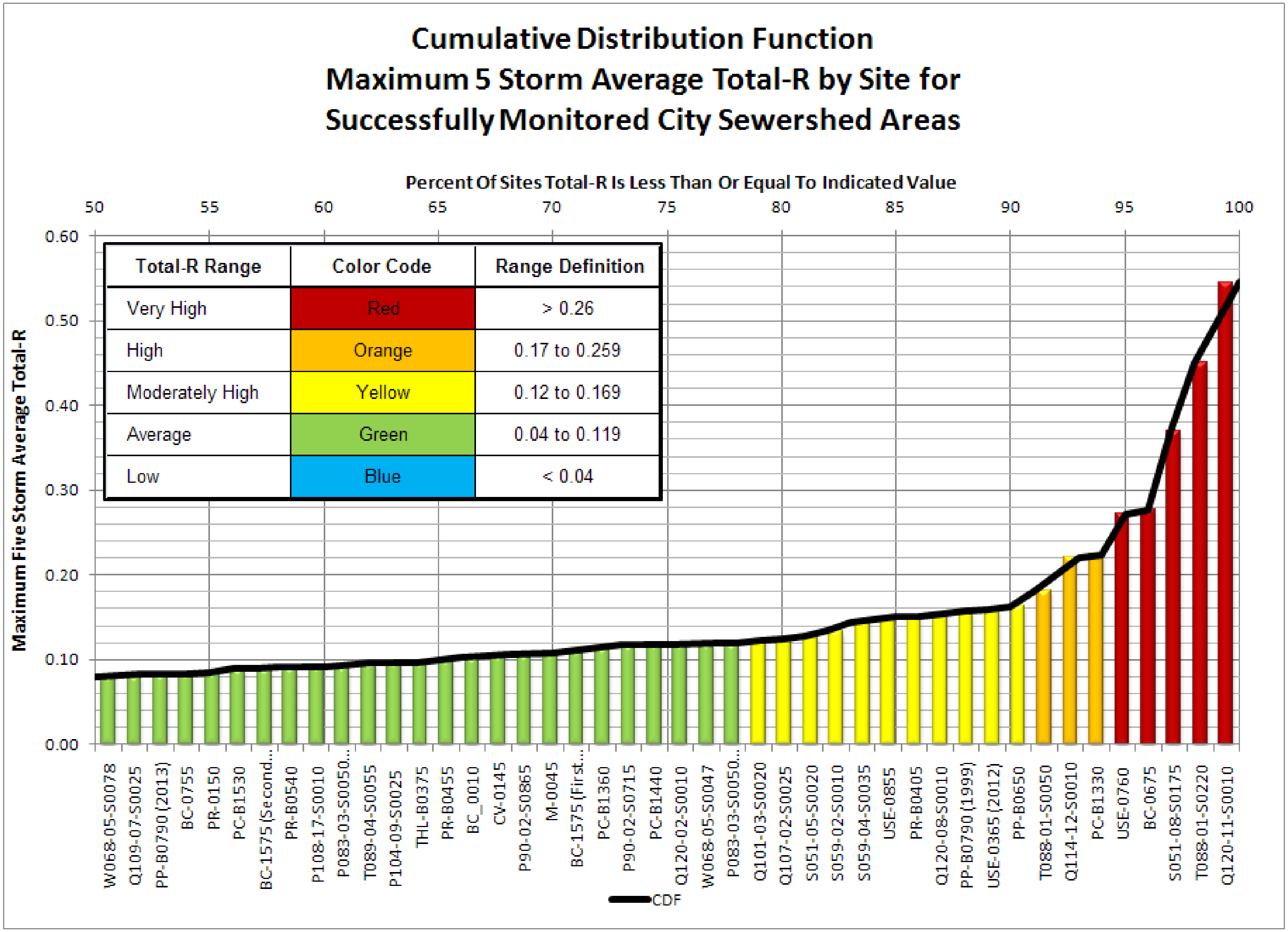


Figure 4-12: CDF of Maximum Five Storm Average Total-R by Site (identifying individual monitoring sites)

Maximum Seasonal Average Total R-Value by Site

For the second RDII analysis approach, a CDF analysis and plot were prepared for the average of all the monitored storms and calculated R-values grouped together over each individual sewershed area and also grouped together by season. The three-month season (spring, summer, fall, or winter) with the highest average total R-value for each of the 81 analyzed City sewershed areas was represented by a point along the CDF curve, from the sewershed with the lowest seasonal average R-value to the sewershed with the highest seasonal average R-value. The CDF plot for the second RDII analysis approach is provided in Figure 4-13 and was color-coded to facilitate interpretation of the results. Individual City sanitary sewershed areas with very high monitored seasonal average total R-values (above 0.16, where 16% of the sewershed rainfall entered the sanitary sewer collection system) were color-coded red. Sewershed areas with high values (from 0.11 to 0.159) were color-coded orange, and areas with moderately high seasonal values (0.070 to 0.109) were color-coded yellow. Sewershed areas with average and low R-values, indicating relatively tight sewer collection systems, were color-coded green and blue, respectively. Figure 4-14 provides the upper ranges from the same CDF curve and indicates the corresponding sewershed names for each point along the CDF curve. The median or 50th percentile seasonal average total R-value over all the analyzed City sewershed areas was 0.053. A clear inflection point, or knee-of-the-curve along the CDF line, can be observed at the 0.12 total R-value. This second alternative analysis approach differs from the first in that its focus extends beyond the worst case scenario of the five storms with the highest RDII volumes, and extends to an entire three month season with the highest RDII volumes. The CDF inflection point indicates that when considering the largest magnitude of monitored extraneous flow, for all the successfully monitored storms extending over an entire three-month season, the sewershed areas with a maximum seasonal average total R-value of 0.12 or higher (the designated orange and red ranges) would be considered to have the highest relative volume of monitored RDII flow.

Average Monitoring Duration Total R-Value by Site

For the third RDII analysis approach, a CDF analysis and plot were prepared based on the average R-value calculated for each site using all of the successfully monitored storms observed over the entire monitoring duration. The average monitoring duration total R-value for each of the 81 analyzed City sewershed areas was represented by a point along the CDF curve, from the sewershed with the lowest average R-value to the sewershed with the highest average R-value. The CDF plot for this RDII analysis approach is provided in Figure 4-15. The red range included the individual City sewershed areas with very high monitored average total R-values (above 0.10, where 10% of the sewershed rainfall entered the sanitary sewer collection system). The orange range was comprised of the sewershed areas with high values (from 0.080 to 0.099), and the yellow range encompassed sewershed areas with moderately high average values (0.060 to 0.079). Sewershed areas with average and low R-values, indicating relatively tight sewer collection systems, were color-coded green and blue, respectively. Figure 4-16 provides the upper ranges from the same CDF curve and indicates the corresponding sewershed names for each point along the CDF curve. For a basis of comparison, the median or 50th percentile average total R-value over all the analyzed City sewershed areas was 0.0375. A clear inflection point, or knee-of-the-curve along the CDF line, can be observed at the 0.080 total R-value.

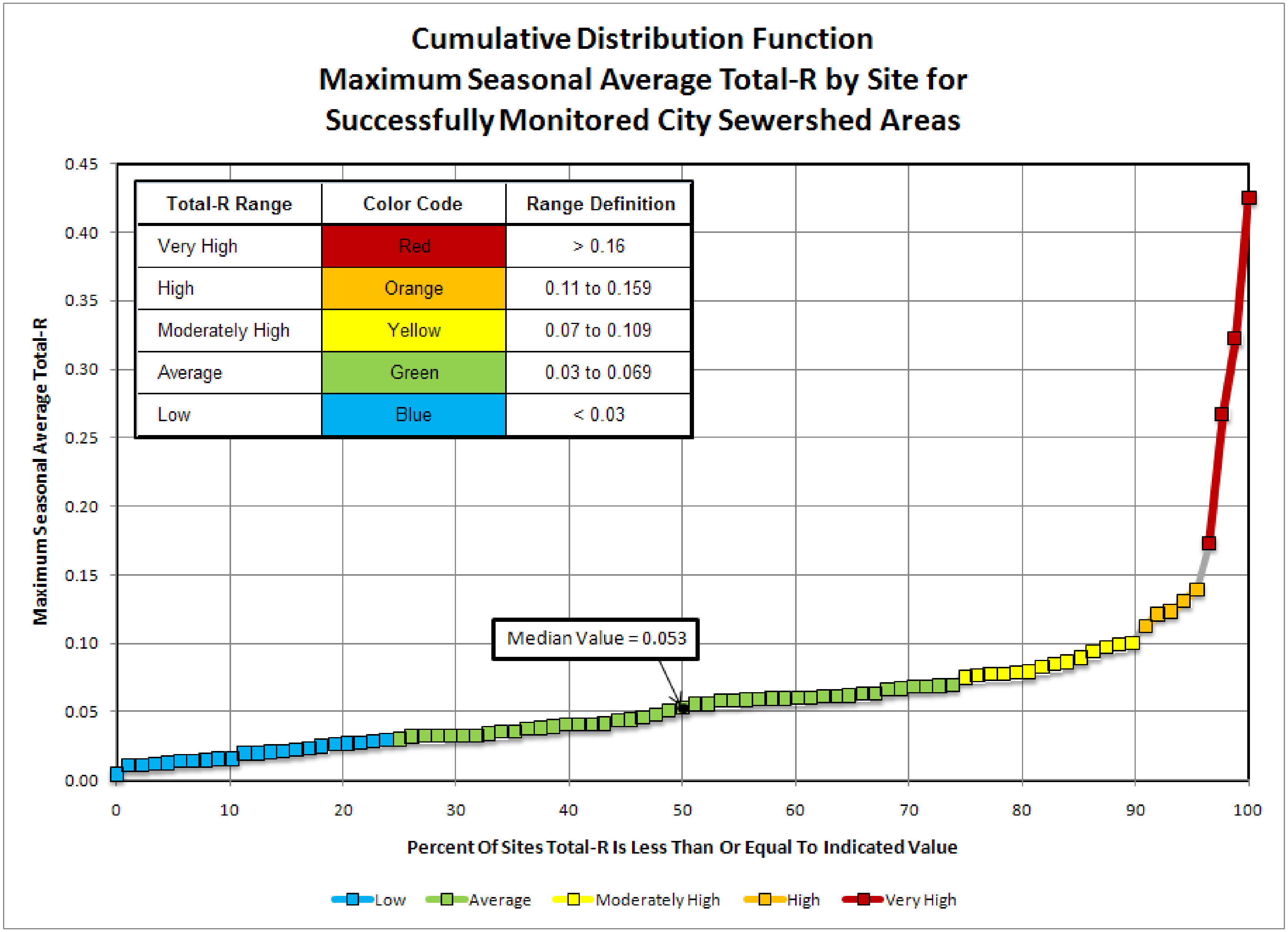


Figure 4-13: CDF of Maximum Seasonal Average Total-R by Site

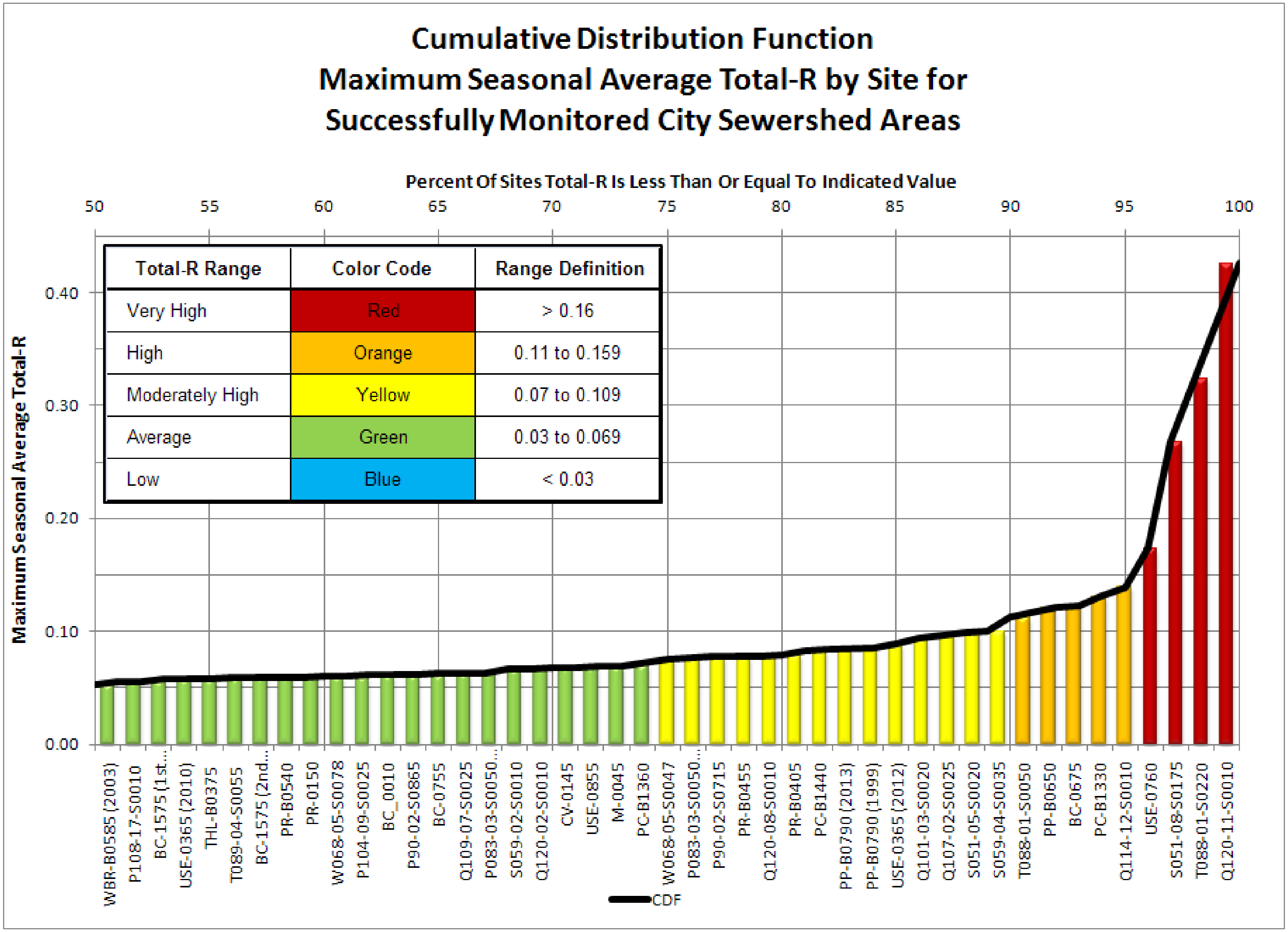


Figure 4-14: CDF of Maximum Seasonal Average Total-R by Site (identifying individual monitoring sites)

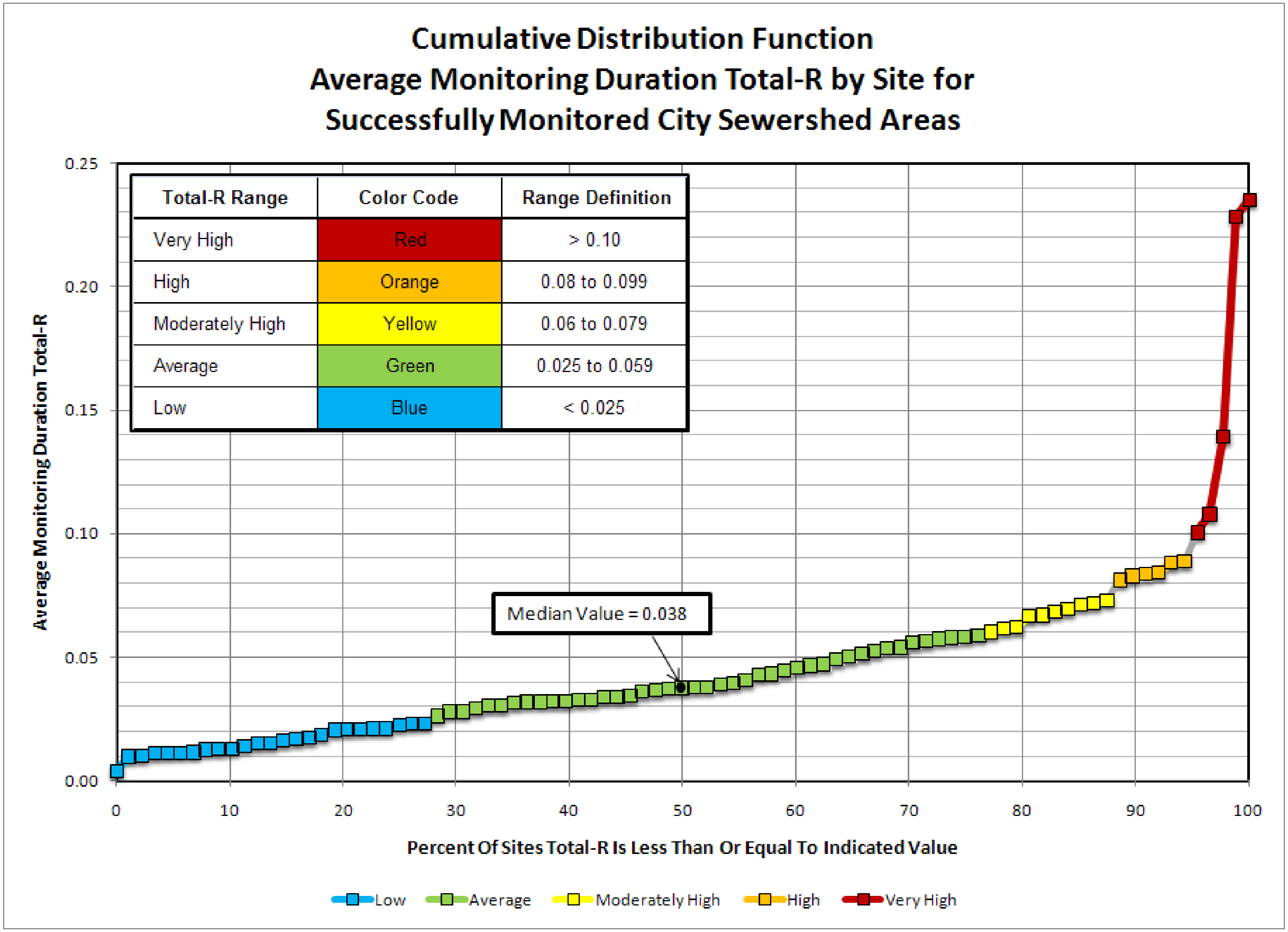


Figure 4-15 CDF of Average Monitoring Duration Total-R by Site

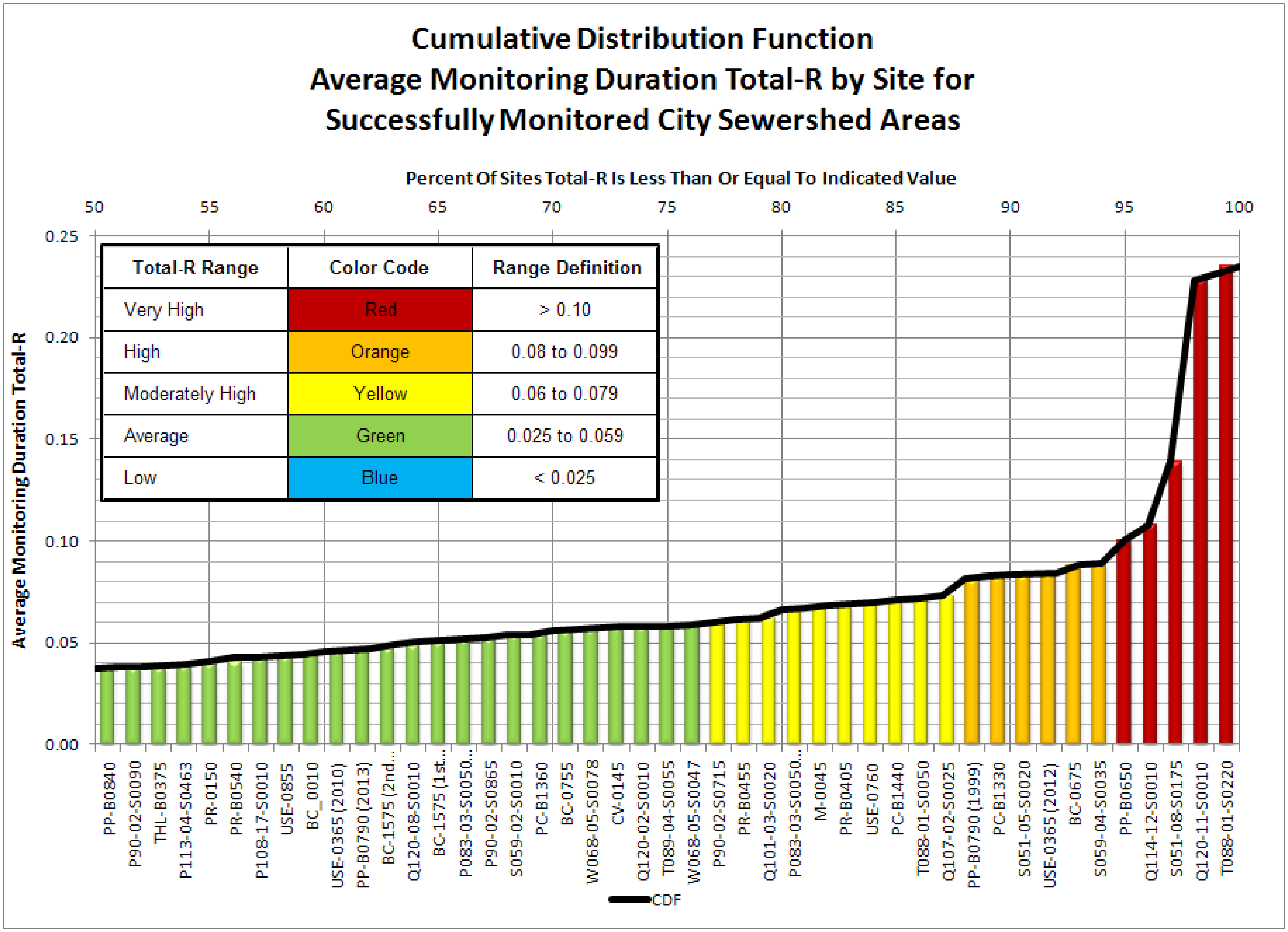


Figure 4-16: CDF of Average Monitoring Duration Total-R by Site (identifying individual monitoring sites)

This third alternative analysis approach differs from the second in that its focus goes beyond the worst 3 month season with the highest RDII volumes, and extends to the entire monitoring period. The CDF inflection point indicates that when considering the largest magnitude of monitored flow, for all the successfully monitored storms extending over the entire monitoring duration, the sewershed areas with a maximum annual average total R-value of 0.080, (where 8.0% of the sewershed rainfall entered the sanitary sewer collection system,) or higher (the designated orange and red ranges) would be considered to have the highest relative volume of monitored RDII flow.

Site Average Five Largest Storm Peaking Factor

For the fourth and final RDII analysis approach, a CDF analysis and plot were prepared for the average of the calculated peaking factors for the five storms with the highest monitored peak flows, grouped together over each individual sewershed area. The peaking factor is the maximum hourly monitored flow during a storm event, divided by the average daily dry weather flow for the monitored sewershed area and represents the magnitude of the increase of RDII flow during large storms, compared to the magnitude of flow occurring during typical dry weather conditions. The five largest storm average peaking factor for each of the 81 analyzed City sewershed areas was represented by a point along the CDF curve, from the sewershed with the lowest average peaking factor to the sewershed with the highest average peaking factor.

The CDF plot for the fourth RDII analysis approach is provided in Figure 4-17. The red range included the individual City sanitary sewershed areas with very high monitored average peaking factors (above 12). The orange range was comprised of sewershed areas with high values (from 10 to 11.9), and the yellow range encompassed sewershed areas with moderately high values (7.0 to 9.9). Sewershed areas with average and low R-values, indicating relatively tight sewer collection systems, were color-coded green and blue, respectively. Figure 4-18 provides the upper ranges from the same CDF curve and indicates the corresponding sewershed names for each point along the CDF curve. The median or 50th percentile average five largest storm peaking factor over all the analyzed City sewershed areas was 4.5. A clear inflection point, or knee-of-the-curve along the CDF line, can be observed at a peaking factor of 10.

This fourth and final alternative analysis approach differs from the other three in that it assesses the severity of RDII flow based upon a peak wet weather flow multiplier, rather than an RDII percentage. The analysts took into consideration that the hourly averaging process for quantifying peak flow would have a greater effect on the smallest sewershed areas than on the largest. The analysts were also careful to consider that the peaking factor itself can be dependent on the size of the tributary drainage area. The CDF inflection point indicates that when considering the largest magnitude of monitored extraneous flow, for the five storms with the highest monitored peak flows, grouped together over each individual sewershed area, the sewershed areas with an average peaking factor of 10 or higher (the designated orange and red ranges) would be considered to have the highest relative volume of monitored RDII flow.

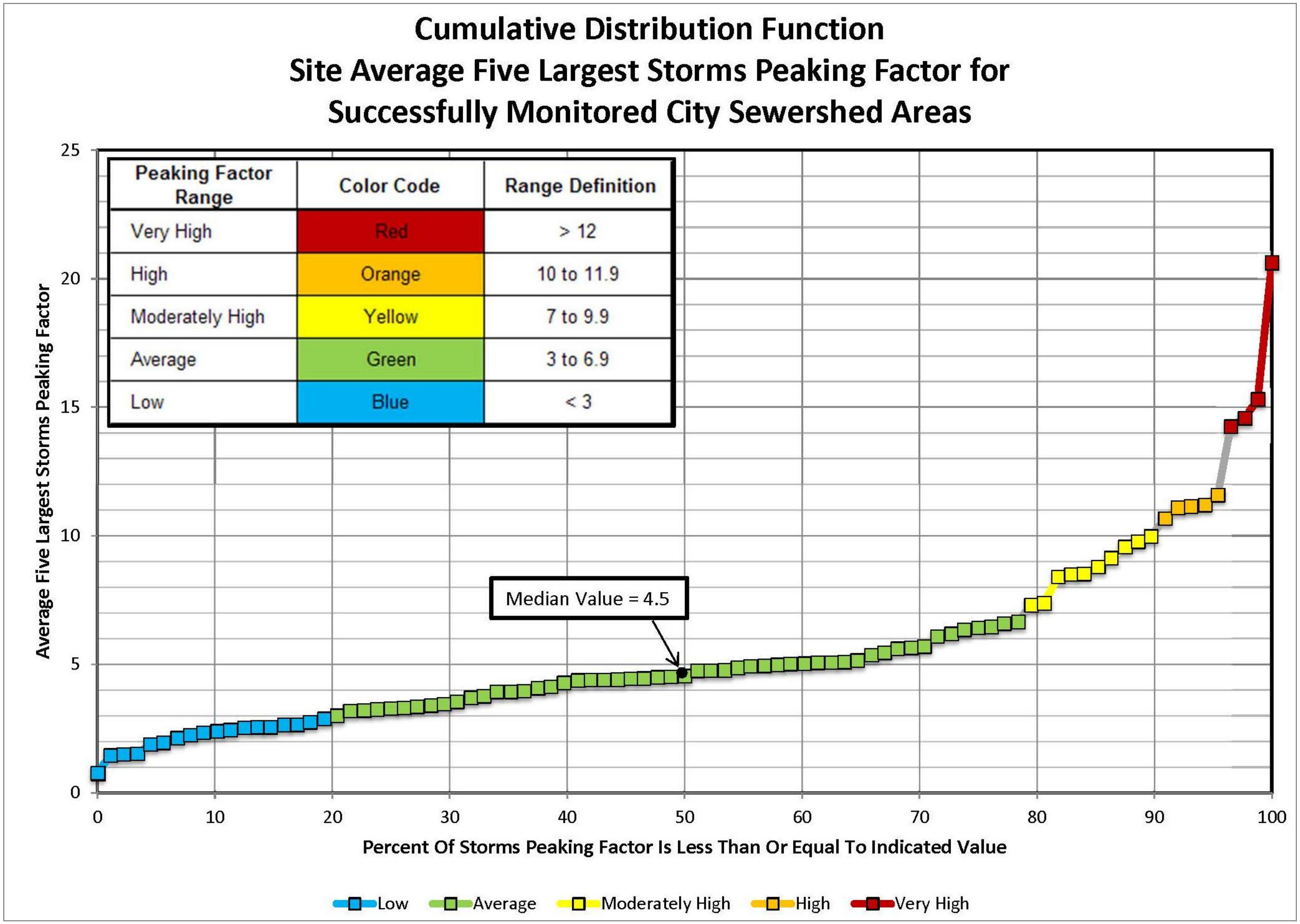


Figure 4-17: CDF of Site Average Five Largest Storms Peaking Factor

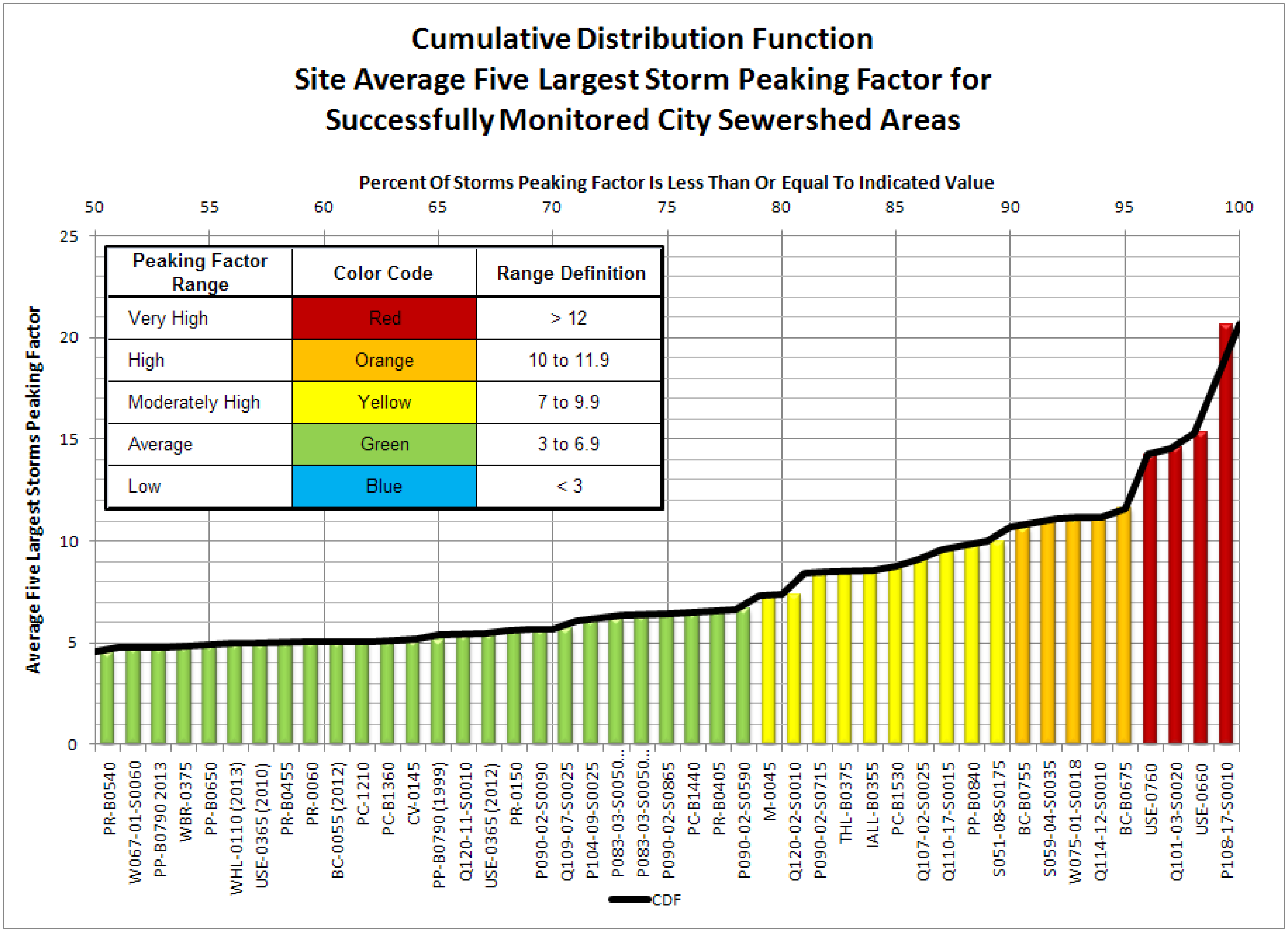


Figure 4-18: CDF of Site Average Five Largest Storms Peaking Factor (identifying individual monitoring sites)

4.3.5 Wet Weather Flow Analysis Conclusions

The completed Phase 2 SSES analysis was successful in identifying specific sanitary sewershed areas within the City of Philadelphia where the quantity of rainfall dependent infiltration and inflow was very high relative to the rest of the system. These very high RDII values could be an indication of a leaky wastewater collection system where RDII reduction efforts could result in significant benefits. Lists are provided below of the specific sewershed areas that were identified as being the leakiest by the application of each of the four alternative analysis methods that were utilized for the SSES. The sites are listed from the highest monitored RDII values to the lowest. Table 4-5 provides a summary of the analysis results produced by each of the completed dry weather and wet weather analyses.

Maximum Five Storm Average Total R-Value by Site

There were 5 sewershed areas within the City of Philadelphia where the maximum five storm average total R-value, calculated from the monitored wastewater flow data, was greater than 0.26, (where 26% of the sewershed rainfall entered the sanitary sewer collection system,) and that were classified as very high (red range along the CDF plot). The locations of these 5 City sewersheds are provided on the Figure 4-19 map. Three of these sites had monitoring durations of approximately 12 months and the other two had monitoring durations of approximately 10 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.

- Monitoring Site Q120-11-S0010 that is tributary to the Poquessing Creek Interceptor
- Monitoring Site T088-01-S0220 that is tributary to the Tacony Creek High Level Interceptor
- Monitoring Site S051-08-S0175 that is tributary to the Upper Schuylkill River East Side Interceptor
- Monitoring Site BC-0675 that is tributary to the Byberry Creek Interceptor
- Monitoring Site USE-0760 that is tributary to the Upper Schuylkill River East Side Interceptor

There were 3 sewershed areas within the City of Philadelphia where the maximum five storm total R-value, calculated from the monitored wastewater flow data, was between 0.17 and 0.259 and classified as high (orange range along the CDF plot). All three sites had monitoring durations of at least 12 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 4 City sewersheds are provided on the Figure 4-19 map.

- Monitoring Site PC-B1330 that is tributary to the Poquessing Creek Interceptor
- Monitoring Site Q114-12-S0010 that is tributary to the Byberry Creek Interceptor
- Monitoring Site T088-01-S0050 that is tributary to the Tacony Creek High Level Interceptor. The tributary sewershed has areas both inside and outside the City limits.

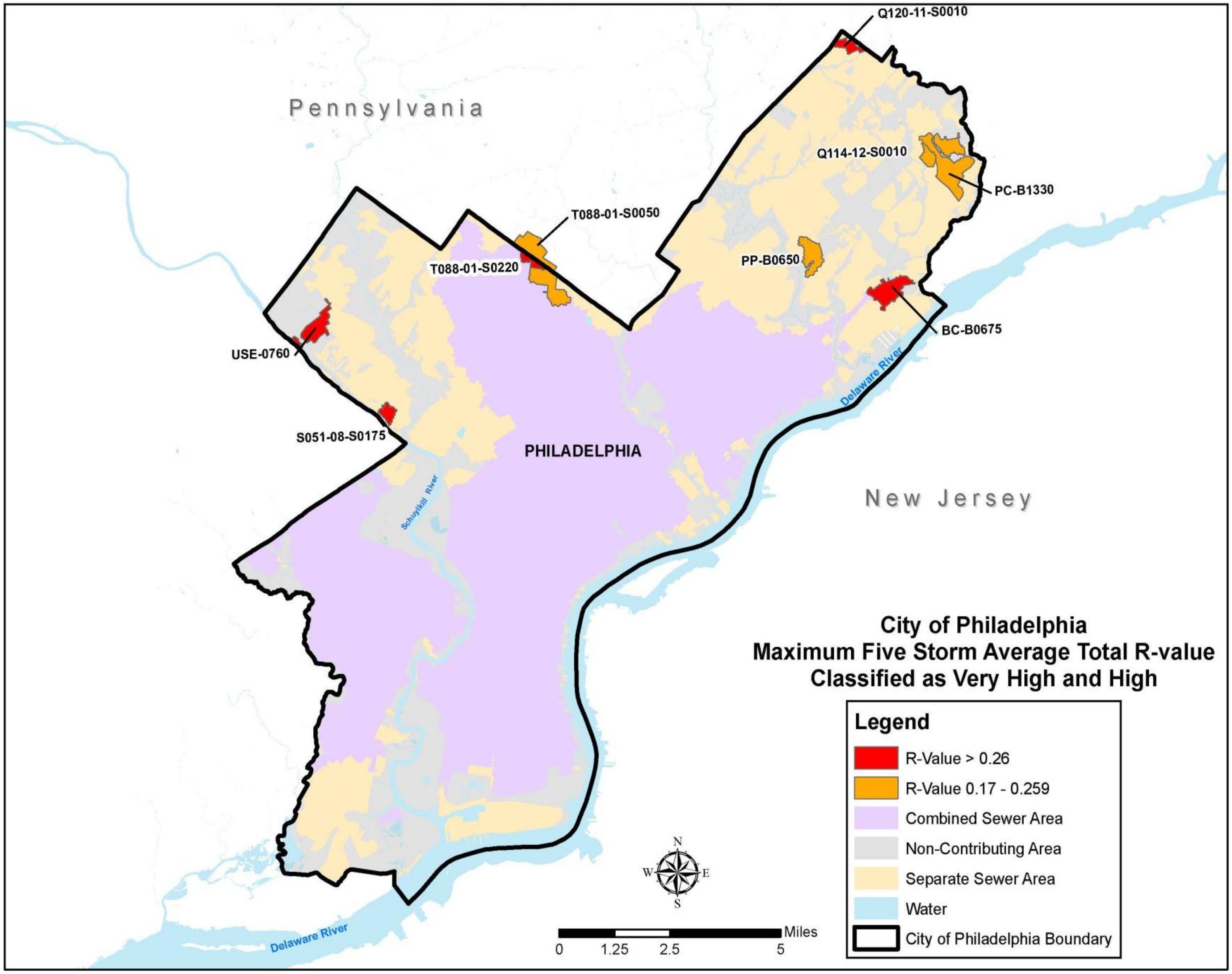


Figure 4-19: Identified Sanitary Sewershed Areas with the Highest RDII Flow – Maximum Five Storm Average Total R-Value Analysis Method

Maximum Seasonal Average Total R-Value by Site

There were 4 sewershed areas within the City of Philadelphia where the maximum seasonal average total R-value, calculated from the monitored wastewater flow data, was greater than 0.16, (where 16% of the sewershed rainfall entered the sanitary sewer collection system,) that were classified as very high (red range along the CDF plot). The locations of these 4 City sewersheds are provided on the Figure 4-20 map. All four of these sewershed areas were also identified as having a maximum five storm average total R-value that was considered to be very high.

- Monitoring Site Q120-11-S0010 that is tributary to the Poquessing Creek Interceptor. The monitoring duration was approximately 12 months which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.
- Monitoring Site T088-01-S0220 that is tributary to the Tacony Creek High Level Interceptor. The monitoring duration was approximately 10 months which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.
- Monitoring Site S051-08-S0175 that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was approximately 7 months, including the typically wetter winter and spring seasons, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.
- Monitoring Site USE-0760 that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was approximately 12 months which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.

There were 5 sewershed areas within the City of Philadelphia where the maximum seasonal average total R-value was between 0.11 and 0.159 and classified as high (orange range along the CDF plot). Four of the five sites had monitoring durations of at least 12 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 4 City sewersheds are provided on the Figure 4-20 map. All five of these sewershed areas were also identified as having a maximum five storm average total R-value that was considered to be high or very high.

- Monitoring Site Q114-12-S0010 that is tributary to the Byberry Creek Interceptor.
- Monitoring Site PC-B1330 that is tributary to the Poquessing Creek Interceptor.
- Monitoring Site BC-0675 that is tributary to the Byberry Creek Interceptor.
- Monitoring Site PP-B0650 that is tributary to the Pennypack Creek Interceptor. The monitoring duration was approximately 9 months, including the typically wet winter and spring seasons, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year.
- Monitoring Site T088-01-S0050 that is tributary to the Tacony Creek High Level Interceptor.

Figure 4-20: Identified Sanitary Sewershed Areas with the Highest RDII Flow – Maximum Seasonal Average Total R-Value Analysis Method

Average Monitoring Duration Total R-Value by Site:

There were 5 sewershed areas within the City of Philadelphia where the average total R-value over the duration of the monitoring period was greater than 0.10 and classified as very high (red range along the CDF plot). For three of the five sites, the monitoring duration was 10 to 12 months which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The other two sites had monitoring durations of 7 to 9 months, including the typically wet winter and spring seasons, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 5 City sewersheds are provided on the Figure 4-21 map. All 5 of these sewershed areas were also identified as having both a maximum five storm average total R-value and a seasonal average total R-value that were considered to be either high or very high. This confirms that all 5 of these identified sewershed areas contribute relatively high RDII flow to the sanitary sewer system, irrespective of the alternative analysis method that was utilized.

- Monitoring Site T088-01-S0220 that is tributary to the Tacony Creek High Level Interceptor.
- Monitoring Site Q120-11-S0010 that is tributary to the Poquessing Creek Interceptor
- Monitoring Site S051-08-S0175 that is tributary to the Upper Schuylkill East Side Interceptor
- Monitoring Site Q114-12-S0010 that is tributary to the Byberry Creek Interceptor
- Monitoring Site PP-B0650 that is tributary to the Pennypack Creek Interceptor

There were 6 sewershed areas within the City of Philadelphia where the average total R-value, calculated from the monitored wastewater flow data, was between 0.080 and 0.099 and classified as high (orange range along the CDF plot). Four of the six sites had monitoring durations from 12 to 15 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 5 City sewersheds are provided on the Figure 4-21 map. Two of these sites, BC-0675 and PC-B1330, were also identified as being potentially problematic using the two other alternative analysis methods. This confirms that these two identified sewershed areas contribute relatively high RDII flow to the sanitary sewer system, irrespective of the alternative analysis method that was utilized.

- Monitoring Site S059-04-S0035 that is tributary to the Upper Schuylkill East Side Interceptor
- Monitoring Site BC-0675 that is tributary to the Byberry Creek Interceptor
- Monitoring Site USE-0365 (2012) that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was approximately 4 months which may or may not provide sufficient data to characterize the sewershed area flow.

Figure 4-21: Identified Sewershed Areas with the Highest RDII Flow – Average Monitoring Duration Total R-Value Analysis Method

- Monitoring Site S051-05-S0020 that is tributary to the Upper Schuylkill East Side Interceptor. The monitoring duration was approximately 2 months, during the typically wet spring season, which may or may not provide sufficient data to characterize the sewershed area flow. Monitoring Site PC-B1330 that is tributary to the Poquessing Creek Interceptor
- Monitoring Site PP-B0790 (1999) that is tributary to the Pennypack Creek Interceptor

Site Average Five Largest Storms Peaking Factor

There were 4 sanitary sewershed areas within the City of Philadelphia where the average five largest storm peaking factor, calculated from the monitored wastewater flow data, was greater than 12 and classified as very high (red range along the CDF plot). The four sites had monitoring durations from 12 to 14 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 4 City sewersheds are provided on the Figure 4-22 map.

The analysts were careful to consider that the hourly averaging process for quantifying peak flow would have a greater effect on the smallest sewershed areas than on the largest. However, the four identified sewersheds all have relatively small tributary areas, ranging from 62 acres to 181 acres. Despite the attenuating effects induced by the averaging process, these four sewershed areas still produced the largest peaking factors observed within the City. The analysts were also careful to consider that the peaking factor can itself be dependent on the size of the tributary drainage area. These potential concerns were regarded to be acceptable because peaking factors were only one of several analysis methods for identifying sewershed areas with high RDII flows. Leaky sewershed areas were also identified using the R-value analysis method, which is not area biased.

Three of these four sites were not previously identified as relatively high RDII areas from the other three alternative analysis methods. However, the USE-0760 sewershed area was also identified as having both a maximum five storm average total R-value and a maximum seasonal average total R-value that were considered to be very high. This confirms that this sewershed area contributes relatively high RDII flow to the sanitary sewer system, irrespective of the alternative analysis method that was utilized.

- Monitoring Site P108-17-S0010 that is tributary to the Paul's Run Interceptor
- Monitoring Site USE-0660 that is tributary to the Upper Schuylkill East Side Interceptor
- Monitoring Site Q101-03-S0020 that is tributary to the Byberry Creek Interceptor
- Monitoring Site USE-0760 that is tributary to the Upper Schuylkill East Side Interceptor

Figure 4-22: Identified Sewershed Areas with the Highest RDII Flow – Site Average Five Largest Storm Peaking Factor Analysis Method

There were 5 sewershed areas within the City of Philadelphia where the average five largest storm peaking factor, calculated from the monitored wastewater flow data, was between 10 and 11.9 and classified as high (orange range along the CDF plot). Four of the 5 sites had monitoring durations from 10 to 15 months, which should provide sufficient data to characterize the sewershed area flow for all seasons of the year. The locations of these 5 City sewersheds are provided on the Figure 4-22 map. Two of these five sites were not previously identified as relatively high RDII areas in the other three alternative analysis methods. However, the BC-B1330 and the Q114-12-S0010 sewershed areas were also identified as having a maximum five storm average total R-value, a maximum quarter total R-value and an average annual total R-value that were all considered to be high or very high. This confirms that these sewershed areas contribute relatively high RDII flow to the sanitary sewer system, irrespective of the alternative analysis method that was utilized. The Site S059-04-S0035 sewershed area was identified as having an average annual total R-value that was considered to be high, providing confirmation using an alternative analysis method.

- Monitoring Site BC-B0675 that is tributary to the Byberry Creek Interceptor
- Monitoring Site Q114-12-S0010 that is tributary to the Byberry Creek Interceptor
- Monitoring Site W075-01-S0018 that is tributary to the Wissahickon Creek High Level Interceptor. The monitoring duration was approximately 1 month, which may or may not provide sufficient data to characterize the sewershed area flow.
- Monitoring Site S059-04-S0035 that is tributary to the Upper Schuylkill East Side Interceptor
- Monitoring Site BC-B0755 that is tributary to the Byberry Creek Interceptor

4.3.6 Flow Characterization Analysis Results

This section presents the results of the completed SSES Phase 2 flow characterization analyses that were conducted for the successfully monitored City sewershed areas. Table 4-5 provides a summary overview of all the individual City of Philadelphia sanitary sewershed areas that were identified, using the four alternative wet weather flow analysis methods and one dry weather flow analysis method (described previously in Sections 3.5 and 4.2.) A numeric ranking system was implemented in order to incorporate all 5 of the completed analysis methods into the process of identifying the City sewershed areas contributing the greatest amounts of extraneous rainfall dependent infiltration and inflow and groundwater infiltration. A point system was applied to each of the CDF plot ranges.

- 5 points: very high RDII, peaking factor or GWI; red range along the CDF curve
- 4 points: high RDII, peaking factor or GWI; orange range along the CDF curve
- 3 points: moderately high RDII; peaking factor or GWI, yellow range along the CDF curve

Points were not assigned when the sewershed RDII, peaking factor or GWI value was determined to be average (green range along the CDF curve) or low (blue range along the CDF curve.) The total points from each alternative analysis method were added together for each of the identified City sewershed areas. The sewersheds are listed in order from those with the highest assessment score (and the leakiest sewer collection systems) to those with the lowest score (and the relatively less leaky sewer systems). The point system gives 80% weighting to RDII quantities and 20% weighting to GWI. The rationale behind this weighting was that RDII reductions generally have a more significant impact on reducing the frequency, duration and volume of CSO discharges.

The table provides the number of storms that were successfully monitored and analyzed in each of the sewershed areas and the number of seasons that were covered by the monitoring duration. This information indicates the relative amounts of analysis data that was available to make the determination that sewers in the sewershed were leaky. The table also provides the sewershed area that was tributary to the monitoring sitebecause peaking factors can be dependent on the size of the tributary drainage area and the hourly averaging process for quantifying peak flow would have a greater effect on smaller sewershed areas than larger ones.

It is important to note that just because a sewershed area was identified as conveying a relatively high RDII and/or GWI volume does **not** necessarily indicate that sewer rehabilitation is recommended. It also needs to be understood that if a sewershed is identified as having relatively high RDII and/or GWI volumes, it does **not** indicate that all the collection sewers within the entire sewershed area tributary to the monitoring site would need to be rehabilitated. There may be a combination of some very leaky subareas along with some acceptably tighter areas.

A similar SSES and report will be prepared to collect, assess and analyze the monitoring data available from the interconnect points between the outside community sewer collection systems and the Water Department trunk sewer and interceptor conveyance system. This SSES, identified as the *Outlying Communities Report* in the *Implementation and Adaptive Management Plan*, will quantify and characterize dry and wet weather flow from the outside communities and identify any sewershed areas that contribute a relatively high amount of extraneous RDII or GWI flow. This *Outlying Communities Report* is scheduled to be submitted to the regulatory agencies by June 1, 2015.

Table 4-5: Identification and Ranking of Sewershed Areas with the Highest Monitored RDII and GWI

Sewershed Name	Interceptor System Receiving the Sewershed Flow	Sewershed Area (acres)	Number of Storms Analyzed	Number of Seasons Analyzed	Wet Weather Analysis Method 1 Maximum 5 Storm Average Total R-Value	Wet Weather Analysis Method 2 Maximum Seasonal Average Total R-Value	Wet Weather Analysis Method 3 Average Annual Total R-Value	Wet Weather Analysis Method 4 Site Average 5 Largest Storms Peaking Factor	Dry Weather Analysis Method GWI Ratio	Total Composite RDII and GWI Score
T088-01-S0220	Tacony Creek High Level	62	67	4	Very High 5 points	Very High 5 points	Very High 5 points		Very High 5 points	20
S051-08-S0175	Upper Schuylkill River East Side	68	30	3	Very High 5 points	Very High 5 points	Very High 5 points	Moderately High 3 points		18
S059-04-S0035	Upper Schuylkill River East Side	141	62	5	Moderately High 3 points	Moderately High 3 points	High 4 points	High 4 points	High 4 points	18
USE-0760	Upper Schuylkill River East Side	184	52	5	Very High 5 points	Very High 5 points	Moderately High 3 points	Very High 5 points		18
BC-0675	Byberry Creek	230	59	4	Very High 5 points	High 4 points	High 4 points	High 4 points		17
Q114-12-S0010	Byberry Creek	68	78	5	High 4 points	High 4 points	Very High 5 points	High 4 points		17
Q120-11-S0010	Poquessing Creek	81	65	5	Very High 5 points	Very High 5 points	Very High 5 points			15
S051-05-S0020[(1)]	Upper Schuylkill River East Side	90	15	2	Moderately High 3 points	Moderately High 3 points	High 4 points		Very High 5 points	15[(1)]
Q101-03-S0020	Byberry Creek	112	56	5	Moderately High 3 points	Moderately High 3 points	Moderately High 3 points	Very High 5 points		14
USE-0365	Upper Schuylkill River East Side	773	66	5	Moderately High 3 points	Moderately High 3 points	High 4 points		High 4 points	14
PP-B0650	Pennypack Creek	181	35	4	Moderately High 3 points	High 4 points	Very High 5 points			12
PC-B1330	Poquessing Creek	478	78	4	High 4 points	High 4 points	High 4 points			12
T088-01-S0050	Tacony Creek High Level	497	71	5	High 4 points	High 4 points	Moderately High 3 points			11

Sewershed Name	Interceptor System Receiving the Sewershed Flow	Sewershed Area (acres)	Number of Storms Analyzed	Number of Seasons Analyzed	Wet Weather Analysis Method 1 Maximum 5 Storm Average Total R-Value	Wet Weather Analysis Method 2 Maximum Seasonal Average Total R-Value	Wet Weather Analysis Method 3 Average Annual Total R-Value	Wet Weather Analysis Method 4 Site Average 5 Largest Storms Peaking Factor	Dry Weather Analysis Method GWI Ratio	Total Composite RDII and GWI Score
PP-B0790	Pennypack Creek	187	70	6	Moderately High 3 points	Moderately High 3 points	High 4 points			10
IALL-B0355	Island Avenue Low Level	214	88	5				Moderately High 3 points	Very High 5 points	8
USE-0855	Upper Schuylkill River East Side	171	66	5	Moderately High 3 points				Very High 5 points	8
M-0045[(2)]	Monoshone Creek	868	22	2			Moderately High 3 points	Moderately High 3 points	[(2)]	6
CV-0145	Cresheim Creek	882	42	3					Very High 5 points	5
P108-17-S0010	Paul's Run	79	56	4				Very High 5 points		5
USE-0660	Upper Schuylkill River East Side	246	46	4				Very High 5 points		5
BC-B0755	Byberry Creek	275	31	2				High 4 points		4
WHL-0110	Wissahickon Creek High Level	1834	86	7					High 4 points	4
W075-01-S0018[(3)]	Wissahickon Creek High Level	141	11	1				High 4 points	[(3)]	4
W086-01-S0060	Cresheim Creek	225	4	1					High 4 points	4

[(1)]Note: The analysis results for this monitoring site were based on only 2.2 months of data and analysis results for this sewershed area should be used with caution.

[(2)]Note: The biased precipitation during the brief monitoring period could potentially make the sewershed appear to have a higher average GWI volume than it should under normal precipitation conditions. Because of the short monitoring duration and the biased precipitation, the dry weather flow analysis results for this sewershed area should be used with caution.

[(3)]Note: The two month monitoring duration had biased precipitation that could potentially make the sewershed appear to have a higher average GWI volume than it should under normal precipitation conditions. Therefore the dry weather analysis results for this sewershed area should be considered to be unrepresentative and invalid.