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Patapsco Sewershed Evaluation Study Plan
Project #1041

Infiltration and Inflow Report

Sanitary Sewer Overflow Consent Decree
Civil Action No. JFM-02-1524

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Site Reports of all flow meters
Yearly hydrograph of every flow monitoring site
Yearly scattergraph of every flow monitoring site
Q vs. I graph (RDII volume/rain volume) at every flow monitoring site
Flowload database from Sliicer.com

Infiltration and Inflow (I&I) Evaluation Report

Executive Summary

As part of Baltimore City Project No. 1041, Whitman, Requardt & Associates, LLP has conducted an analysis of infiltration and inflow (I&I) into the City's sewer collection system within the Patapsco sewershed. This report provides the results of the I&I evaluation.

To fully understand the dynamics of the sewage collection system, the City completed a detailed City-wide flow monitoring program. The monitoring program consisted of over 350 flow monitors throughout the City, with 17 of the meters located within the Patapsco sewershed, from May 9, 2006 to May 18, 2007. Some meters deemed long term meters have stayed in place. In addition to the flow monitors, 20 rain gauges were installed throughout the City with some gauges installed outside of the City limits.

Sliicer is a tool developed by ADS Environmental Services, Inc. to analyze flow and rainfall data collected from the flow monitors and help find the locations of the most severe inflow/infiltration problems in a sanitary sewer collection system.

Base Infiltration (BI) is the extraneous flow in a sewer system during dry weather. Because BI enters the sewer system at pipe joints, holes, or other breaks in the pipe, the volume of BI is heavily dependent on the diameter and length of sewer. When comparing different areas to determine the severity of BI, looking at volume of flow alone is not sufficient. BI needs to be normalized to provide an accurate comparison. For this project, BI was normalized based on inch-diameter-miles (IDM) of sewer, which takes into account the length and size of the sewers being considered.

Rainfall Dependent Infiltration/Inflow (RDII) is the component of wastewater flow that is influenced by wet weather. As with BI, RDII needs to be normalized to allow for a realistic comparison between different sewershed areas. For this project, RDII was normalized based on linear footage of sewer main (gal/1.f./in-of-rain). A graphical technique for evaluating and comparing the performance of sewershed basins under widely varying rain events is the Q (I&I volume) vs. I (rainfall intensity) diagram. The slope (S) of the regression line on the Q vs. I plot was used to obtain the capture coefficient (R). A total of 29 storms during the metering period met the criteria for a storm event as defined by the global setting. These storms were used in the wet weather analyses.

Flow Monitoring Basin PA02, measured by flow monitor TSPA03, had the highest base infiltration severity at 14,143 gpd/IDM, which represents 59.2% of the average dry flow (ADF). Flow monitor TSPA03 is at the bottom of the Patapsco Sewershed. It receives pumped flow that originates from the Brooklyn Pumping Station, and may also be affected by wetwell levels in the Patapsco WWTP Influent Pumping Station. Although these concerns may exaggerate the amount of BI, the effect is difficult to quantify. Flow Monitoring Basins PA01 and PA09 were both over 6200 gpd/IDM, with 90.9% and 63.0%, respectively, of the ADF in these basins being Base Infiltration. Eight basins had BI over 4600 gpd/IDM.

Within the Patapsco sewershed in the City, the basin with the lowest base infiltration severity is PA06, with only 840 gpd/IDM representing 15.2% of the ADF. Sub-sewershed BPA03 from Anne Arundel County has the lowest calculated BI severity at 570 gpd/IDM.

The average BI percentage of all basins is 42.6% of ADF.

The base infiltration coming from the three Anne Arundel County sub-sewersheds with flow monitors is 27.3, 37.5 and 19.0 percent of the average daily flow computed from the metering data. All of these values are below the average BI rate of 42.6%, indicating that Anne Arundel County is not a significant source of severe base infiltration.

The basin with the highest RDII severity is PA02, which is measured by flow monitor TSPA03 located on the Patapsco Interceptor Sewer just upstream of the Patapsco Wastewater Treatment Plant. There are a total of five basins which have a normalized RDII value greater than 10 gallons per linear foot per inch of rainfall.

The sub-sewershed with the lowest RDII severity is PA10. Sub-sewershed PA08 also had a relatively low rate of RDII.

The scattergraphs were reviewed to assess the hydraulic performance of the collection system. Flow monitors PA03, PA05, PA05A, PA06, PA07 and PA08 showed no surcharging occurred during the metering period. Meters PA04, PA09, PA10 and PA12 experienced infrequent surcharging, usually less than 24-inches above the crown of the pipe. PA11 experienced the largest surcharging with a maximum depth of approximately 8.5 feet. PA02, measured by meter TSPA03, had surcharges as high as three feet. The meter with the most frequent surcharging was PA01, although these were less than three feet.

Based on a review of both the dry weather, BI severity, and the wet weather, RDII severity, sub-sewersheds PA02 (TSPA03), PA05, PA01, PA05A, PA12, PA03 and PA11 would be the highest priority basins for further investigations, such as smoke testing, and possible future rehabilitation and repair to remove extraneous flow. Additional investigations in PA02 and PA05 will help determine if the calculated BI and RDII are as severe as predicted, or whether the high values are the results of pumping station interference or relatively low Q_{net}/Q_{gross} percentages.

1.0 Introduction

1.1 Sewershed Description

The Patapsco sewershed is located at the far southern end of Baltimore City, south and southeast of the Patapsco River at the boundary between the City and Anne Arundel and Baltimore Counties. The Patapsco sewershed consists of approximately 5,000 acres of land with 1744 manholes or other wastewater structures, and 313,282 feet of sanitary sewers that drain to the Patapsco Wastewater Treatment Plant. Of that total, 12,975 feet of sewers lie in sub-sewershed PA-13, which drains to the Westport Pumping Station, which then discharges into the Southwest Diversion. The sewers and manholes in PA-13 are not a part of the Patapsco Sewershed evaluation, but are included in the Gywnn's Falls sewershed study, Project #1032. The sanitary sewers in the Patapsco sewershed range in size from 4 to 64 inches. The largest sewer is the central trunk sewer, known as the Patapsco Interceptor. The interceptor receives pumped flow from the Brooklyn Pumping Station, just east of Hanover Street and north of Frankfurst Avenue, and flows southeasterly to the Patapsco Wastewater Treatment Plant at Wagner's Point. The interceptor is a cast in place concrete and tile box sewer, square, rectangular, or arched in cross section, ranging in size from 24 by 24 inches to 54 by 64 inches. See Figure 1 for an overview of the sewershed and its major sewer lines and features.

There are two major pumping stations located within the sewershed, the Patapsco WWTP Influent Pumping Station and the Brooklyn Pumping Station. The Patapsco influent pumping station lifts wastewater from the so called low level system into the treatment facility. All of the flow in the Patapsco interceptor, as measured by trunk sewer flow monitor TSPA03, as well as flow from a 24-inch sewer in Asiatic Avenue, measured by flow monitor PA01, enters the Patapsco WWTP and is pumped by the influent pumps in the Pump and Blower Building to the treatment processes. The Brooklyn pumping station receives flow from the Cherry Hill neighborhood to the west, through a 30-inch influent sewer, measured by flow monitor PA10, that crosses the Patapsco River, as well as from the southwestern section of Brooklyn, through a 27-inch influent sewer in Hanover Street, which is measured by flow monitor PA09. There is also a small pumping station at Hawkin's Point that currently pumps only leachate collected from the Quarantine Road landfill through a 10/12-inch force main into the Patapsco sewerage system at Benhill and Curtis Avenues. In the future, a new pumping station may collect and pump domestic wastewater from proposed development in the Hawkin's Point area. The Patapsco Plant receives most of its wastewater flow from the Southwest Diversion, which is an 84-102 inch pressure sewer that traverses the entire width of the Patapsco sewershed. The Southwest Diversion contains flow transferred from the Gywnn's Falls sewershed in southwestern Baltimore City, as well as flow from Baltimore County. Although the Southwest Diversion is located in the Patapsco sewershed, it does not intercept any wastewater generated in the sewershed, with the exception of PA-13, as

noted above. The Patapsco sewershed also receives flow from Anne Arundel County at three metered locations along the City/County boundary, namely BPA01, BPA02 and BPA03, and an unmetered location at Church Street and Muriel Avenue.

The major water bodies in the area are Curtis Bay, which borders the sewershed on the south and east, and the Patapsco River which crosses through the sewershed just north and west of the Brooklyn pumping station. The Patapsco sewershed includes the residential neighborhoods of Cherry Hill, Brooklyn, Curtis Bay and Brooklyn Manor, as well as the industrial areas of Fairfield and Wagner's Point. The industrial areas include heavy industries such as oil and chemical refineries, petroleum and chemical storage tanks, warehousing and manufacturing facilities. In addition, the CSX Curtis Bay Yard and CSX Coal and Ore piers add to the heavy industrial and rail activity in the sewershed. Although there is an extensive industrial presence in the area, there are also large tracts of residential areas. Although most of the waterfront properties are now in industrial/commercial use, redevelopment along waterfront areas could bring increased population and wastewater flows compared to the current land uses.

1.2 Objectives of the Study

The City established two main objectives for the Comprehensive Flow Monitoring Program:

1. Collect accurate rainfall and flow data – The program would accomplish this goal by requiring:
    - The use of the latest metering technology and Doppler radar rainfall measurement.
    - Daily data collection using wireless communication, which identifies equipment malfunctions sooner and, therefore, maximizes rainfall and flow data availability.
    - A multiple-tier data processing and data quality assurance by the service providers and the City.

2. Standardize the I&I evaluation – This goal would be accomplished by:
    - Establishing standard I&I evaluation parameters and definitions for the use of all Sewershed Consultants.
    - Requiring all Sewershed Consultants to use standard I&I evaluation software (Sliicer.com®, a registered trademark of ADS Corporation).

1.3 Recently Completed Sanitary Projects

Unlike other sewersheds in the City, the Patapsco sewershed did not have any so-called paragraph 8 projects. This refers to paragraph 8 of the City's Consent Decree with EPA and MDE, which required a number of design and construction projects to eliminate sanitary sewer overflows into the waters of the State. Other than maintenance type projects such as point repairs or relining of sewers, and an occasional Developer Agreement (DA) project where developers build City sewers as a condition of their development approval process, there have not been any recent major sanitary sewerage system improvements in the Patapsco sewershed. After the flow monitoring period ended, the force main from the Brooklyn Pumping Station was replaced, but this was not a section 8 project. At the Patapsco Wastewater Treatment Plant, there have been a number of treatment process improvements, and there have been repairs made to the Southwest Diversion; however, as noted above, there have not been sanitary projects in the Patapsco sewershed that have altered the capacity of the collection system.

1.4 BaSES Manual Requirements

The Baltimore Sewer Evaluation Standards (BaSES) Manual, developed by the City for the sewershed studies, establishes guidelines to be followed for the I&I analyses in all city sewersheds and outlines additional requirements to be included in the sewershed studies.

2.0 Flow Monitoring Program

2.1 Overall Description

To fully understand the dynamics of the sewage collection system, the City completed a detailed City-wide flow monitoring program. The program consisted of flow meters within the City's collection system and rain gauges spread throughout the City and Baltimore County. The monitors measured depth and velocity, from which flow was calculated at five minute intervals. The monitoring program consisted of over 350 flow monitors City-wide, with 21 of the meters located within the Patapsco sewershed from May 9, 2006 to May 18, 2007. Of the 21 meters, 13 are at the low points of each of the sub-sewershed areas. One is in sub-sewershed PA-13, which, as previously explained, flows to the Westport Pumping Station and is not a part of the Patapsco collection system evaluation, and another is the flow meter in the Westport pumping station. Among the other six meters, three measure flow coming into the Patapsco system from Anne Arundel County, two are on the Southwest Diversion, which does not contain wastewater from the Patapsco sewershed, and one measures the discharge from the Brooklyn pumping station. Of the 21 meters physically within the Patapsco sewershed, 17 measure flow that is included in the scope of the Patapsco sewershed study. Some meters deemed long term meters have stayed in place. See Table 1 below for a list of meters, their sub-basin, and primary purpose, and Figure 2 for a location map of the meters and rain gauges. Figure 3 depicts a schematic of the flow monitoring plan. In addition to the flow monitors, 20 rain gauges were installed City-wide with some gauges installed outside of the City limits. All 20 rain gauges were utilized in conjunction with the generated radar rainfall for analysis. There are three rain gauges in the Patapsco sewershed. One is located at the Patapsco Wastewater Treatment Plant (PA01-RG), one is located in the western end of the sewershed in PA11 in Cherry Hill (PA03-RG), and one is in Baltimore County, southwest of the City line (PA02-RG).

TABLE 1 - LIST OF FLOW METERS

METER_ID	MANHOLE_ID	LOCATION	PURPOSE
BPA01 (LT)	S39E2_004MH	4116 Townsend Ave.	Model Calibration
BPA02 (LT)	S35Y1_026MH	59 Talbot St.	Model Calibration
BPA03 (LT)	S45K2_011MH	1525 Benhill Ave	Model Calibration
PA01 (LT)	S55A2_003MH	300 N. Northbridge on Asiatic Ave.	I&I Analysis/Model Calibration
PA03	S47K2_029MH	5014 Curtis Ave at Benhill Ave.	I&I Analysis/Model Calibration
PA04	S47G2_011MH	4512 Curtis Ave.	I&I Analysis/Model Calibration

PA05 (LT)	S49A2_002MH	1750 Patapsco Ave	I&I Analysis/Model Calibration
PA05A	S41U1_007MH	751 Frankfurst Ave.	Model Calibration
PA06	S43W1_015MH	3400 9th St.	I&I Analysis/Model Calibration
PA07	S41Y1_027MH	700 Pontiac Ave.	I&I Analysis/Model Calibration
PA08	S39U1_017MH	5th Street at Baltic Ave.	I&I Analysis/Model Calibration
PA09 (LT)	S37U1_028MH	3500 Hanover St. at Baltic Ave.	I&I Analysis/Model Calibration
PA10 (LT)	S33Q1_008MH	3200 Cherryland Road	I&I Analysis/Model Calibration
PA11	S33Q1_006MH	700 Reedbird Ave.	I&I Analysis/Model Calibration
PA12	S29U1_004MH	600 W. Patapsco Ave	I&I Analysis/Model Calibration
PA13 (LT)	S27G1_020MH	2900 Waterview Ave	*
PSBRO	S337S1_012PS	Hanover St. at Frankfurst Ave.	Model Calibration
PSWES	S27G1_022PS	Waterview Ave. att Cherry Hill Rd.	*
TSPA01(LT)	PATAPSCO	Patapsco WWTP	**
TSPA02	-	Chesapeake Ave. and 6th Street	**
TSPA03 (LT)	S55C2_006MH	In Easement South of Northbridge Ave.	I&I Analysis/Model Calibration

* Part of Gwynn's Falls (GF) Sewershed
** Trunk Sewer Meters on Southwest Diversion, Part of P9 GF SS

LT = long Term Meter that remained after the May, 2006 to May, 2007 assessment period

2.2 Summary Description of the Metering Network Within the Sewershed

The seventeen (17) flow-monitoring sites within the Patapsco Sewershed were utilized to develop dry and wet weather flows. The majority of the sites were installed for infiltration and inflow (I&I) evaluation, although several of these will aid in calibration of the hydraulic model. Five of the sites will primarily be used in the calibration of the hydraulic model. See Table 1 which lists the meters and their primary purpose. Using the City's Geographical Information System (GIS) the metering sites for I&I evaluation were selected at a meter density of approximately one for every 25,000 linear feet of sewer pipe. Figure 3 is a schematic of the flow metering network within the Patapsco Sewershed.

2.3 Flow Metering

2.3.1 Equipment Description

The meters used for the City-wide Flow Monitoring Program were depth-velocity meters designed to calculate flow based on measured depths and velocities in sanitary sewer pipes under free-flow and surcharged conditions. The primary depth sensor is ultrasonic with a resolution to the nearest 0.01 foot. The meters have level measurement redundancy, in the form of a pressure sensor, with accuracy of +/- .25 percent of full scale. The project required that the primary velocity sensor use Doppler technology, capable of measuring flow velocities in the range between -5 to +15 feet per second. The sensors were securely attached to the pipe by means of metal bands or anchoring hardware designed specifically for that purpose.

2.3.2 Installation

Every flow monitoring location was verified by the flow monitoring Contractor by performing a thorough site investigation, including descending the manhole. The hydraulic conditions at each site dictated the metering equipment selection and optimal sensor placement. If a location was deemed unsuitable for flow monitoring, the Contractor was required to coordinate with the City and to investigate up to two alternate sites for consideration. The Contractor also checked for debris in the manhole that could impact data quality. For each location the Contractor prepared and submitted an electronic site investigation report, which included a general site location map, a sketch of the installation, the physical characteristics (diameter or other measurements as necessary to define the pipe cross-section, material, etc.) of the sewer pipe in which the sensors would be installed, manhole depth, and other comments deemed pertinent by the Contractor. In addition, survey-grade GPS (Maryland State Plane, +/- 0.5 inch) coordinates, pipe inverts and rim elevations and three digital images of the site were required, including one showing the sensor installation. The site reports of all meters in the Patapsco Sewershed are included in a CD which is appended to this report.

The Contractor was required to evaluate the level of silt and debris at each monitoring location, and to provide sewer cleaning to ensure accuracy and reliability at each metering site. In the case of odd-shape pipes, or in sites where debris or sediment was present, the Contractor developed a profile to accurately determine the cross sectional area of the pipe at the depth measuring point. A typical flow monitor installation included the primary ultrasonic depth sensor mounted at the crown of the pipe, a redundant

depth sensor mounted in the invert, and a Doppler primary velocity sensor mounted in or near the invert of the pipe. All flow meters and rain gauges were synchronized in time to the same clock, and programmed to collect depth and velocity data at five (5) minute intervals.

Upon installation and activation of each flow meter, the Contractor took manual depth and velocity readings using independent instrumentation to confirm that the in-situ monitor yielded data representative of actual field conditions. The field crews were required to take manual velocity readings of the cross-section (velocity profile) of the flow in order to determine the pipe hydraulic profile.

2.4 Rainfall Measurement

The Contractor was required to measure the contribution from rainfall to all sewersheds within the City's jurisdictional boundary using a network of rain gauge stations with a minimum coverage of one (1) rain gauge station per ten (10) square miles, as well as data compiled by Doppler radar utilizing a minimum resolution of one (1) pixel per four (4) square kilometers. To measure the contribution from rainfall occurring in portions of the Collection System outside Baltimore City limits, the Contractor installed additional rain gauges in Baltimore County.

2.4.1 Equipment Description

The equipment consisted of a data logger able to accept data from an industry standard rain tipping bucket. The equipment was able to measure 0.1 inches (1mm) per tip of bucket. The tipping bucket consisted of a corrosion resistant funnel collector with tipping bucket assembly.

2.4.2 Installation

Most rain gauges were installed on the roof of public schools in the City and the County, and facilities owned by the City's Department of Public Works (such as pump stations and treatment plants).

2.4.3 Radar Rainfall

In accordance with the requirements of the Consent Decree, the City performed Doppler Radar Rainfall Analysis in conjunction with rain gauges at a resolution of 1 gauge for every 10 square miles. The Contractor utilized the CALAMAR software platform to process each recorded rainfall event with an average total depth of greater than 0.5 inches of rain. CALAMAR is a tool used to study the hydrologic impacts

of precipitation through a combination of radar images and a network of rain gauges installed over a geographic area. CALAMAR uses three databases: a radar image database, a rain gauge database and a geographical database. After collecting the rain gauge network data and the radar images, CALAMAR produces a model that provides geographically accurate, integrated rainfall intensity data for any pre-defined area. The Baltimore City geographical area was divided into 1 square kilometer pixels, and for every significant rain event Doppler Radar rainfall images were generated for every pixel within the Back River and Patapsco WWTP service areas. There were a total of 29 storms that met the definition of a global storm during the primary flow monitoring period. The dates and lengths of those storm events are listed in Table 2 below.

TABLE 2 – GLOBAL STORM EVENTS

Meter	Rain Start Time	Rain End Time	Storm Start Time (Calculation)	Storm Period Length Minutes	R1 Period Length Minutes	R2 Period Length Minutes
Global	5/11/06 12:00	5/11/06 22:00	5/11/06 12:00	2160	1440	60
Global	5/14/06 23:00	5/15/06 16:00	5/14/06 23:00	2880	1440	60
Global	6/2/06 19:00	6/3/06 6:00	6/2/06 19:00	1440	1440	1440
Global	6/19/06 14:00	6/19/06 16:00	6/19/06 14:00	1440	1440	1440
Global	6/24/06 13:00	6/24/06 22:00	6/24/06 13:00	1080	60	60
Global	6/25/06 4:00	6/26/06 22:00	6/25/06 4:00	8640	60	60
Global	7/5/06 11:00	7/6/06 6:00	7/5/06 16:00	5760	60	60
Global	7/22/06 14:00	7/23/06 0:00	7/22/06 14:00	1440	1440	1440
Global	9/1/06 6:00	9/2/06 17:00	9/1/06 6:00	3600	60	60
Global	9/5/06 2:00	9/5/06 17:00	9/5/06 2:00	2880	1440	60
Global	9/14/06 1:00	9/14/06 21:00	9/14/06 1:00	4320	60	60
Global	9/28/06 17:00	9/28/06 22:00	9/28/06 16:00	2160	60	60
Global	10/5/06 20:00	10/6/06 16:00	10/5/06 20:00	7200	60	60
Global	10/17/06 7:00	10/18/06 2:00	10/17/06 7:00	2160	60	60
Global	10/19/06 20:00	10/20/06 11:00	10/19/06 20:00	2160	60	60
Global	10/27/06 15:00	10/28/06 8:00	10/27/06 14:00	3600	60	60
Global	11/7/06 20:00	11/8/06 15:00	11/7/06 20:00	3600	60	60
Global	11/16/06 8:00	11/16/06 17:00	11/16/06 8:00	7200	60	60
Global	11/22/06 11:00	11/23/06 3:00	11/22/06 10:00	5760	60	60
Global	12/22/06 12:00	12/23/06 3:00	12/22/06 12:00	3600	60	60
Global	12/25/06 12:00	12/26/06 1:00	12/25/06 12:00	4320	60	60
Global	12/31/06 16:00	1/1/07 14:00	12/31/06 22:00	4320	60	60
Global	1/7/07 17:00	1/8/07 16:00	1/7/07 17:00	4320	60	60
Global	3/1/07 18:00	3/2/07 9:00	3/1/07 18:00	5760	60	60
Global	3/15/07 16:00	3/16/07 17:00	3/15/07 16:00	8640	60	60
Global	3/23/07 13:00	3/24/07 10:00	3/23/07 13:00	4320	60	60
Global	4/4/07 3:00	4/4/07 9:00	4/4/07 3:00	1440	60	60
Global	4/11/07 21:00	4/12/07 6:00	4/11/07 21:00	2880	60	60
Global	4/14/07 19:00	4/16/07 3:00	4/14/07 19:00	7200	60	60

2.5 Ground Water Measurement

The Contractor installed groundwater gauges at 33 flow monitoring sites designated by the City. Three of these were in the Patapsco sewershed. Each groundwater gauge consisted of a conduit (preferably a clear flexible tube) of sufficient diameter to accommodate a pressure sensor. The pressure sensor was calibrated prior to installation.

2.5.1 Equipment and Installation

The groundwater gauge connected through the manhole wall to the ground around the manhole near the bench of the manhole. The conduit was secured to the manhole wall or steps and extended vertically to a point 6 inches below the manhole lid. The connection through the manhole consisted of a drilled hole no larger than 1.25 inches in diameter, through which a PVC or metal pipe extended to approximately 6.0 inches outside the manhole and into the ground. At the end of this PVC or metal pipe a fine mesh was installed to let groundwater through but keep dirt and debris from clogging the pipe. The space between the manhole wall and the PVC or metal pipe was water-tight sealed with silicon caulking or similar material. The conduit connected securely to the PVC or metal pipe with the proper fittings and hardware to provide a water-tight connection.

2.6 Data Collection and Processing

The Contractor was required to use a host software support application program for remote wireless data collection of all flow meters, rain gauges, and ground water gauges. The host software maintained clock synchronization with the host system's clock for all field RTUs, thus insuring time interval integrity for all collected data. The City required the Contractor to use a system employing client/server architecture, capable of storing all project deliverables including flow and rainfall data; equipment configurations; event logs; and site parameters into a SQL database. The software allowed any networked computer (with the appropriate access rights) access to the data stored in the SQL database using a common web browser (e.g. Microsoft Internet Explorer). The web module was read only in order to protect data integrity, and had the ability to present near-real time data. Field data measurements could be forwarded to the server immediately following collection by the field RTUs, and the server could immediately post the data to the web site for viewing by authorized parties.

The Contractor was required to employ trained data analysts experienced in processing and analyzing flow and rainfall data from sanitary sewer systems. Various analytical tools, such as hydrographs, scattergraphs, and flow balancing

methods were used to verify the accuracy and precision of the flow data. Data collection was performed remotely at least twice a week and was scheduled in a manner to allow data review by a trained data analyst within 24-hours of the data collection. The analyst assessed any maintenance or monitor performance issues, and a crew was dispatched within 48 hours, and the issue resolved within 72 hours from the time the issue was identified. All measurements, adjustments, and efforts undertaken during site visits were logged in an installation/maintenance log specific to that installation.

2.7 Monitoring Period

The period of flow metering extended from May 9, 2006 to May 18, 2007. Some meters deemed long term meters have stayed in place. See Table 1 for a list of meters, their sub-basin, and purpose.

2.8 Equipment Operation, Maintenance, and Uptime

The Contractor's qualified field crews visited each monitor installation as appropriate to perform any necessary maintenance to the equipment. As stated above, field crews were dispatched within 48 hours and any O&M issue was resolved within 72 hours from the time the issue was identified. The Contractor was required to collect useable flow data a minimum of 90% of the time throughout the monitoring period, and to submit to the City an "Uptime" table each month demonstrating compliance with the uptime requirement.

The uptime requirement would be generally satisfied with actual measured data. However, in instances where a velocity measurement was not available, inferred velocity from a reliable depth measurement would not be considered downtime if the Contractor demonstrated that accurate data could be obtained without the velocity measurement, and that the loss of velocity data was not caused by maintenance neglect. In any case, however, no velocity could be inferred for any measurement interval where (1) a corresponding depth measurement has not been obtained for that measurement interval or (2) independent calibration measurements have not been acquired for the site. The Contractor was required to identify all inferred velocity data or other data derived from inferred data in all reports and deliverables.

3.0 I&I Evaluation

3.1 Sliicer.com Wet Weather Analysis Tool

Sliicer™ is a tool developed by ADS Environmental Services, Inc. to find the locations of the most severe inflow/infiltration problems in a sanitary sewer collection system using rainfall and flow data. By itself in its raw form, flow data can be difficult to interpret. The purpose of Sliicer is to make interpreting flow data easier, so that conclusions about what to do to enhance the performance of the collection system can be developed. Sliicer also allows the user to integrate flow data with physical inspection data to find the best approach to fixing the collection system. Finally, for each flow monitor, Sliicer generates the dry and weather flow components necessary to calibrate the hydraulic model to actual observed flows.

3.2 Global Settings

Global Settings are Sliicer parameters established by the City to be used by all Sewershed Consultants. These parameters should not be changed and will provide a necessary degree of standardization. Global settings include:

- The average dry day flow normalized by the linear feet contained in each sub-basin.
- The time step averaging will be 30 minutes.
- Criteria for defining dry days and which days should be excluded.
- Two "seasons" will be considered: Eastern Daylight Time ("Summer") and Eastern Standard Time ("Winter").
- The minimum rain event to be included in the analysis is 0.5 inches in 24 hours.
- The default method for computing wastewater production will be the Stevens-Schutzbach Method.
- The rolling method will be used for rainfall peaks.
- The units used are million gallons per day for flow rates, million gallons for volume, feet per second for velocity, and inches for flow depth.

3.3 Dry Weather Analysis

3.3.1 Dry Day Selection

Following the criteria established within the BaSES Manual, dry days were defined according to the following table:

TABLE 3 - CRITERIA FOR DRY DAYS

NUMBER OF PRIOR DAYS	CUMULATIVE ANTECEDENT RAIN (Inches)
1	0.1
3	0.4
5	1.0

In addition, dry days with flow volumes that are 15 percent higher or lower than the average volume of all dry days were excluded from the analysis. Next, the dry day traces (hydrographs) for each meter were visually reviewed and any outliers that may have passed through the filtering requirements noted above were removed. After removing days that did not meet the dry day criteria, Sliicer calculated the Average Dry Flow (ADF) from the remaining traces.

3.3.2 Dry Day Groups

The dry day groups used were weekdays and weekends. The weekdays include Mondays through Fridays. The weekends include Saturdays and Sundays**.**

3.3.3 Season Groups

The seasons used for the study were Eastern Daylight Saving Time (DST – second Sunday in March through the first Sunday in November; also referred to as "Summer") and Eastern Standard Time (EST – first Sunday in November through the second Sunday in March, referred to as "Winter").

3.3.4 Waste Water Production and Base Infiltration Components

The wastewater production (WWP) was calculated by subtracting the base infiltration (BI) from the average dry flow (ADF). As required, the Stevens-Schutzbach Method was used to determine the base infiltration. The Stevens-Schutzbach Method is as follows:

$$BaseInfiltration = \frac{0.4 \times MDF}{\left(1 - \left(0.6 \times \left(MDF / ADF\right)^{MDF^{0.7}}\right)\right)}$$

Where: MDF = minimum dry flow

The gross infiltration rate was used for basins that exhibited negative net infiltration. Table 4 presents the results of the dry-weather analysis.

3.3.5 Base Infiltration Normalization by IDM

Normalizing BI is important when comparing basins with severe infiltration problems. Simply looking at infiltration flow rates or volumes does not always lead to the correct conclusion about the location of the most severe infiltration problems in the collection system. For this project, BI was normalized based on inch-diameter-miles (IDM). The IDM normalization was selected for BI because it takes into account not only the length, but also the diameter of the pipes in the basin. Regardless of the length, the larger the pipe diameter the more pipe surface is exposed to groundwater. Sliicer provided the data necessary to calculate normalized BI for each basin.

3.4 Wet Weather Analysis

3.4.1 Global Storms

A total of 29 storms during the metering period met the criteria for a storm event as defined by the global setting. The dates, start and end times, durations, and recovery periods for these storms are listed in Table 2. Each storm event was analyzed for its impact at each flow meter using the Sliicer.com software.

3.4.2 Pre-Composition Period

For each storm, a pre-composition period (typically 24 hours prior to the storm event) was established to adjust the dry day hydrograph to match the actual hydrograph immediately prior to the start of the storm. This either raises or lowers the dry day hydrograph so that the calculated rainfall-dependent infiltration and inflow (RDII) is a direct result of the storm event only.

3.4.3 Storm Measurement Periods

Sliicer.com calculates I&I for three periods following the start of the storm. These periods are: Storm, Recovery 1 and Recovery 2. Each period by default is 24 hours long which is set by the global settings. For this project, however, the storm periods were set by the City, and are specific for each storm event, and are long enough to capture all the RDII. Recovery periods 1 and 2 were set to 60 minutes, but were not used in any calculations.

3.4.4 RDII Calculations

In order to estimate the RDII, Sliicer superimposes the typical dry day hydrograph on the storm hydrograph. The difference between the two hydrographs represents the RDII.

3.4.5 RDII Normalization

3.4.5.1 By Linear Footage

Normalizing the RDII is extremely important when comparing results to find the basins with the most severe I&I. Simply looking for the largest wet weather flow does not always lead to the correct conclusion about the location of the worst I&I problems in the collection system. Although flow information is part of the picture, it needs to be correlated with basin size and rainfall information before it becomes useful. For this project, RDII was normalized based on linear footage of sewer (gal/l.f./in-of-rain). Sliicer provided the data need to calculate normalized RDII for each meter for each storm. The average of all storms was then calculated.

3.4.5.2 By Area (Capture Coefficient)

A graphical technique for evaluating and comparing the performance of sewershed basins under widely varying rain events is the Q vs. I diagram. "Q" is the calculated I&I for a storm and "I" is the corresponding rainfall. The slope (S) of the regression line on the Q vs. I plot was used in the following equation to obtain the capture coefficient (R).

$$R = (36.83_{(acres\text{-}in/mg)} * S_{(mg/in)}) / Area_{(acres)}$$

The capture coefficient represents the percentage of the volume of rain water that fell on the basin during a storm that found its way into the collection system. Since winter season storms (EST season group) typically yield higher R values, all storms were considered in this analysis. Plots of the Q vs. I diagrams for each flow meter are provided in the CD attached to this report.

4.0 Evaluation Results

4.1 Dry Day Results

Table 4 below summarizes the results of the Dry Weather Analysis. For each sub-sewershed, the Average Dry Flow (ADF) was calculated from Sliicer.com and used to analyze flow data recorded by the flow monitors. The DST 2006 Summer Weekdays group of flow data was used for the analysis. For BPA03 and TSPA03, the DST 2007 Summer Weekdays flow data was used because of a lack of reliable data for these meters for DST 2006. ADF was then disaggregated into Base Infiltration (BI) and Wastewater Production (WWP) as explained in Section 3.3.4 above. To compare the relative severity of the BI, it was normalized by dividing by the inch-diameter-miles of sewers in the sub-sewershed. There was limited data on the sewerage system in Anne Arundel county basins BPA01 and BPA02, so gross estimates of sewer size and length were utilized from data obtained from county record drawings. Table 5 below ranks the sub-sewersheds in the Patapsco Sewershed on the severity of BI normalized by IDM.

TABLE 4 – DRY WEATHER ANALYSIS

DST – SUMMER 2006 – WEEKDAYS ONLY (EXCEPT WHERE NOTED)													
Basin	**A_{gross} (acres)**	**A_{net} (acres)**	**A_{net}/A_{gross} (%)**	**IDM (in-dia-mile)**	**ADF_{gross} (MGD)**	**ADF (MGD)**	**Q_{net}/Q_{gross} (%)**	**WWP (MGD)**	**BI_{net} (MGD)**	**BI Severity (gpd/idm)**	**BI Rate (%)**	**WWP Rate (gln/l.f.)**	**Notes**
BPA01	363.4	323.4	89.0%	50.00	0.33	0.33	100.0%	0.24	0.09	1800	27.3%	5.65	*
BPA02	579.7	579.7	100.0%	60.00	0.48	0.48	100.0%	0.3	0.18	3000	37.5%	4.03	*
BPA03	541.1	541.1	100.0%	70.17	0.21	0.21	100.0%	0.17	0.04	570	19.0%	3.97	**
PA01	562.3	562.3	100.0%	39.78	0.33	0.33	100.0%	0.03	0.3	7541	90.9%	1.82	
PA03	329.5	194.1	58.9%	37.27	0.41	0.22	53.7%	0.08	0.13	3488	59.1%	3.78	
PA04	135.4	135.4	100.0%	38.42	0.26	0.26	100.0%	0.13	0.13	3384	50.0%	5.73	
PA05	2843.1	358.7	12.6%	62.84	5.09	1.42	27.9%	1.13	0.29	4615	20.4%	86.19	
PA05A	1748.7	178.7	10.2%	33.40	2.75	0.57	20.7%	0.4	0.16	4790	28.1%	64.11	
PA06	735.7	197.4	26.8%	59.54	0.92	0.33	35.9%	0.28	0.05	840	15.2%	8.35	
PA07	538.3	214.9	39.9%	38.34	0.59	0.26	44.1%	0.17	0.09	2347	34.6%	7.68	
PA08	43.6	43.6	100.0%	16.26	0.15	0.15	100.0%	0.07	0.08	4920	53.3%	7.23	
PA09	745.6	165.9	22.3%	54.03	1.03	0.54	52.4%	0.2	0.34	6293	63.0%	1.43	
PA10	780.8	381	48.8%	78.75	1.36	0.76	55.9%	0.39	0.37	4698	48.7%	1.84	
PA11	203.4	203.4	100.0%	40.33	0.45	0.45	100.0%	0.24	0.21	5207	46.7%	10.33	
PA12	196.4	196.4	100.0%	27.85	0.15	0.15	100.0%	0.08	0.06	2154	40.0%	5.89	
TSPA03	4253.2	539.5	12.7%	82.02	6.56	1.96	29.9%	0.8	1.16	14143	59.2%	8.39	**

***in-dia-mile estimated from County record drawings**
****2007 DLS Weekdays**

TABLE 5 - PATAPSCO SEWERSHED BI SEVERITY RANKING

BASIN (Sub-sewershed)	BI SEVERITY (gpd/idm)	RANKING (1-Most severe)
TSPA03 (PA02)	14143	1
PA01	7541	2
PA09	6293	3
PA11	5207	4
PA08	4920	5
PA05A	4790	6
PA10	4698	7
PA05	4615	8
PA03	3488	9
PA04	3384	10
PA07	2347	11
PA12	2154	12
PA06	840	13

Figure 4 graphically indicates the BI severity for each sub-sewershed. As noted, basin PA02, measured by flow monitor TSPA03, has by far the most severe Base Infiltration. As this basin is at the bottom of the sewershed, it has a relatively low percentage of Q_{net} to Q_{gross} at 29.9 %. In addition, any errors that may exist in the upstream flow monitors may be passed down and accumulated in TSPA03. TSPA03 also receives pumped flow from the Brooklyn Pumping Station, although it is far upstream. PA05A and PA05 are closer to the pumping station, yet their calculated BI is ranked only 6th and 8th, respectively of the thirteen Patapsco subsewersheds. TSPA03 also appears to be affected by the wetwell levels in the Patapsco Influent Pumping Station, due to backwater. Despite these cautions that the BI is overstated, this sub-sewershed is recommended for further analysis to try and identify the source of dry weather infiltration. The basin with the next largest BI severity is PA01. This basin has the smallest population of any sub-sewershed, only 46, which is reflected in the low wastewater production rate. As a result, the BI rate is 90.9%, the highest of any sub-sewershed. There are many abandoned and partially razed buildings and homes in this sub-sewershed. It is possible that there are improperly abandoned water and sewer service connections contributing to the high BI rate. CCTV inspection has verified that there are areas of significant infiltration in this basin.

Overall, the Base Infiltration rate (BInet/ADF) is 42.6% in the Patapsco sewershed. Eight sub-sewersheds – PA01, PA03, PA04, PA08, PA09, PA10, PA11 and PA02 (TSPA03) – have BI rates higher than the median rate of 42.6%. Of these eight, all but two – PA03 and PA04 – have BI Severity over 4000 gpd/idm. These 6 sub-sewersheds would be the priority basins for base infiltration removal potential. PA03 and PA04 have BI rates above the median but BI severity less than 3400 gpd/idm. Conversely, PA05 and PA05A have BI rates less than the median, but BI severity

over 4600 gpd/idm. These four basins should be the next level of priority for remedial action and/or further dry weather infiltration source investigation and determination.

Three sub-sewersheds from Anne Arundel County enter the Patapsco sewershed at the City/County boundary. The BI rate for sub-sewersheds BPA01, BPA02 and BPA03 are 27.3%, 37.5% and 19%, respectively. All three of these values are below the average BI rate for the Patapsco sewershed. In addition, BPA03 had the lowest BI severity, at 570 gpd/idm, of any sub-sewershed in or contributing to the Patapsco sewershed. There was limited data on the Anne Arundel County sanitary sewer system in BPA01 and BPA02 to calculate inch-diameter miles and normalize the BI for these basins, so gross estimates of sewer size and length were made from County record drawings. Based on the BI Rate data, BI from Anne Arundel County is not a significant contribution to the BI in the Patapsco sewershed.

4.2 Wet Weather Results

A total of 29 global storms were analyzed to compute Rainfall Dependent Infiltration and Inflow (RDII), which is the wet weather component of wastewater flow. See Table 6 below for the dates of the global storms with corresponding depths of precipitation and durations of the storms. Sliicer.com estimates RDII by superimposing the dry day hydrograph on the corresponding wet day hydrograph, with the difference in volume being the wet weather flow or RDII. To make comparisons among different areas as to the severity of RDII, it is normalized, first by linear feet of sewer system contributory to a metering site, and then by capture coefficient, which is the percentage of rainfall that makes its way into the sanitary sewer system during a storm event. As explained in Section 3.4.5.2 of this report, the capture coefficient is a function of the slope of the regression line on the Q vs. I (RDII vs. inches of precipitation) graphs. Table 7 below summarizes the results of the wet weather analysis, indicating the RDII for each sub-sewershed, normalized in gallons/linear foot/inch of precipitation, and by capture coefficient. Table 7 also ranks the sub-sewersheds of the Patapsco Basin in terms of the severity of RDII as well as showing the relative ranking based on capture coefficients.

TABLE 6 – LIST OF GLOBAL STORMS

DATE	DEPTH (in)	DURATION (hr)
May 11, 2006	1.33	10
May 14, 2006	0.47	17
June 2, 2006	0.99	11
June 19, 2006	0.22	2
June 24, 2006	0.57	9
June 25, 2006	6.27	42
July 5, 2006	2.1	19

July 22, 2006	0.78	10
September 1, 2006	2.88	35
September 5, 2006	1.97	15
September 14, 2006	1.51	20
September 28, 2006	0.97	5
October 5, 2006	1.73	20
October 17, 2006	1.02	19
October 19, 2006	0.64	15
October 27, 2006	2.15	17
November 7, 2006	1.55	19
November 16, 2006	2.32	9
November 22, 2006	1	16
December 22, 2006	1.23	15
December 25, 2006	0.67	13
October 10, 2006	1.15	0
January 7, 2007	0.87	21.5
March 1, 2007	0.95	14
March 15, 2007	2.63	25
March 23, 2007	0.41	15
April 4, 2007	0.6	6
April 11, 2007	1.1	9
April 14, 2007	2.88	32

TABLE 7 – WET WEATHER ANALYSIS

BASIN	RDII (gal/l.f./ in)	Capture Coefficient (R)		Basin	RDII Ranking	Capture Coefficient Ranking
PA01	46.1	6.91%		TSPA03	1	2
PA03	8.77	3.44%		PA05	2	1
PA04	5.11	2.44%		PA01	3	3
PA05	60.04	19.00%		PA05A	4	4
PA05A	33.46	6.76%		PA12	5	11
PA06	5.4	0.03%		PA03	6	6
PA07	3.63	1.82%		PA11	7	5
PA08	2.92	1.69%		PA06	8	13
PA09	3.62	2.59%		PA04	9	8
PA10	1.78	0.55%		PA07	10	9
PA11	8.34	4.52%		PA09	11	7
PA12	10.94	0.93%		PA08	12	10
TSPA03	112.16	13.06%		PA10	13	12

Figure 5 graphically indicates the RDII severity for each sub-sewershed. As noted in Table 7, sub-sewershed PA02, measured by flow monitor TSPA03, has, by far, the most severe RDII. As this basin is at the bottom of the sewershed, any errors in the upstream flow monitors may be passed down and accumulated in TSPA03. Nonetheless, this sub-sewershed is recommended for further analysis, including smoke testing, to try and identify the source of wet weather inflow. In addition, sub-sewersheds PA05, PA01, PA05A and PA12 had RDII severity greater than 10 gallons/l.f./inch of rainfall and are candidates for further analysis, investigation and possible remedial action.

The sub-sewershed with the lowest RDII severity is PA10, with only 1.78 gal/l.f./inch of RDII. Sub-sewershed PA08 also had a relatively low rate of RDII, at 2.92 gal/l.f./inch. Four sub-sewersheds – PA07, PA08, PA09 and PA10 - had RDII severity less than 5 gal/l.f./inch.

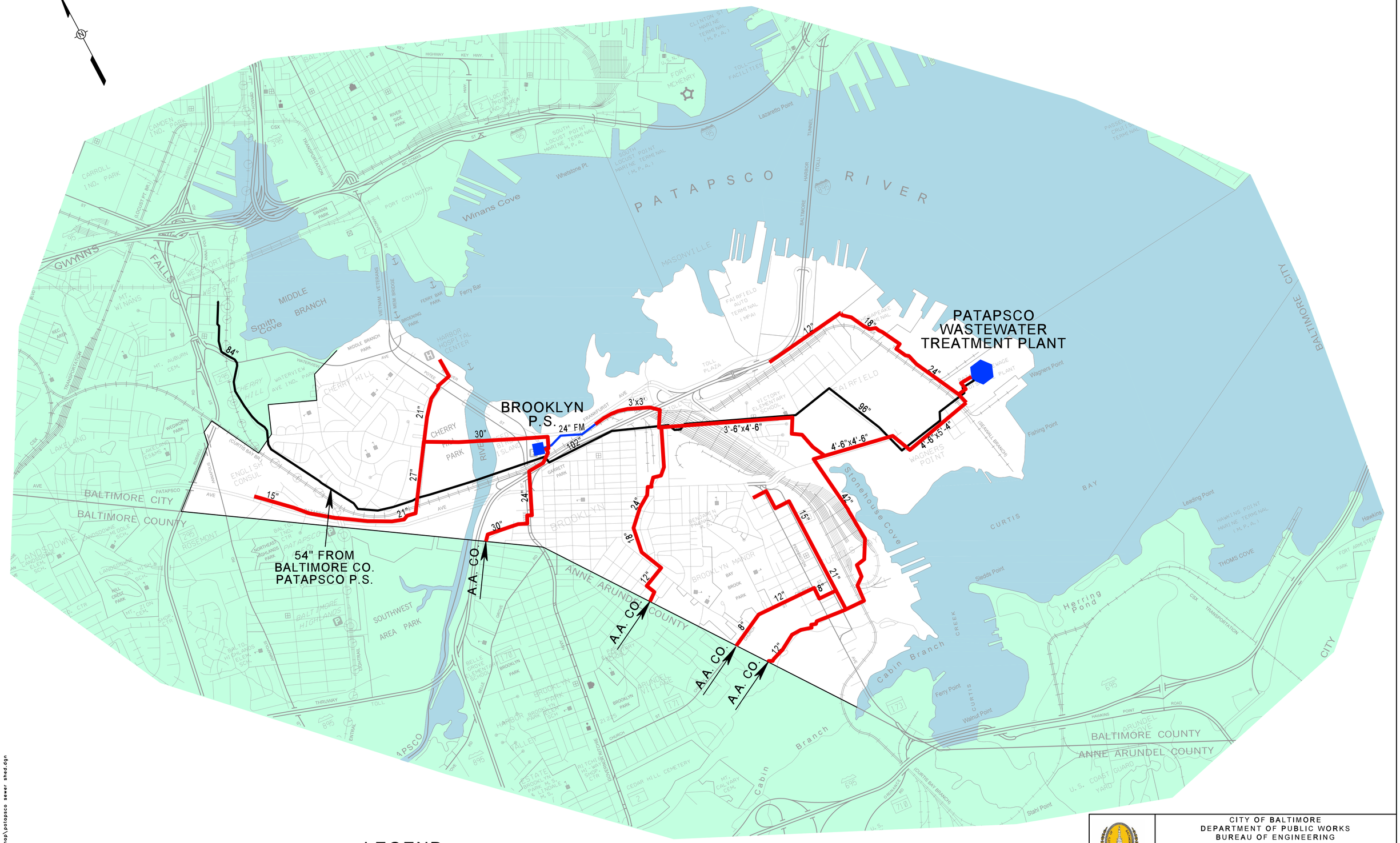
The scattergraphs developed during the flow monitoring period showing plots of depth vs. velocity at each metering site were reviewed to assess the frequency and level of surcharging. In addition, these plots help to identify hydraulic bottlenecks and backwater due to possible downstream obstructions. Flow monitors PA03, PA05, PA05A, PA06, PA07 and PA08 showed no surcharging during the metering period. Meters PA04, PA09, PA10 and PA12 experienced infrequent surcharging, usually less than 24-inches above the crown of the pipe. PA11 experienced the largest surcharging with a maximum depth of approximately 8.6 feet (103”) above the pipe crown, or 10.3 feet (124”) above the invert. This computed result conforms to the observations made during CCTV inspection of the sewers in this area, which showed high water and surcharged conditions. Considerable extra heavy cleaning of sewers in this area removed tons of debris contributing to the high water in this area. The manhole in which the flow monitor for PA11 was located is S33Q1_006MH. Through inspection of this manhole, the measured distance from the manhole rim to the invert of the pipe was 14.91 feet. Given this, a surcharge of 10.3 feet above the pipe invert would not have caused an overflow. PA02, measured by meter TSPA03, had surcharges as high as three feet above the crown of the 54-inch pipe. The meter with the most frequent surcharging was PA01, although these were less than three feet above the pipe crown in a manhole nearly 17 feet deep. The surcharging and high water at PA01 were also corroborated with observations made during manhole and CCTV inspections performed in this area.

5.0 Summary and Conclusions

Based on a review of both the dry weather analysis, which computed Base Infiltration (BI) severity, and the wet weather analysis, which computed Rainfall Dependent Infiltration and Inflow (RDII) severity, sub-sewersheds PA02 (TSPA03), PA05, PA01, PA05A, PA12, PA03 and PA11 would be the highest priority basins for further investigations, such as smoke testing, and possible future rehabilitation and repair to remove extraneous flow. These seven basins were the seven highest ranked sub-sewersheds in terms of RDII severity. In addition, PA02 (TSPA03), PA01, PA11 and PA05A were also ranked in the top six sub-sewersheds in terms of BI severity. Of the seven basins with the most severe RDII, only PA11, in the Cherry Hill neighborhood, and PA03, in the Curtis Bay area, are predominately residential areas. The other five sub-sewersheds with severe RDII are industrial and commercial areas with minimal residential areas. This suggests that roof leaders and area drains from private property are not a significant contributor to RDII in the Patapsco sewershed. The high RDII in industrial/commercial areas may be indicative of damaged pipe in rail yards and other industrial areas, possible discharge of process wastewater that does not originate from the potable water supply, and other extraneous wastewater that will need to be further investigated.

FIGURES

PATAPSCO SEWERSHED



LEGEND

- SEWERSHED BOUNDARY
- PUMPING STATION
- WASTEWATER TREATMENT PLANT
- GRAVITY INTERCEPTOR
- SOUTHWEST DIVERSION
- FORCE MAIN

WR&A

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Achieving is working together

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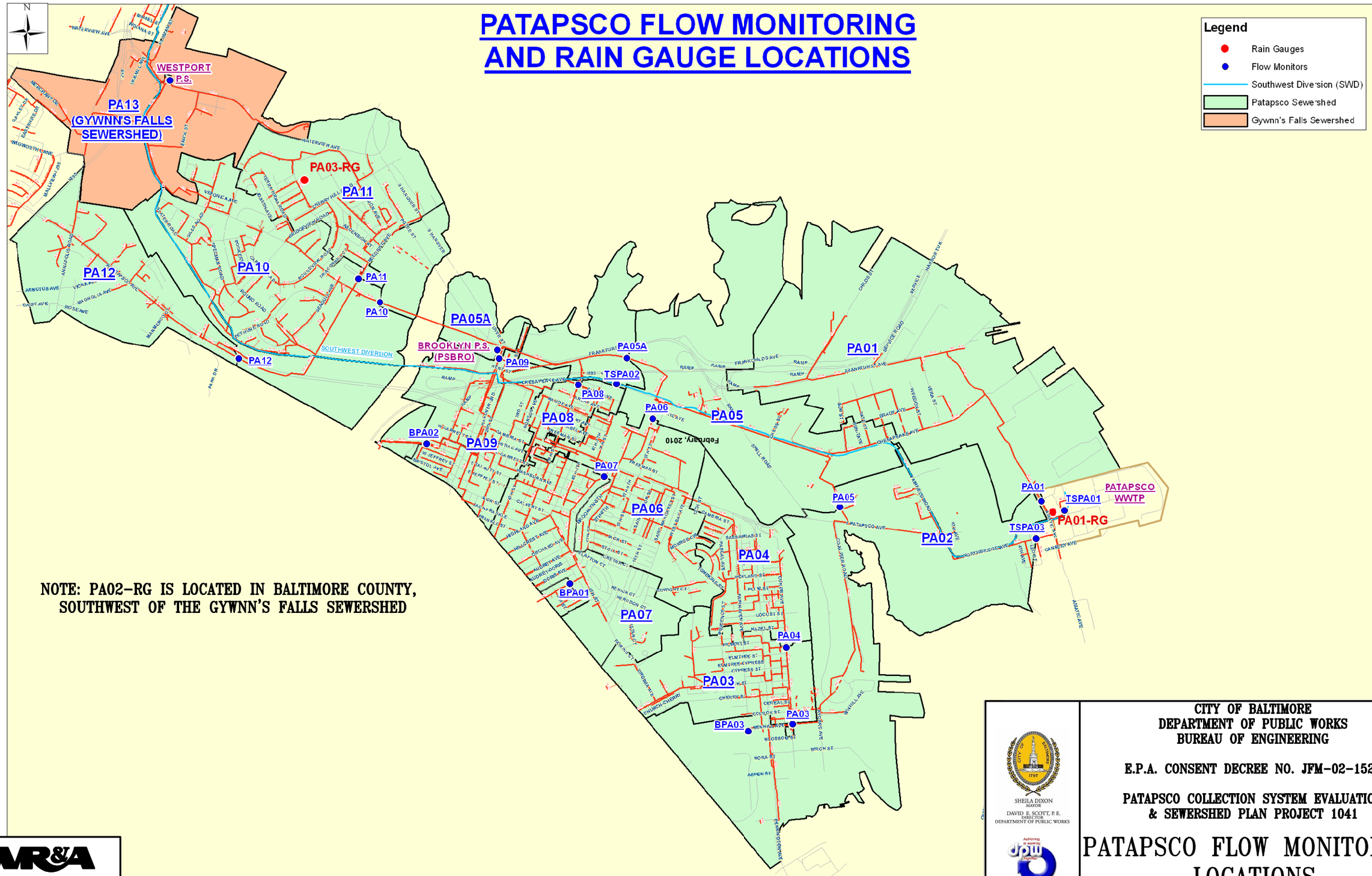
PATAPSCO COLLECTION SYSTEM EVALUATION & SEWERSHED PLAN PROJECT 1041

PATAPSCO SEWERSHED AND SURROUNDING AREA

DATE: SEPTEMBER, 2009

FIGURE: 1

PATAPSCO FLOW MONITORING AND RAIN GAUGE LOCATIONS



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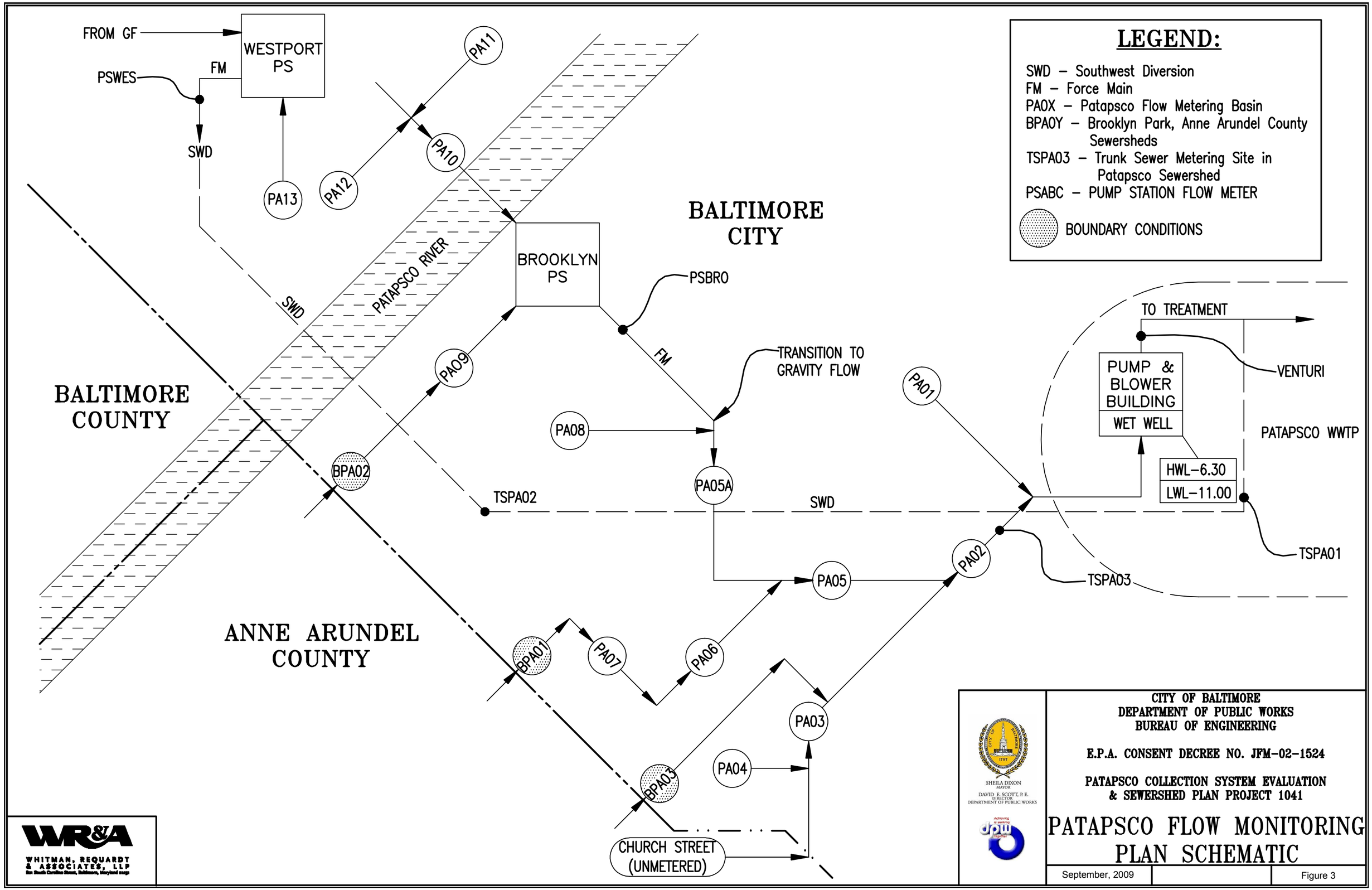
PATAPSCO COLLECTION SYSTEM EVALUATION & SEWERSHED PLAN PROJECT 1041

PATAPSCO FLOW MONITORING LOCATIONS

September, 2009		Figure 2


LEGEND:
SWD – Southwest Diversion
FM – Force Main
PA0X – Patapsco Flow Metering Basin
BPA0Y – Brooklyn Park, Anne Arundel County Sewersheds
TSPA03 – Trunk Sewer Metering Site in Patapsco Sewershed
PSABC – PUMP STATION FLOW METER
BOUNDARY CONDITIONS
FROM GF
WESTPORT PS
FM
PSWES
SWD
PA13
PA12
PA11
PA10
PATAPSCO RIVER
BROOKLYN PS
PSBRO
BALTIMORE CITY
BALTIMORE COUNTY
ANNE ARUNDEL COUNTY
PA09
FM
TRANSITION TO GRAVITY FLOW
PA08
BPA02
TSPA02
PA05A
SWD
PA01
TO TREATMENT
PUMP & BLOWER BUILDING
WET WELL
VENTURI
PATAPSCO WWTP
HWL–6.30
LWL–11.00
TSPA01
PA02
TSPA03
PA05
BPA01
PA07
PA06
PA03
PA04
BPA03
CHURCH STREET (UNMETERED)
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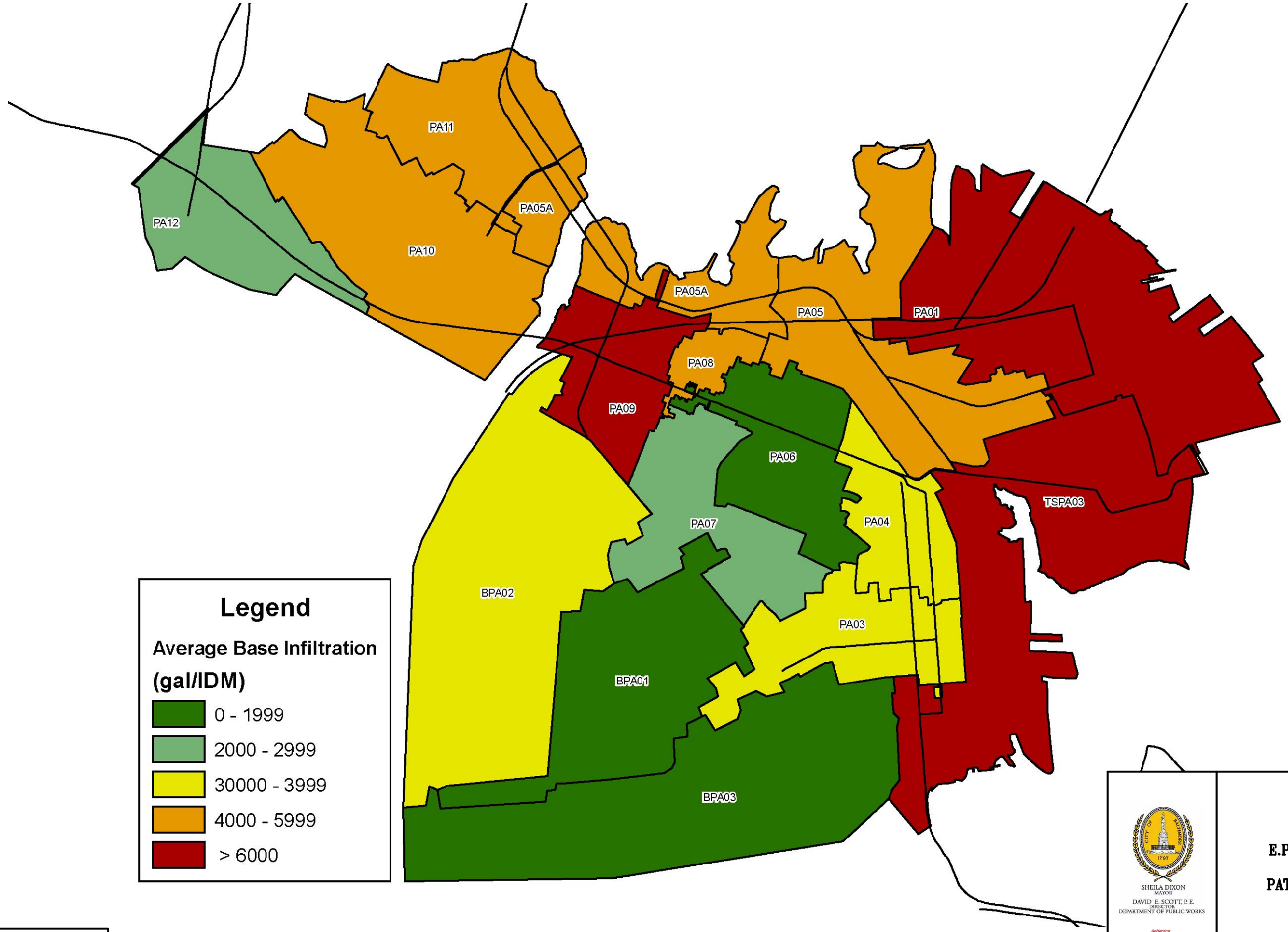
PATAPSCO COLLECTION SYSTEM EVALUATION & SEWERSHED PLAN PROJECT 1041
PATAPSCO FLOW MONITORING PLAN SCHEMATIC
September, 2009
Figure 3



AVERAGE BASE INFILTRATION

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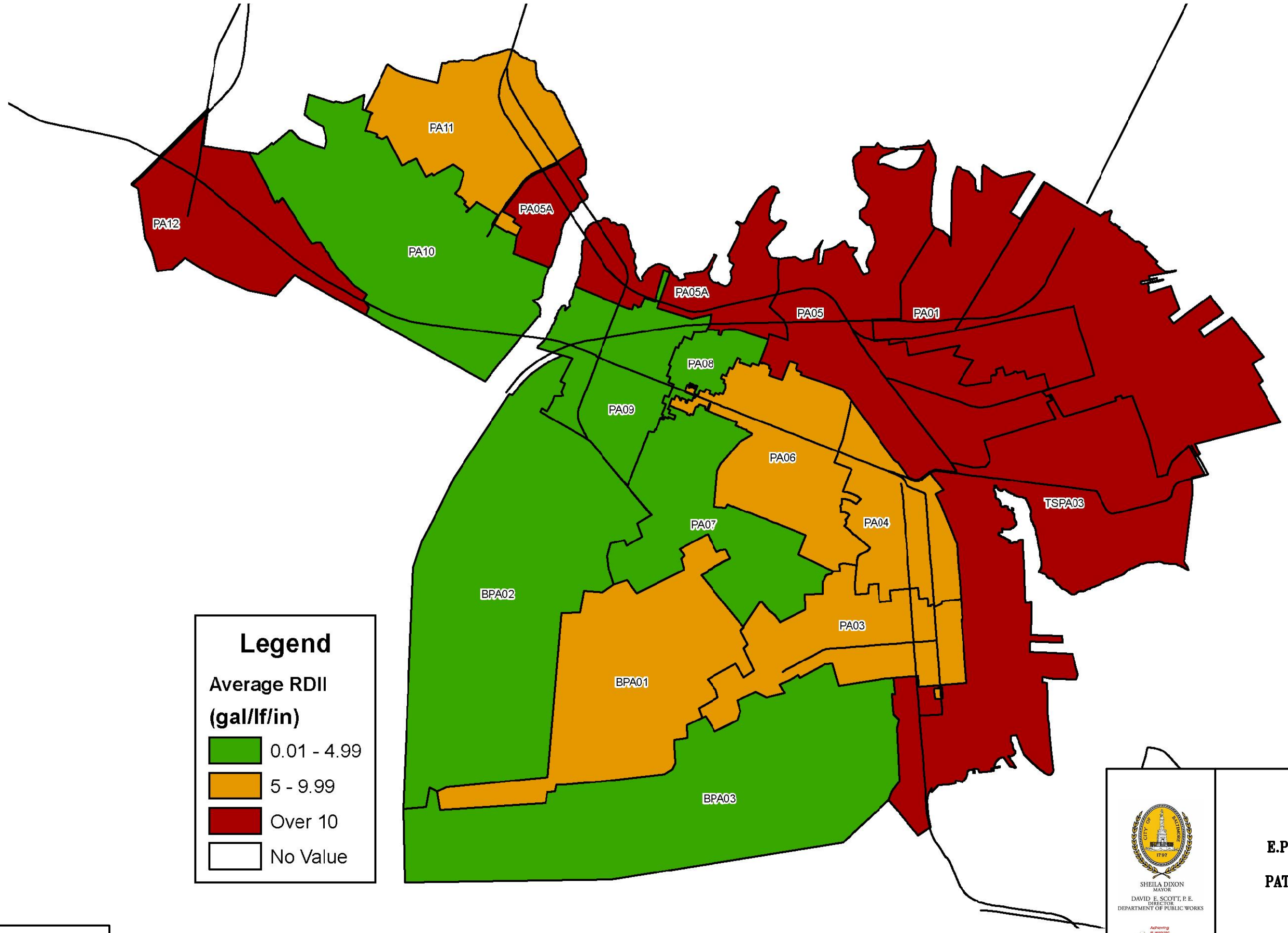
PATAPSCO COLLECTION SYSTEM EVALUATION
& SEWERSHED PLAN PROJECT 1041

AVERAGE BASE INFILTRATION

DATE: SEPTEMBER 2009

FIGURE: 4



AVERAGE RDII SEVERITY

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PATAPSCO COLLECTION SYSTEM EVALUATION
& SEWERSHED PLAN PROJECT 1041

AVERAGE RDII SEVERITY

DATE: SEPTEMBER 2009

FIGURE: 5