CITY OF BEXLEY, OHIO

FINAL OEPA SUMMARY OF SANITARY SEWER EVALUATION SURVEY FINDINGS AND IMPLEMENTATION SCHEDULE

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1.0 INTRODUCTION

EMH&T was contracted by the City of Bexley to assist in meeting the requirements set forth in the Ohio EPA Director's Final Findings and Orders (DFFOs) placed on City of Columbus Satellite Communities on February 11, 2009. The goal of these Orders is for the Satellite Communities to properly manage, operate, and maintain all parts of its sewer system and to:

a. Provide adequate capacity to convey base flows and peak flows for all parts of the sewer system;

b. Take all feasible steps to stop Sanitary Sewer Overflows (SSOs) and Water-in-Basements (WIBs) and to mitigate the impact of SSOs and WIBs from the Sewer System;

c. Minimize excessive infiltration and inflow (I&I); and

d. Provide notification to parties with a reasonable potential for exposure to pollutants associated with an overflow event.

As part of the DFFO requirements, the City of Bexley is required to complete a Sewer System Evaluation Study (SSES) of the entire sanitary sewer system. The purpose of this SSES, as stated in Order #4 of the DFFO, is to identify sources and quantities of clear water infiltration and inflow (I/I) entering the City of Bexley and to identify all feasible cost-effective actions needed to eliminate or minimize excessive I/I entering the sewer system that causes or contributes to sanitary sewer overflows (SSOs) or water-in basements (WIBs) within Satellite Community's sewer system as well as all downstream sewer systems. The SSES shall include, but not be limited to:

a. An evaluation of the Sanitary Sewer System, including:

   i. A physical survey of the sanitary sewer system and confirmation of locations, size, and capacity of all sewers, manholes, pump stations, overflow points (if they exist), cross-connections with storm sewers (if they exist), and any other appurtenance specific to the sanitary sewer system;

   ii. Flow monitoring to adequately characterize the sanitary sewer system during wet and dry weather.

   iii. Estimate of peak flows (including flow that escape from the sanitary sewer system) associated with wet weather conditions;

   iv. Identification of the locations of any hydraulic deficiencies within the sanitary sewer system that are causing or contributing to SSOs or WIBs;

   v. Identification of material sources of I/I entry into the sanitary sewer system and an estimate of the benefit of eliminating material source of I/I entry;

vi. Evaluate the usefulness of permanent flow meters at connection points to the downstream sewers that are owned by a different entity; and

vii. Identification of the locations of structural deficiencies within the sanitary.

b. The identification of short and long term actions to eliminate structural and hydraulic deficiencies within the sanitary sewer system.

c. The identification of remediation to minimize material source of excessive I/I into the sanitary sewer system.

d. The SSES will be reviewed and updated as needed to reflect current information.

The City has elected to complete the SSES within five years of the effective date of these Orders As required, a schedule was submitted to the Ohio EPA on August 10, 2009. A copy of this submitted schedule is provided in **Appendix A**.

This document summarizes the findings of the completed SSES investigations to meet Order #5 of the DFFO, which states that Satellite Communities are to submit to the Ohio EPA for review and comment a completed SSES, which shall include a schedule for the implementation of any remediation. This document includes recommendations to remediate sources of I/I and improve the overall performance of the collection system to assure adequate capacity for the current service area. The recommended projects have been evaluated and prioritized with respects to cost and benefit to establish an implementation plan.

2.0 SSES APPROACH

The City of Bexley has taken a phased approach consisting of flow monitoring, hydraulic modeling, and detailed SSES field investigations to study the sanitary sewer system and identify sources of excessive I/I, as well as structural and hydraulic deficiencies. Findings from these investigations have led to the recommendation and prioritization of remediation projects.

2.1 System-Wide Flow Monitoring Program

The first step in the proposed SSES schedule is to complete a system-wide flow monitoring program for characterization of dry and wet weather flows in concurrence with Items (ii) and (iii) under Order #4a.

This program includes installation of flow meters at various points within the City's sanitary sewer collection system, including all discharge points to/from the City of Columbus. The goal of the flow monitoring is to:

a. Characterize the flow within the sanitary sewer collection system.

b. Estimate dry and wet weather flows.

c. Quantify infiltration and inflow (I/I) entering the sanitary sewer collection system.

d. Prioritize areas for future detailed SSES.

The information collected in this phase will be evaluated to determine if the individual sub-basins are operating as designed and within acceptable limits with respect to I/I. Sanitary sewer design calculations will be used as a basis for defining excessive I/I. If an area is determined to be acting within design standards and is experiencing no WIBs or SSOs, the detailed SSES will not be completed and the area will be monitored under the City's current CMOM program. If it is determined that these areas are still experiencing excessive I/I, detailed SSES investigation will be performed.

2.2 Hydraulic Modeling

The purpose of hydraulic modeling is to evaluate the existing trunk sewers in the City with respect to system hydraulics and capacity to convey peak wet weather flows in concurrence with Items (iii) and (iv) under Order #4a.

The developed and calibrated model will identify hydraulic deficiencies in the trunk sewer system and determine the activity of (unintended) system overflows and (intended) designed sewer reliefs (DSRs). The model will develop recommendations to ensure adequate conveyance capacity in the trunk sewer system.

2.3 Detailed SSES Investigations

A detailed SSES is a systematic process to identify and verify system deficiencies and sources of I/I in the sanitary sewer system in concurrence with Items (i), (iv), (v) and (vii) under Order #4a.

The principal investigative procedures include manhole inspection, smoke testing, dyed water testing and closed-circuit televising (CCTV).

2.3.1 Manhole Inspection

GPS mapping and inspection of manholes was performed over the City's sanitary sewer system and provided confirmation of the location, size, and capacity of all sewers, manholes, overflow points, and cross-connections with storm sewers in concurrence with Item (i) under Order #4a.

Manhole inspection aims to evaluate the condition of the manhole structure and its component parts: frame and cover, chimney, cone, walls, bench and channel, and connecting conduits. The purpose of the inspection is to look for deterioration of materials and evidence of I/I entering the manhole. The manhole inspections are also used to verify the location and connectivity of the sewers and create a new base map for the City.

2.3.2 Smoke Testing

Smoke testing is a broad-spectrum type procedure in which the sanitary sewer system is injected with non-toxic smoke for the purpose of identifying potential sources of I/I. Smoke will be observed exiting the sewer system through potential I/I sources.

2.3.3 Dyed-Water Testing

Dyed water testing is a verification test of potential sources of I/I identified through smoke testing procedures. The objective is to observe the transfer of dyed water through the suspected I/I source. Dyed water is inserted at the suspected I/I source. CCTV equipment is then utilized to determine how the dyed water is entering the sewer system.

2.3.4 Closed Circuit Television Inspection

CCTV Inspection will allow for an assessment of the internal condition of the sanitary sewer system. With the use of previously-collected field data, possible defect locations can be identified for further investigation. CCTV inspection can be used to confirm suspected defects such as: potential I/I sources, structural defects, and operation and maintenance issues.

3.0 SEWER SYSTEM BACKGROUND

The City of Bexley operates and maintains its sanitary sewer collection system, which consists of approximately 737 manholes and over 215,000 linear feet of gravity pipe. The system is an older system that was constructed as early as 1920. It consists of mostly vitrified clay pipe sewers and brick manholes. There are also no design sewer reliefs to the storm sewer system within the City's collection system.

The City of Bexley is a landlocked suburb of Columbus. Its boundary is fixed and there is no opportunity for expansion. The City consists mostly of residential area, with commercial area along Main Street, Broad Street and Livingston Ave. The City of Bexley is also home to Capital University and Trinity Lutheran Seminary. Capital University is partially served by Bexley's collection system and partially by a private sanitary sewer that discharges flow from the University directly to the Alum Creek Trunk Sewer.

The City's sanitary sewer system serves approximately 1,510 total acres and discharges to the City of Columbus as per a service agreement. The collection system is divided up into four main tributary areas per the trunk sewer that services that area. There are also various connections between the identified tributary areas to relieve flow between areas. The collection system discharges to the City of Columbus at eight different locations. It also receives flow from the City of Columbus at one location. The tributary areas, relief connections, and discharge locations are shown in **Figure 3-4.** The following sections describe each tributary area in further detail.

3.1 Clifton Tributary Area

This small area has 77 tributary acres and discharges to the Alum Creek Trunk Sewer at one location: Clifton Avenue. It also receives flow from the Alum Creek Tributary Area through a relief connection at Clifton Avenue and Parkview Avenue. This relief connection was built in 2007 to relieve excessive surcharge in the Parkview Avenue sewer.

3.2 Alum Creek Tributary Area

This area has 534 tributary acres and discharges to the Alum Creek Trunk Sewer at three locations: Bryden Road, East Main Street and Village Creek Drive. The main trunk sewers in this area run along Parkview Avenue and Main Street. It receives flow from the Livingston Tributary Area through a relief connection at East Broad Street and Stanberry Avenue.

3.3 Livingston Tributary Area

This area has 527 tributary acres and discharges to the Alum Creek Trunk Sewer at one location: Livingston Avenue at the southwest corner of Bexley's corporation limits. The main trunk sewer in the area runs along Livingston Avenue, Cassady Avenue and Dawson Avenue. It receives flow from the Alum Creek Tributary Area through two relief connections along Cassady Avenue, at Bexley Park Road and at East Main Street.

3.4 Gould Tributary Area

This area has 408 tributary acres and discharges to the City of Columbus' sewer system at one main location: Livingston Avenue at the southeast corner of Bexley's corporation limits. This flow is ultimately tributary to the Big Walnut Sanitary Trunk Sewer. The main trunk sewer in the area runs along Gould Road.

There are two cross-connections with the City of Columbus that act as relief connections for the Gould Road Trunk Sewer. They are located at Denver Avenue and Powell Avenue. Both connections convey flow from the Gould Road Trunk Sewer into the City of Columbus' Truro #1 Subtrunk. The Truro #1 Subtrunk then discharges back into Bexley's Gould Road Trunk Sewer at Charles Street cross-connection. Refer to **Figure 3-4** for the location of the Truro #1 Subtrunk. There are also numerous 8-inch sanitary sewers that serve the City of Columbus and discharge into the Gould Road Trunk Sewer.

The Gould Road Trunk Sewer, after combining with the Truro #1 Subtrunk at Charles Street, ultimately discharges to the City of Columbus sewer system at Manhole GU-100 located just north of Livingston Avenue. The flow continues south from Livingston Avenue in the 48-in Truro #1 Subtrunk.

3.4.1 Denver Avenue Cross-Connection

The Denver Avenue cross-connection is located in Manhole GU-129a. **Figure 3-1** illustrates the configuration of the connection. This manhole was constructed in 1956, 26 years after the 12-in Gould Road Trunk Sewer was built for the purpose of connecting a 15-in pipe to relieve flow to Columbus. The flow entering the manhole can either exit through the 15-in pipe to Columbus (east) or through the 12-in pipe to Bexley (south).

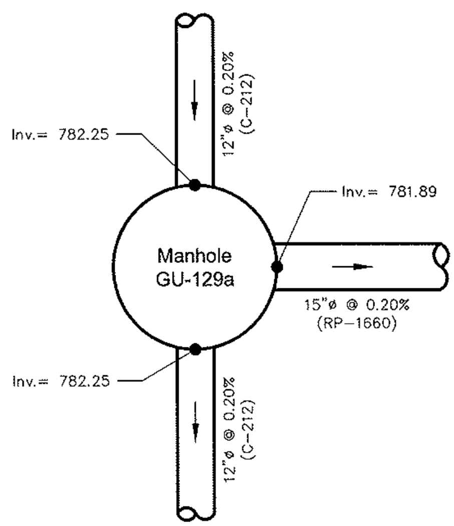

Figure 3-1: Denver Avenue Cross-Connection Configuration

3.4.2 Powell Avenue Cross-Connection

The Powell Avenue cross-connection is located in Manhole GU-121. **Figure 3-2** illustrates the configuration of the connection. The 18-in Gould Road Trunk Sewer, built around 1930, flows into the manhole from the north and exits to the south. An 8-in sewer from the west, serving the Powell Avenue Sub-Area, also drops into this manhole. In 1956, a 21-in relief pipe was connected to manhole so that flow entering the manhole can continue flowing south in the trunk sewer or flow to the east through the 21-in City of Columbus sewer line.

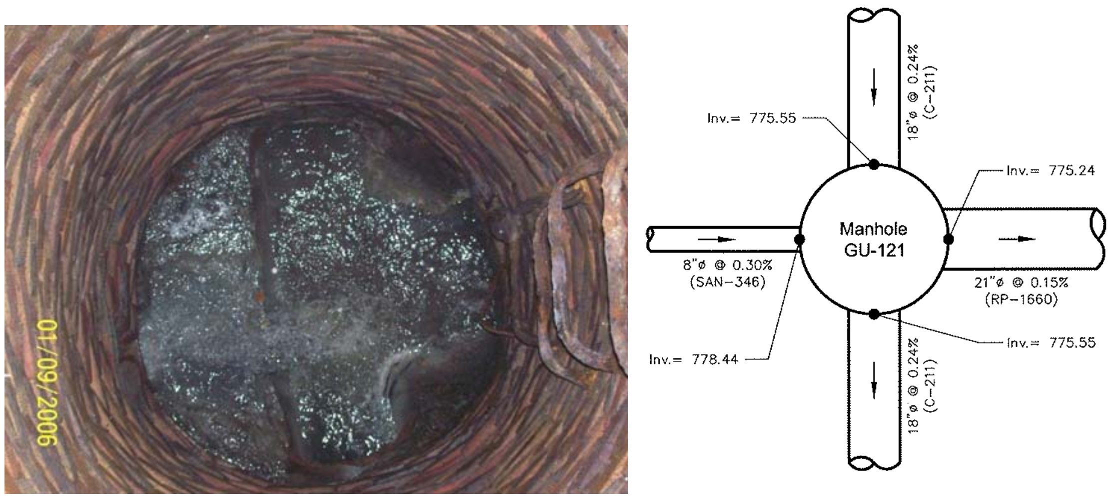

Figure 3-2: Powell Avenue Cross-Connection Configuration

3.4.3 Charles Street Cross-Connection

The Charles Street cross-connection is located in Manhole GU-103. At this manhole, the 18-in Gould Road Trunk Sewer combines with the 45-in Truro #1 Subtrunk serving the Charles Street Sub-Area. Both of these sewers were constructed around 1930. Originally, the flow from both sewers was conveyed south through a 36-in pipe. However, the 36-in pipe was abandoned in 1955 and replaced with the current 48-in pipe. **Figure 3-3** illustrates the configuration of the connection.

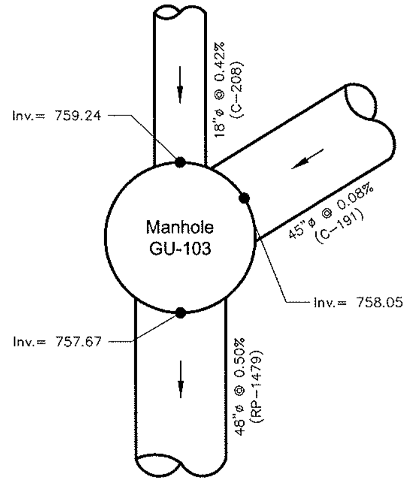

Figure 3-3: Charles Street Cross-Connection Configuration

3.5 Capital University Tributary Area

A portion of Capital University is serviced by a private sewer that discharges directly to the Alum Creek Trunk Sewer at Astor Avenue. Approximately 16 acres of the Capital University campus are tributary to this sewer. This sewer is not included in this study.

4.0 SYSTEM FLOW CHRACTERIZATION

Flow characteristics within the sanitary sewer system were observed through system-wide flow monitoring. The flow is characterized with respects to dry and wet weather flow, I/I entering the system, and overall performance of the sewer system. The flow monitoring program is also used to determine if individual sub-basins are operating as designed and within acceptable limits of I/I based on sanitary sewer design calculations.

Flow Monitoring was performed in two separate programs. In 2007, the City completed the *Gould Road Sanitary Sewer Flow Monitoring Program* to monitoring flow in the Gould Road tributary area. In 2011, the City completed the *System-Wide Flow Monitoring Program* to monitor flow in the Alum Creek and Livingston tributary areas.

Flow meters record the level and velocity of the sanitary flow in 15-minute increment readings.

4.1 Flow Meter Installation

A total of 20 flow meters were installed in the City of Bexley by two flow monitoring programs to characterize sewerage flows. Table 4-1 describes the locations and pipe characteristics of each flow meter installed. The pipe capacity was determined from record plan information. The locations of the flow meters are shown in **Figure 4-1**.

4.1.1 2007 Gould Road Sanitary Sewer Flow Monitoring Program

Eight flow meters (FM#1 - FM#8) were installed along the Gould Road Trunk Sewer to observe the flow characteristics in the trunk sewer and its cross-connections to the City of Columbus. The tributary area to the Gould Road trunk sewer includes portions of the City of Columbus and City of Bexley. The trunk sewer serves a total of 384 acres within the City of Bexley and approximately 745 acres within the City of Columbus through numerous 8-inch sewers discharging to the trunk sewer as well as the 45-inch Truro #1 Subtrunk that discharges to the trunk sewer at Charles Street. The Gould Road tributary area was divided into six tributary sub-basins in the City of Bexley for characterization of sewerage flows.

The flow meters were operational for three months, from mid-May to mid-August in 2007.

4.1.2 2011 System-Wide Flow Monitoring Program

Twelve flow meters (FM#2 - FM#13) were installed at various locations within the Alum Creek and Livingston tributary areas to monitor the discharge to the City of Columbus' sewer system and to divide the collection system into sub-basins for characterization of sewerage flows. The Alum Creek and Livingston tributary areas were divided into 10 sub-basins. The sub-basins are evaluated by adding all sub-basin discharges and subtracting all upstream flows. These sub-basins are described in further detail in **Table 2-1** and are also shown in **Figure 4-1**. Due to the difficulty in metering relief connections, Sub-basins 11&12 and 5&7 are combined for certain analysis.

The flow meters were installed on October 20, 2010 and were operational for approximately 5 months. They were removed on April 1, 2011.

Table 4-1: Flow Monitoring Locations

Program Year	Flow Meter No.	Bexley MH No.	Pipe Size (in)	Full Pipe Capacity (cfs)	Location Description
2007	#1	GU-130	12	1.59	Gould Road Trunk Sewer, upstream of the Denver Avenue cross-connection, tributary to FM#2
2007	#2	GU-129	12		Gould Road Trunk Sewer, downstream of the Denver Avenue cross-connection, tributary to FM#3
2007	#3	GU-121	18	5.15	Gould Road Trunk Sewer, upstream of the Powell Avenue cross-connection, tributary to FM#4
2007	#4	GU-120	18		Gould Road Trunk Sewer, downstream of the Powell Avenue cross-connection, tributary to FM#6
2007	#5	GU-256	8	0.66	Sewer in Powell Avenue, tributary to FM#4
2007	#6	GU-104	18	6.81	Gould Road Trunk Sewer, upstream of the Truro #1 Subtrunk from Columbus, tributary to FM#8
2007	#7	GU-101	10	1.90	Sewer in alley north of Livingston, tributary to FM#8
2007	#8	GU-100	48	40.63	Discharge to City of Columbus at Livingston Ave (East end)
2011	#1	CL-101	8	0.76	This flow meter was <u>NOT INSTALLED</u>. MH could not be located and an adequate secondary location was not available.
2011	#2	AL-240	15	10.42	Discharge to City of Columbus' Alum Creek Trunk Sewer at Bryden Road
2011	#3	AL-110	18	3.64	Discharge to City of Columbus' Alum Creek Trunk Sewer at East Main Street
2011	#4	AL-103	15	4.83	Discharge to City of Columbus' Alum Creek Trunk Sewer at Village Creek Drive
2011	#5	LI-102	27	20.78	Discharge to City of Columbus' Alum Creek Trunk Sewer at Livingston Avenue (West end)
2011	#6	LI-102	15	3.77	Sewer in Ferndale Place
2011	#7	AL-155	12	2.22	Sewer in East Main Street, tributary to FM #3
2011	#8	AL-115	12	2.17	Sewer in Parkview Ave, tributary to FMs #2 and #3
2011	#9	LI-122	18	5.36	Sewer in Cassady Avenue at Bexley Park Road, tributary to FM #5

Table 4-1 continued					
Program Year	Flow Meter No.	Bexley MH No.	Pipe Size (in)	Full Pipe Capacity (cfs)	Location Description
2011	#10	AL-164	12	Unknown	Relief connection between the two sanitary sewers running south in Cassady Avenue at Bexley Park Road
2011	#11	LI-134	18	3.93	Sewer in Dawson Avenue south of East Broad Street, tributary to FM #9
2011	#12	AL-243	10	1.49	Sewer in East Broad Street, tributary to FM #8
2011	#13	CL-118	8	1.13	Relief connection at Clinton Avenue and Parkview Avenue

4.2 Flow Meter Sub-basins

The flow meters installed in the two flow monitoring programs divided the tributary areas into 16 sub-basins. These sub-basins are shown in **Figure 4-1** and described in the following table.

Table 4-2: Tributary Sub-basins (2007)

Program Year	Sub-basin	Discharges	Upstream Flows	Sub-basin Area (acres)
2007	Maryland Avenue	Discharges to Denver Ave cross-connection (FM#1)	No upstream flows	97
2007	Broad Street	Discharges to Powell Ave cross-connection (FM#3)	Receives flow from the Denver Ave cross-connection (FM#2)	108
2007	Powell Avenue	Discharges to Powell Ave cross-connection (FM#5)	No upstream flows	52
2007	East Main Street	Discharges to Charles Street cross-connection (FM#6)	Receives flow from the Powell Ave cross-connection (FM#4)	117
2007	Livingston Avenue	Gould Road Trunk Sewer (FM#7)	No upstream flows	102
2007	Charles Street (Columbus Trib Area)	Discharges to Columbus at Livingston Ave, east end (FM#8)	Receives flow from Livingston Ave Sub-basin (FM#7), East Main St Sub-basin (FM#6), and the Denver and Powell Avenue cross-connections	665

Table 4-3: Tributary Sub-basins (2011)

Program Year	Sub-basin	Discharges	Upstream Flows	Sub-basin Area (acres)
2011	1	Discharges to ACTS at Clifton Drive (FM #1 – Not Installed)	Receives flow Sub-basin 8 through a relief connection (FM #13)	77
2011	2/3	Discharges to ACTS at Bryden Road (FM #2) and East Main Street (FM #3)	Receives flow from Sub-basin 7 (FM #7) and Sub-basin 8 (FM #8)	137
2011	4	Discharges to ACTS at Village Creek Drive (FM #4)	No upstream flows, though a relief connection exists to Sub-basin 2/3 on East Main Street (no FM)	29
2011	5	Discharges to ACTS at Livingston Avenue, west end (FM #5)	Receives flow from Sub-basin 9 (FM #9) and from Sub-basin 7 through relief connections at Cassady and Main St (no FM) and Cassady and Bexley Park Rd (FM #10)	155
2011	6	Discharges to the ACTS in Livingston Avenue (FM #6)	No upstream flows	21
2011	7	Discharges to Sub-basin 2/3 (FM #7) and to Sub-basin 5 through relief connections at Main St and Cassady (no FM) and at Bexley Park Rd and Cassady (FM #10)	No upstream flows	143
2011	8	Discharges to Sub-basin 2/3 (FM #8) and to Sub-basin 1 through a relief connection (FM #13)	Receives flow from Sub-basin 12 (FM #12)	189
2011	9	Discharges to Sub-basin 5 (FM #9)	Receives flow from Sub-basin 11 (FM #11)	103
2011	11	Discharges to Sub-basin 9 (FM #11) and to Sub-basin 12 through a relief connection (no FM)	No upstream flows	214
2011	12	Discharges to Sub-basin 8 (FM #12)	Receives flow from Sub-basin 11 through relief connection at Broad St and Stanberry Ave (no FM)	35

4.3 Dry Weather Flow

Dry weather flow (DWF) consists of base infiltration and sanitary flow. Base infiltration represents groundwater infiltration that enters the sewer through leaky joints and cracked sections in the pipe. Sanitary flow represents the wastewater flow generated from residential, commercial and industrial sources.

Dry weather flow exhibits two distinct diurnal patterns – weekdays and weekends. Multiple dry weather days were used to formulate an average curve for each pattern. From the diurnal pattern, the average, peak and minimum daily dry weather flow is obtained. Base infiltration is estimated as a constant number equal to 85% of the minimum dry weather flow. The sanitary flow component is calculated by subtracting the base infiltration from the dry weather flow. The following table summarizes the dry weather flow components at each meter and provides the total net dry weather flow originating in Bexley.

Table 4-4: Dry Weather Flow Summary

Program Year	Flow Meter	Average DWF (cfs)	Peak DWF (cfs)
2007	#1	0.19	0.25
2007	#2	0.01	0.02
2007	#3	0.25	0.47
2007	#4	0.01	0.02
2007	#5	0.05	0.10
2007	#6	0.30	0.47
2007	#7	0.06	0.13
2007	#8	1.71	2.39
2011	#2	0.299	0.364
2011	#3	0.186	0.254
2011	#4	0.018	0.026
2011	#5	1.084	1.496
2011	#6	0.045	0.074
2011	#7	0.365	0.546
2011	#8	0.124	0.165
2011	#9	0.770	0.998
2011	#10	0.312	0.451
2011	#11	0.036	0.051
2011	#12	0.299	0.364

Table 4-5: Base Infiltration and Sanitary Flow Summary

Program Year	Flow Meter Sub-basin	Estimated Base Infiltration (cfs)	Base Infiltration Unit Rate (cfs per 100 acres)	Average Sanitary Flow (cfs)	Per capita Sanitary Flow (gpdc)
2007	Maryland Ave	0.085	0.088	0.095	35
2007	Broad St	0.119	0.110	0.131	64
2007	Powell Ave	0.009	0.016	0.041	42
2007	East Main St	0.077	0.043	0.133	42
2007	Livingston Ave	0.026	0.025	0.034	12
2011	2/3	0.198	0.144	0.102	51
2011	4	0.010	0.049	0.008	11
2011	5/7	0.123	0.040	0.251	45
2011	6	0.016	0.078	0.029	38
2011	8	0.046	0.024	0.042	48
2011	9	0.332	0.321	0.127	67
2011	11/12	0.142	0.058	0.206	58

4.4 Wet Weather Flow

4.4.1 Rainfall Observations

Rainfall data was used along with the flow meter data to approximate the amount of rainfall derived infiltration and inflow (RDII) that impacts the collection system after a rainfall event.

One rain gage was installed in the study area to collect rainfall data during the 2007 *Gould Road Sanitary Sewer Flow Monitoring* program and the 2011 *System-Wide Flow Monitoring Program*. The rain gage was located on the rooftop of the Municipal Building at 2242 East Main Street. Rainfall data was collected in 15-minute increments.

The rain gage began to malfunction in December of 2011, resulting in lost rainfall data thereafter. Rain Gage 24 of the City of Columbus' Rain Gage Network was used as a backup. RG 24 was installed at the Columbus Metropolitan Library on East Long Street, approximately a half mile west of Bexley's corporation limits.

Table 4-6 lists the rainfall events that occurred over the monitoring period that measured at a 2-month recurrence and over.

Table 4-6: Rainfall Event Summary

Event Start Date	Event Start Time	Event Duration (hrs)	Total Rain (in)	Peak Intensity (in/hr)	Return Frequency
5/16/2007	18:45	8	0.56	1.00	< 2-month
6/4/2007	1:00	2	0.26	0.36	< 2-month
6/4/2007	14:00	2	0.95	1.24	4-month
7/5/2007	9:30	1.25	1.31	1.88	2-year
7/27/2007		0.75	0.54		3-month
7/27/2007		0.75	1.66		10-year
8/5/2007		0.5	0.31		< 2-month
10/26/2010	13:45	5.5	0.89	1.72	4-month
11/16/2010	12:45	5.25	0.52	0.28	< 2-month
11/24/2010	16:45	33.25	2.09	0.60	9-month
11/30/2010	0:30	21	1.22	0.32	2-month
12/11/2010	19:20	14.75	0.68	0.24	< 2-month
12/30/2010	2:05	30.5	0.21	0.12	< 2-month
1/1/2011	3:15	9.92	0.32	0.24	< 2-month
1/18/2011	7:40	16	0.22	0.12	< 2-month
2/20/2011	13:45	28.67	1.16	0.72	2-month
2/24/2011	5:25	31.17	1.33	0.36	2-month
2/27/2011	19:30	10.83	0.57	2.16	4-month
3/4/2011	9:30	39	1.71	0.60	4-month
3/9/2011	0:50	61.5	1.58	0.24	3-month
3/21/2011	1:25	28.83	0.61	0.84	< 2-month

4.4.2 Rainfall Derived Infiltration and Inflow

Rainfall Derived Infiltration and Inflow (RDII) refers to the amount of stormwater entering a sanitary collection system. Stormwater can enter the sewer as both infiltration and inflow. Inflow sources include direct runoff connections to the sewer such as roof drains, basement drains, catch basins and leaky manhole covers. Stormwater that soaks into the ground can enter the sewer system as infiltration through cracks, leaky joints and other defects in the pipe and laterals.

RDII is quantified by subtracting the dry weather flow at the start of the event from the observed wet weather flow. The resulting volume will establish the total RDII volume. The percent capture of the system is the RDII volume divided by the total rainfall volume over the tributary area. This measurement is useful in identifying the extent of RDII problems among the metered sewer basins. From past experience, values less than 5% represent fairly "tight" systems. Percent capture values over 5% indicate that performance-related problems may exist in the sewer system.

Tables 4-7 and **4-8** list the calculated percent capture values for each flow monitoring sub-basin or combination of sub-basins in Bexley. Percent capture values are considerably affected by seasonal and antecedent moisture conditions, therefore, rainfall events occurring in the winter and spring often result in higher percent capture values than events in the summer. Evidently, the percent capture values significantly increased in February and March of 2011. In some cases, infiltration from a prior event was still evident at the start of a new event. For such cases, consecutive events were treated as a single event until DWF returned to within a normal range. The effect of seasonal and antecedent moisture conditions was not seen during the 2007 flow monitoring program. The monitoring took place during a dry spring and into the summer. It is suspected that the percent capture values for the sub-basins in the Gould Road tributary area will increase during saturated conditions. Overall, the percent capture values indicate that all sub-basins have elevated I/I and that performance and/or operational related problems may exist in the system.

Table 4-7: Percent Capture Summary (2007)

Rainfall Event Date	Maryland Avenue Sub-Area	Broad Street Sub-Area	Powell Avenue Sub-Area	E. Main Street Sub-Area	Livingston Avenue Sub-Area
5/16/2007	*	3.3 %	*	*	0.9 %
6/3/2007	*	3.7 %	*	4.5 %	1.7 %
7/4/2007	2.5 %	*	3.0 %	3.4 %	*
7/10/2007	2.5 %	4.9 %	2.1 %	2.5 %	*
7/27/2007	1.7 %	4.6 %	3.1 %	5.5 %	3.9 %
8/5/2007	2.6 %	4.9 %	2.5 %	4.5 %	*

** indicates that meter data is inconclusive for RDII analysis*

Table 4-8: Percent Capture Summary (2011)

Rainfall Event Date	Sub-Basin							
	2/3	4	5/7	6	8	9	11/12	9/11/12
10/26/2010	2.6%	*	2.1%	3.3%	4.0%	*	*	5.3%
11/24/2010	4.4%	0.2%	4.0%	5.9%	5.9%	*	*	8.1%
11/30/2010	4.8%	0.1%	5.9%	11.6%	9.3%	*	*	13.5%
12/12/2010	6.7%	*	9.4%	*	5.3%	*	*	9.8%
2/21/2011	35.5%	3.0%	15.9%	28.2%	24.2%	16.4%	32.7%	27.8%
3/4/2011	40.8%	10.5%	18.1%	36.6%	33.7%	34.3%	43.5%	40.6%
3/22/2011	8.8%	5.6%	11.0%	21.7%	8.7%	22.2%	11.8%	14.8%

** indicates that meter data is inconclusive for RDII analysis*

4.4.3 Wet Weather Performance

The wet weather performance in the system is evaluated by observing the sewer's response to rainfall events through flow monitoring. The observed peak values and flow characteristics aid in identifying any capacity issues in the trunk sewer. Scattergraphs, which plot the depth vs. velocity readings, provide critical insight to flow conditions in the sewer, such as backwater, debris, surcharge, and overflows. A summary of the flow observations at each meter location is described in the following subsections. The summaries include:

- Peak flow, depth and velocity recorded for each significant rainfall event.
- Capacity ratios to assess the available capacity remaining in the sewer. The following capacity ratios are calculated from the recorded flow data.
    - Percent Full – The ratio of the observed peak flow rate (Q_{meter}) to the sewer full capacity (Q_{full}) based on manning's equation will establish the percent full (Q_{meter} / Q_{full}).
    - Depth Ratio – The ratio of the maximum observed depth (d_{meter}) to the pipe diameter (D) will establish the depth ratio (d_{meter} / D).
- Peaking factor for each significant storm event, which is the ratio of the peak observed wet weather flow to the average daily dry weather flow.

4.4.3.1 Clifton Tributary Area

Discharge from the Clifton tributary area was not monitored due to a lack of a suitable flow meter location. This subarea is relatively small and services only 77 acres. No sewer performance issues are expected in this area.

4.4.3.2 Alum Creek Tributary Area

The Alum Creek tributary area has three discharges to the Alum Creek Trunk Sewer that are monitored by FM#2 at Bryden Road, FM#3 at Main Street and FM#4 at Village Creek.

- At FM#2, the peak observed flow reached 30% of the pipe capacity. High velocities are observed in the pipe due to a 16-ft drop in the upstream pipe. Upstream of the flow meter, the pipe has a lower capacity and the peak flow reached 68% of the pipe capacity. No abnormal conditions or deficiencies were observed in the flow.
- At FM#3, the peak observed flow reached 72% of the pipe capacity. High velocities are observed in the pipe due to a 7-ft drop in the upstream pipe. No abnormal conditions or deficiencies were observed in the flow.
- At FM#4, the peak observed flow reached only 4% of the pipe capacity. The sewer has very low velocity and flow. This sewer was originally sized for a larger tributary flow, however since the connection to the Alum Creek Trunk Sewer at East Main Street was completed, tributary flow now diverts directly to the trunk sewer at East Main Street instead. The scattergraph also shows some debris in the sewer, which is likely a result of low velocities that are unable to provide sufficient cleaning.

Table 4-9: Wet Weather Performance at Flow Meters #2, #3 & #4

Event	Diam (in)	Peak Depth (in)	Depth Ratio (%)	Peak Velocity (fps)	Pipe Capacity (cfs)	Peak Flow (cfs)	Percent Full (%)	Peaking Factor	Flow Conditions
Flow Meter #2									
2/21/11	15	4.4	29%	7.5	10.42	2.05	20%	6.9	Normal
2/24/11	15	5.1	34%	8.7	10.42	3.10	30%	10.4	Normal
2/27/11	15	4.8	32%	7.6	10.42	2.47	24%	8.3	Normal
3/4/11	15	5.3	35%	8.3	10.42	2.83	27%	9.5	Normal
3/9/11	15	5.1	34%	8.5	10.42	3.01	29%	10.1	Normal
Flow Meter #3									
2/21/11	18	7.9	44%	2.2	3.64	1.51	41%	8.1	Normal
2/24/11	18	9.5	53%	2.8	3.64	2.61	72%	14.0	Normal
2/27/11	18	8.4	46%	2.4	3.64	1.93	53%	10.4	Normal
3/4/11	18	9.3	51%	2.5	3.64	2.23	61%	12.0	Normal
3/9/11	18	9.0	50%	2.7	3.64	2.27	62%	12.2	Normal
Flow Meter #4									
2/21/11	15	3.9	26%	0.4	4.83	0.10	2%	5.6	Normal
2/24/11	15	4.3	29%	0.6	4.83	0.16	3%	9.2	Normal
2/27/11	15	4.8	32%	0.5	4.83	0.14	3%	8.0	Normal
3/4/11	15	4.1	28%	0.5	4.83	0.16	3%	8.9	Normal
3/9/11	15	4.3	29%	0.6	4.83	0.18	4%	10.0	Normal

The Parkview Avenue sewer collects flow from the northern portion of the tributary area and directs it south to the area's discharge locations. This sewer is monitoring by FM#8 in Parkview Avenue and FM#12 in Broad Street. FM#12 also picks up relieved flow from the Livingston Tributary Area. There is a connection to the Clifton tributary area that relieves flow in the Parkview Avenue sewer at Clifton Avenue. The relief is activated when the water depth reaches 0.5 feet in MH AL-123. This connection is monitored by FM#13 located on the relief sewer.

- At FM#8, the peak observed flow exceeded the capacity of the pipe during four events. The largest wet weather response occurred during the 2/24/2011 event, where the observed peak flow reached 131% of the pipe capacity resulting in one inch of surcharge. The peak velocities are higher than expected based on the manning's equation, which represents pressurized flow and free flow conditions downstream.

- At FM#12, the peak observed flow reached 52% of the pipe capacity. No abnormal conditions or deficiencies were observed in the flow.

- At FM#13, the peak observed flow reached 40% of the pipe capacity. This relief is only active during the larger rainfall events and activated seven times during the flow monitoring period. No abnormal conditions or deficiencies were observed in the flow.

Table 4-10: Wet Weather Performance at Flow Meters #8, #12 & #13

Event	Diam (in)	Peak Depth (in)	Depth Ratio (%)	Peak Velocity (fps)	Pipe Capacity (cfs)	Peak Flow (cfs)	Percent Full (%)	Peaking Factor	Flow Conditions
Flow Meter #8									
2/21/11	12	10.3	86%	3.1	2.17	2.15	99%	17.4	Normal
2/24/11	12	13.1	109%	3.6	2.17	2.84	131%	22.9	Surcharge
2/27/11	12	10.5	87%	3.2	2.17	2.28	105%	18.4	Normal
3/4/11	12	12.3	102%	3.5	2.17	2.75	127%	22.1	Surcharge
3/9/11	12	12.6	105%	3.5	2.17	2.78	128%	22.4	Surcharge
Flow Meter #12									
2/21/11	10	6.6	66%	1.5	1.49	0.55	37%	15.2	Normal
2/24/11	10	8.3	83%	1.7	1.49	0.76	51%	21.2	Normal
2/27/11	10	6.5	65%	1.7	1.49	0.55	37%	15.3	Normal
3/4/11	10	8.0	80%	1.6	1.49	0.71	48%	19.9	Normal
3/9/11	10	8.0	80%	1.7	1.49	0.77	52%	21.5	Normal
Flow Meter #13									
2/21/11	8	1.7	22%	3.5	1.13	0.19	17%	n/a	Normal
2/24/11	8	2.6	33%	4.5	1.13	0.45	40%	n/a	Normal
2/27/11	8	1.8	23%	2.4	1.13	0.14	13%	n/a	Normal
3/4/11	8	2.3	28%	4.0	1.13	0.33	29%	n/a	Normal
3/9/11	8	2.4	30%	4.2	1.13	0.37	33%	n/a	Normal

The Main Street sewer collects flow from the eastern portion of the tributary area and directs flow to the discharge at East Main Street. This sewer is monitored by FM #7. There are two connections upstream that relieve flow to the trunk sewer serving the Livingston Avenue tributary area. The connection in Cassady Avenue, north of Main Street, was monitored by FM#10. The connection at the intersection of Cassady Avenue and Main Street was not monitored.

- At FM#7, the peak observed flow reached 56% of the pipe capacity. During a wet weather field investigation, a large blockage was identified upstream of this meter. Wet weather flow that typically would be conveyed through this pipe was backed up and conveyed through the unmetered relief pipe at the intersection of East Main Street and Cassady Avenue and diverted south to FM #5. The blockage was reported to the City and appears to have been fully or partially removed during the March 22nd event.

- At FM#10, the observed flows were very low, with a peak observed flow of 0.11 cfs. The relief pipe is approximately 4 inches above the invert of the manhole at the level of the bench.

Table 4-11: Wet Weather Performance at Flow Meters #7 & #10

Event	Diam	Peak Depth	Depth Ratio	Peak Velocity	Pipe Capacity	Peak Flow	Percent Full	Peaking Factor	Flow Conditions
	(in)	(in)	(%)	(fps)	(cfs)	(cfs)	(%)		
Flow Meter #7									
2/21/11	12	3.2	27%	2.9	2.22	0.36	16%	n/a	Blockage upstream
2/24/11	12	2.9	24%	1.9	2.22	0.25	11%	n/a	Blockage upstream
2/27/11	12	1.9	16%	2.4	2.22	0.14	6%	n/a	Blockage upstream
3/4/11	12	3.0	25%	2.4	2.22	0.22	10%	n/a	Blockage upstream
3/9/11	12	3.5	29%	2.5	2.22	0.34	15%	n/a	Blockage upstream
Flow Meter #10									
2/21/11	12	0.9	8%	1.2	Unknown	0.05	n/a	n/a	
2/24/11	12	1.0	9%	1.5	Unknown	0.06	n/a	n/a	
2/27/11	12	1.1	9%	1.4	Unknown	0.06	n/a	n/a	
3/4/11	12	1.3	11%	1.2	Unknown	0.09	n/a	n/a	
3/9/11	12	1.4	11%	2.1	Unknown	0.11	n/a	n/a	

4.4.3.3 Livingston Tributary Area

The Livingston tributary area has one discharge to the Alum Creek Trunk Sewer. The majority of the flow to the discharge location is monitored by FM#5 near the west end of Livingston Avenue. A small portion of the Livingston tributary area that is missed by FM#5 is monitored by FM#6. These meters are installed in the same manhole.

- At FM#5, the peak observed flow reached only 40% of the pipe capacity. The flow exhibits higher than expected velocity based on the manning's equation, likely due to steep slope upstream.

- At FM#6, the peak observed flow reached only 9% of the pipe capacity. Due to the hydraulics of the manhole, the depth vs. velocity relationship is very inconsistent.

Table 4-12: Wet Weather Performance at Flow Meters #5 & #6

Event	Diam	Peak Depth	Depth Ratio	Peak Velocity	Pipe Capacity	Peak Flow	Percent Full	Peaking Factor	Flow Conditions
	(in)	(in)	(%)	(fps)	(cfs)	(cfs)	(%)		
Flow Meter #5									
2/21/11	27	8.9	33%	5.0	20.78	5.64	27%	5.2	Normal
2/24/11	27	10.3	38%	5.8	20.78	7.82	38%	7.2	Normal
2/27/11	27	10.5	39%	5.5	20.78	7.51	36%	6.9	Normal
3/4/11	27	10.8	40%	5.7	20.78	8.04	39%	7.4	Normal
3/9/11	27	11.2	42%	5.8	20.78	8.35	40%	7.7	Normal
Flow Meter #6									
2/21/11	15	3.7	24%	1.8	3.77	0.34	9%	7.6	Normal
2/24/11	15	4.1	27%	1.3	3.77	0.33	9%	7.4	Normal
2/27/11	15	3.7	25%	1.3	3.77	0.29	8%	6.4	Normal
3/4/11	15	3.6	24%	1.9	3.77	0.32	8%	7.1	Normal
3/9/11	15	3.6	24%	1.8	3.77	0.30	8%	6.7	Normal

The main trunk sewer in this tributary area is also monitored by FM#9 at Cassady Ave and Bexley Park Road, and by FM#11 at Dawson Avenue south of Broad Street. At Dawson Avenue and Broad Street, flow can be relieved to the Alum Creek Tributary Area. The relief is activated when the water depth reaches 3.55 feet in MH LI-135. Flow being relieved to the west is tributary to FM#12.

- At FM #9, the peak observed flow reached 100% of the pipe capacity. This occurred on 3/9/2011 and was measured as a 3-month event with 1.58 inches of rain. Despite not exceeding the pipe capacity, the sewer has surcharged during three events. On 2/24/2011, which was a 2-month event with 1.33 inches of rain, the sewer surcharged 1.35 feet above the crown of pipe. The peak velocities are higher than expected based on the manning's equation.

- At FM #11, the peak observed flow exceeded the capacity of pipe three times, reaching up to 108% of the pipe capacity. The sewer surcharged on 2/24/2011 almost an inch above the crown of pipe. The scattergraph also indicates there was a slight backwater condition. The peak velocities are also higher than expected based on the manning's equation.

Table 4-13: Wet Weather Performance at Flow Meters #9 & #11

Event	Diam	Peak Depth	Depth Ratio	Peak Velocity	Pipe Capacity	Peak Flow	Percent Full	Peaking Factor	Flow Conditions
	(in)	(in)	(%)	(fps)	(cfs)	(cfs)	(%)		
Flow Meter #9									
2/21/11	18	12.1	67%	4.0	5.36	4.55	85%	6.3	Normal
2/24/11	18	34.2	190%	4.2	5.36	5.21	97%	7.3	Surcharge
2/27/11	18	13.0	72%	4.3	5.36	4.76	89%	6.6	Normal
3/4/11	18	27.6	153%	4.2	5.36	5.28	98%	7.3	Surcharge
3/9/11	18	23.5	130%	3.9	5.36	5.36	100%	7.5	Surcharge
Flow Meter #11									
2/21/11	18	11.4	63%	3.0	3.93	3.09	79%	9.9	Normal
2/24/11	18	18.3	102%	3.3	3.93	4.17	106%	13.4	Surcharge & Slight backwater
2/27/11	18	11.4	63%	3.1	3.93	3.10	79%	9.9	Normal
3/4/11	18	14.4	80%	3.4	3.93	4.24	108%	13.6	Normal
3/9/11	18	13.3	74%	3.5	3.93	4.20	107%	13.4	Normal

4.4.3.4 Gould Tributary Area

The capacity of the Gould Road Trunk Sewer can be evaluated at four meter locations. These locations are downstream of the tributary sub-areas and upstream of the cross-connections.

- FM#1 receives tributary flow from the Maryland Avenue Sub-Area. It is also upstream of the Denver Avenue cross-connection.
- FM#3 receives tributary flow from the Broad Street Sub-Area in addition to upstream tributary flow that conveys through the Denver Avenue cross-connection. It is also upstream of the Powell Avenue cross-connection.
- FM#6 receives tributary flow from the East Main Street Sub-Area in addition to tributary flow that conveys through the Powell Avenue cross-connection.
- FM#8 receives all tributary flow and outlets to the City of Columbus collection system

Table 4-14 lists the peak meter readings and capacity ratios for each of the major storm events. The meter readings show that the Gould Road Trunk Sewer did not reach full pipe capacity during the monitoring period. The largest percentage of full pipe capacity was achieved during the July 27, 2007 afternoon event, which had a 10-year recurrence. During this event, the trunk sewer reached approximately 70% of its capacity. Also during this event, the depth ratio indicates that the water level in the trunk sewer did not rise much more than half the pipe upstream the Charles Street cross-connection.

The flow monitoring data did not reveal any backup conditions in the Gould Road Trunk Sewer during the rainfall events encountered. The sanitary flow appears to be flowing under steady-state conditions. However, at the outlet to the City of Columbus (Meter GU-100), the velocity is observed to be abnormally slow and the depth ratios are relatively high. This is a result of a change of slope in the 48-in trunk sewer. The 48-in pipe begins at 0.50% slope downstream of Manhole GU-103, where the 45-in Truro Trunk Sewer discharges. The slope changes to 0.08% between Manholes GU-101 and GU-100. And finally, the section downstream of Manhole GU-100, which is a part of the Truro #1 Subtrunk of the City of Columbus, has a slope of -0.63% based on RP-4860. After that pipe section, the Subtrunk continues with a 0.24% slope. The decrease in slope will cause a drop in velocity and an increase in depth.

The 8-in pipe in Powell Avenue discharging to Manhole GU-121 of the Gould Road Trunk Sewer, where the Powell Avenue cross-connection exists, appears to be affected by backwater conditions. The flow monitoring data shows that the depth jumps when the flow exceeds 0.20 cfs. Despite the backwater conditions, the depth did not exceed 6-in during any of the rainfall events. Possible explanations for the backwater condition include sagging, broken or collapsed pipe and the malfunction of the outside drop at the Powell Avenue cross-connection.

The 10-in pipe in the alley north of Livingston Avenue discharging to Manhole GU-101 of the Gould Road Trunk Sewer reached 98% of its flowing full capacity during the July 27, 2007 rainfall event. The depth ratio during this event was 71%.

Table 4-14: Gould Road Trunk Sewer Wet Weather Performance

Storm Event	Pipe Characteristics		Flow Meter Readings			Capacity Ratios	
	Pipe Size (in.)	Pipe Capacity (cfs)	Peak Level (in.)	Peak Velocity (fps)	Peak Flow (cfs)	Depth Ratio (%)	Percent Full (%)
Meter GU-130							
7/27/07 PM	12	1.59	6.32	2.63	1.10	53 %	69 %
7/04/07	12	1.59	4.99	2.33	0.65	42 %	41 %
6/3/07 PM	12	1.59	6.27	2.64	1.10	52 %	71 %
7/27/07 AM	12	1.59	3.39	1.81	0.33	28 %	21 %
5/16/07	12	1.59	3.50	2.70	0.59	29 %	37 %
6/3/07 AM	12	1.59	4.33	1.94	0.50	36 %	32 %
8/5/07	12	1.59	3.78	2.02	0.41	31 %	26 %
Meter GU-121							
7/27/07 PM	18	5.15	8.22	3.18	2.37	46 %	45 %
7/04/07	18	5.15	6.53	3.32	1.44	36 %	28 %
6/3/07 PM	18	5.15	7.06	3.53	1.70	39 %	33 %
7/27/07 AM	18	5.15	4.66	2.41	0.64	26 %	12 %
5/16/07	18	5.15	5.50	2.97	0.98	31 %	19 %
6/3/07 AM	18	5.15	5.42	3.36	1.08	30 %	21 %
8/5/07	18	5.15	4.41	2.59	0.87	25 %	17 %
Meter GU-104							
7/27/07 PM	18	6.81	9.13	5.26	4.56	51 %	67 %
7/04/07	18	6.81	5.28	4.87	2.10	29 %	31 %
6/3/07 PM	18	6.81	4.96	4.84	1.83	28 %	27 %
7/27/07 AM	18	6.81	2.81	3.84	0.68	16 %	10 %
5/16/07	18	6.81	3.03	4.17	0.82	17 %	12 %
6/3/07 AM	18	6.81	3.26	4.26	0.91	18 %	13 %
8/5/07	18	6.81	3.05	3.83	0.75	17 %	11 %
Meter GU-100							
7/27/07 PM	48	40.63	36.60	1.90	19.15	76 %	47 %
7/04/07	48	40.63	28.84	1.65	12.69	60 %	31 %
6/3/07 PM	48	40.63	26.48	1.56	10.78	55 %	27 %
7/27/07 AM	48	40.63	17.90	0.75	3.09	37 %	8 %
5/16/07	48	40.63	18.66	0.96	4.15	39 %	10 %
6/3/07 AM	48	40.63	19.06	0.97	4.34	40 %	11 %
8/5/07	48	40.63	19.54	0.76	3.46	41 %	9 %

Figure 4-2 presents an overview of the wet weather performance by illustrating the peak flow, percent full and depth ratio within the system for the largest rainfall event, which occurred on July 27, 2007. The system reached 45% to 65% of its capacity and appears to be operating under normal conditions.

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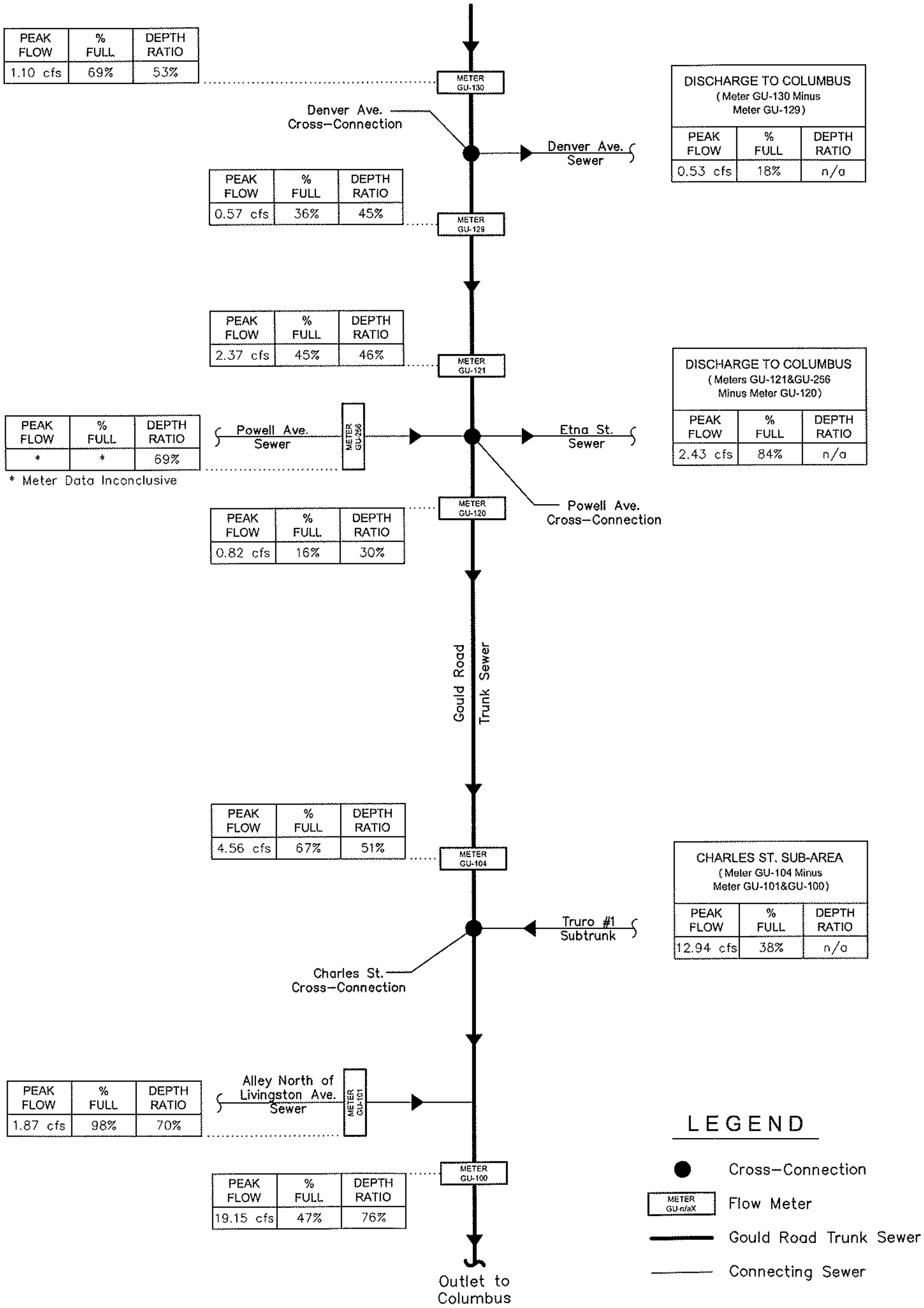

Figure 4-2: Gould Road Wet Weather Performance Overview

4.5 Performance of Gould Road Cross-Connections

There are three cross-connections with the City of Columbus along the Gould Road Trunk Sewer. The performance of each cross-connection has been examined through flow monitoring. By adding and subtracting metered flows, the flow to/from Columbus is estimated. **Figure 4-3** illustrates the flow balance at each cross-connection by way of the percentage of peak wet weather flow entering and exiting. The cross-connection performance is described in more detail in the following sections.

4.5.1 Denver Avenue Cross-Connection (Discharge)

The Denver Avenue cross-connection discharges flow from the Gould Road Trunk Sewer to the City of Columbus. Flow meters are located on the Gould Road Trunk Sewer upstream (Meter GU-130) and downstream (meter GU-129) of the cross-connection. The 15-in pipe that discharges flow to the Columbus is not metered; however, the flow can be calculated by subtracting the metered flow downstream from the metered flow upstream (Meter GU-130 minus Meter GU-129).

Meter GU-129, located downstream of the cross-connection, shows a significant drop in average dry weather flow after the June 4th rainfall event. Before the event, approximately 80% to 90% of the average dry weather flow entering the Denver Avenue cross-connection flows south in the Gould Road Trunk Sewer and remains in the Bexley sewer system. This means that only 10% to 20% of the average daily flow is being diverted to the City of Columbus. However, after the June 4th rainfall event, approximately 94% of the average dry weather flow is diverted to the City of Columbus, while only 6% remains in the Bexley sewer system. After CCTV inspection of the Gould Road Trunk Sewer between Manhole GU-129 and GU- 129a, no apparent blockage was found. It is likely that a small blockage had occurred in the relief pipe to Columbus and the June 4th rainfall event flushed it away.

The suspected blockage does not appear large enough to have a significant effect on the wet weather flow characteristics. During the largest 3 storm events, the flow split is approximately 50%. During the smaller storm events, about 65%-85% of the flow stays in the Gould Road Trunk Sewer, while only 15%-35% enters the City of Columbus.

4.5.2 Powell Avenue Cross-Connection (Discharge)

The Powell Avenue cross-connection discharges flow from the Gould Road Trunk Sewer to the City of Columbus. Flow meters are located on the Gould Road Trunk Sewer upstream (Meter GU-121) and downstream (Meter GU-120) of the cross-connection. There is also a meter on the 8-inch sewer to the east (Meter GU-256), which conveys flow from the Powell Avenue Sub-Area into the trunk sewer. The 21-in pipe that discharges flow to Columbus is not metered; however, the flow can be calculated by adding the metered flow at the two upstream connections and then subtracting the metered flow downstream from the metered flow upstream (Meter GU-121 plus Meter GU-256, minus Meter GU-120).

Based on the average daily flows obtained at the flow metering locations, it appears that approximately 95% of the dry weather flow is diverted to the City of Columbus through the Powell Avenue cross-connection. This results in about 5% of the dry weather flow staying in the

Gould Road Trunk Sewer. During wet weather, approximately 70%-90% of the flow is diverted to the City of Columbus while only 10%-30% stays in the Gould Road Trunk Sewer.

4.5.3 Charles Street Cross-Connection (Inflow)

The Charles Street cross-connection is where the Gould Road Trunk Sewer serving the City of Bexley joins with the Truro #1 Subtrunk serving the City of Columbus. One flow meter is located upstream (Meter GU-104) of the cross-connection and two meters are located downstream. The downstream meters are located at the outlet to the City of Columbus (Meter GU-100) and at the 12-in sewer conveying flow from the Livingston Avenue Sub-Area into the Gould Road Trunk Sewer at the alley north of Livingston Avenue (Meter GU-101). The flow from the two downstream meters can subtracted from the flow upstream to estimate the flow entering the system from the City of Columbus at the Charles Street cross-connection (Meter GU-104 minus Meters GU-100 and GU-101). This calculated flow from Columbus at the Charles Street will also include a small amount of flow discharging to the Gould Road Trunk Sewer from a 15-in sewer to the east located in the alley north of Livingston Avenue.

From the observed flow monitoring data, it is estimated that the Bexley collection system contributes only 20%-30% of the flow discharging to Columbus at the outlet. The 45-in Truro #1 Subtrunk flowing into the Charles Street cross-connection accounts for approximately 70%-80% of the total flow at the outlet to the City of Columbus at Livingston Avenue.

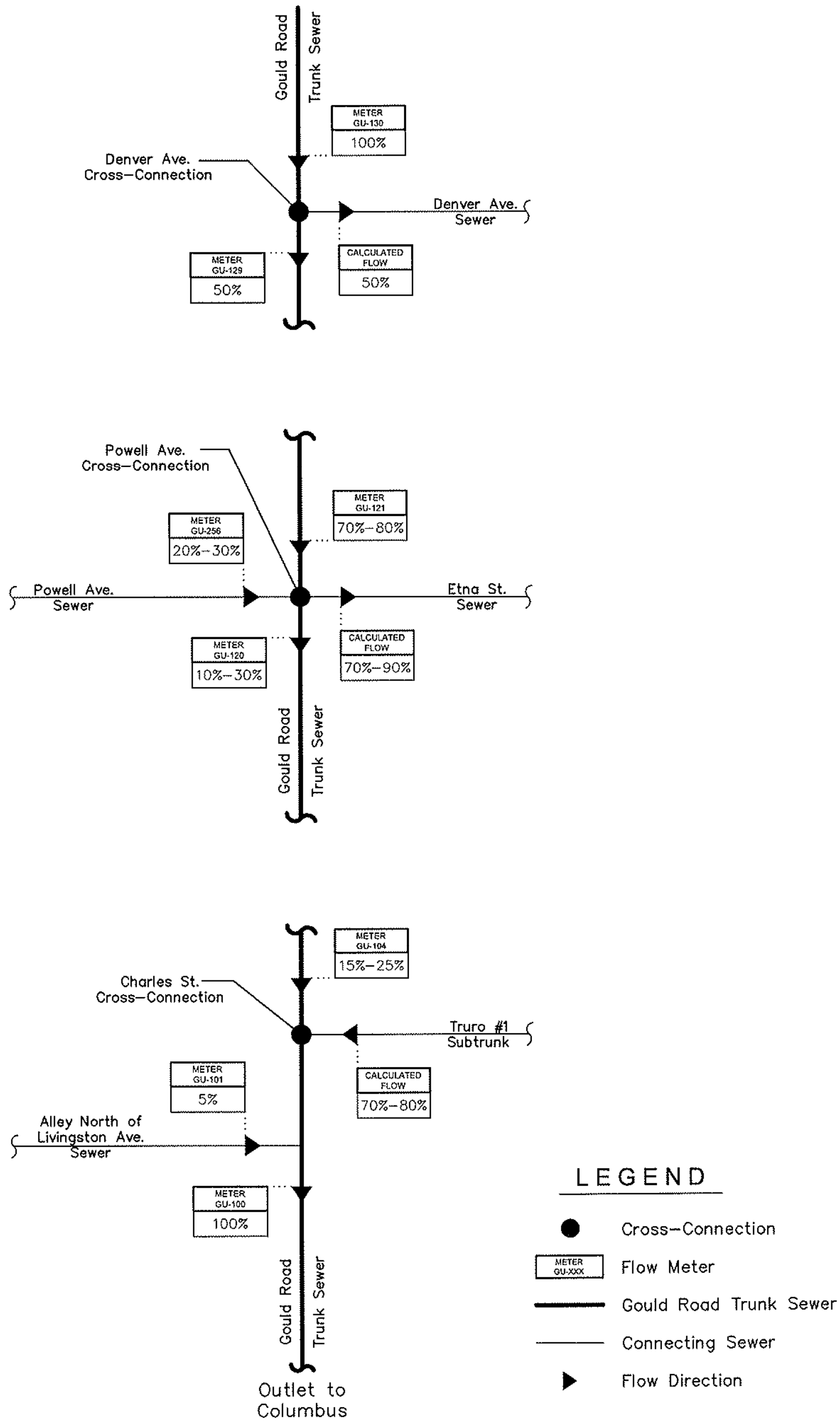

Figure 4-3: Cross-Connection Performance Wet Weather Flow Balance

4.5.4 Impact of Cross-Connections on Capacity

To determine the impact of the cross-connections to the City of Columbus, it is necessary to determine the performance of the Gould Road Trunk Sewer considering only the sanitary flow and infiltration from the City of Bexley. To accomplish this, the calculated peak flows leaving and entering the trunk sewer from the City of Columbus at the cross-connections have been removed from the Gould Road Trunk Sewer. However, the smaller 8-in sewers from the City of Columbus that discharge into the trunk sewer will remain. **Table 4-15** shows the estimated peak flows in the Gould Road Trunk Sewer without the cross-connections.

Table 4-15: Predicted Gould Rd Trunk Sewer Performance w/o Cross-Connections

Flow Meter Location	Pipe Capacity (cfs)	Average Dry Weather Flow (cfs)	07/27/07 PM Rainfall Event (10-Year Recurrence)	
			Peak Flow (cfs)	Percent Full (%)
MH GU-130	1.59	0.18	1.10	69 %
MH GU-121	5.15	0.46	2.90	56 %
MH GU-104	6.81	0.71	7.52	110 %
MH GU-100	40.63	0.77	9.17	23 %

The table indicates that without the two cross-connections at Denver Avenue and Powell Avenue, the Gould Road Trunk Sewer may experience capacity limitations upstream of MH GU-104. For the July 27, 2007 rainfall event, this 18-in sewer section has exceeded its capacity by reaching 110% of its calculated flowing full capacity. In addition, the 48-in pipe downstream of MH GU-103 is oversized without the Truro #1 Subtrunk discharging into it.

4.6 Sanitary Sewer Design Calculations

Sanitary flow at the metered locations in Bexley is also evaluated utilizing the City of Columbus Sanitary Sewer Design Standards. The design flows are calculated based on the existing service area and population estimates and are compared to the observed peak flows to assess the performance of the sewershed. Future tributary area was not considered in this study because the City of Bexley is fully developed. The following general design assumptions were made accordingly to calculate the expected sanitary flows:

- Average sanitary flow per capita is 0.0002 cfs (130 gpd)
- Peaking factor is 3.5
- Infiltration is 0.003 cfs per acre

The 2011 population for the Clifton, Livingston and Alum Creek Tributary areas was estimated using the following densities.

- Single-family units: 2.9 people per unit
- Multi-family units: 2.2 people per unit

- Commercial areas: 10 people per acre
- Schools: uses an equivalent population of 0.15 person per student

University housing dormitories and apartments were included in addition to the estimated school equivalent population. The housing population was estimated using the occupancy listed under the school's website for university housing.

Table 4-16 summarizes the design flows for Bexley at each 2011 monitoring location and compares the expected design flow for the service area to the peak flow observed during the flow monitoring period. The calculated design flows do not account for any flow lost or gained in a sub-basin through relief connections. The total design flow for the system is also calculated and compared to the total peak flow exiting the system calculated by adding together the peak flow at each discharge point.

Table 4-16: Design Flow Summary

Sub-Basin	Flowing Full Pipe Capacity at FM (cfs)	Design Calculations**			Flow Meter Data			Observed Flow Greater than Design Flow?
		Sub-Basin Design Flow (cfs)	Total Design Flow at FM (cfs)	Design Percent Full at FM	Peak Observed Flow from Sub-Basin (cfs)	Total Observed Flow at FM (cfs)	Peak Observed Percent Full at FM	
1	0.76	0.47	0.47	62%	Not Metered			Indeterminate
2/3	#2- 4.57 #3- 3.71	1.35	3.75	45%	2.62	5.71	69%	Yes
4	#4- 4.83	0.40	0.40	8%	0.18	0.18	4%	No
5	#5- 20.78	1.87	5.22	25%	3.00	8.35	40%	Yes
6	#6- 3.77	0.41	0.41	11%	0.34	0.34	9%	No
7	#7- 2.22	1.24	1.24	56%	1.23	1.23	56%	Yes
8	#8- 2.17	0.98	1.15	53%	2.53	2.78	131%	Yes
9	#9- 5.36	1.17	3.35	63%	1.66	5.36	100%	Yes
11	#11- 3.93	2.18	2.18	55%	4.24	4.24	108%	Yes
12	#12- 1.49	0.17	0.17	11%	0.77	0.77	52%	Yes
System Total			**9.76**			**14.49**		**Yes**

***Design calculations do NOT consider flow lost or gained through relief connections between sub-basins.*

The 2007 population for the Gould Road tributary area was estimated using the following densities.

- Single-family residential density is 3.5 people per unit
- Multi-family residential density is 24 people per acre
- Commercial density is 10 people per acre

Table 4-17 compares the observed peak flow in the Gould Road Trunk Sewer to the calculated City of Columbus design flow for the sewer. Based on sanitary sewer design calculations, the Gould Road Trunk Sewer is near full capacity at manholes GU-130 and GU-104. The design calculations do not take into account the existing cross-connections discharging to Columbus at Powell Avenue and Denver Avenue. These cross-connections will aid the Gould Road Trunk Sewer in conveying tributary flow to the outlet at Livingston Avenue. For the rainfall event of July 27, 2007, the observed flow did not surpass the calculated design flow in the Gould Road Trunk Sewer due to the existing cross-connections.

The calculated design flows for both the 8-in sewer in Powell Avenue and the 10-in sewer in the alley north of Livingston Avenue come close to the flowing full pipe capacity. This leaves a very small factor of safety to accommodate severe rainfall and infiltration.

Table 4-17: Comparison of Observed Flows to City of Columbus Design Standards

Sub-Basin	Meter Location	Full Pipe Capacity	Design Calculations**		Flow Meter Data (7/27/07 Event)		Observed Flow Greater than Design Flow?
		cfs	cfs	% full	cfs	% full	
Maryland Ave	GU-130	1.59	1.52	96 %	1.10	69 %	No
Broad St	GU-121	5.15	2.77	54 %	2.37	46 %	No
Main St	GU-104	6.81	5.33	78 %	4.56	67 %	No
Charles St	GU-100	40.63	14.52	36 %	19.15	47 %	Yes
Powell Ave	GU-256	0.66	0.6	90 %	*	*	Indeterminate
Livingston Ave	GU-101	1.90	1.21	63 %	1.87	98 %	Yes

**indicates that meter data is inconclusive*
***Design calculations do NOT consider flow lost or gained through relief connections between sub-basins.*

4.7 Assessment of Tributary Sub-Basins

One of the goals of the flow monitoring programs is to evaluate the City's sanitary sewer collection system to determine if the system has sufficient capacity to provide service to the tributary area and/or is experiencing excessive I/I.

The criteria selected for determining if a system has excessive I/I is based on the City of Columbus Sanitary Sewer Design Standards. Excessive I/I in a tributary area is defined in this report as having observed peak flows during the flow monitoring period exceeding the expected design flow based on the Sanitary Sewer Design Standards.

The observed peak flows at the flow meters met or exceeded the design standards in most sub-basins. Operational and performance related issues are identified by assessing the wet weather performance at the flow monitoring locations. Surcharge is a key indicator of performance issues in the sewer and was present at FMs #8, #9 and #11, which are located in the trunk sewers in Parkview Avenue and Cassady Avenue. The observed percent capture values, which are the percentage of rainfall that enters the system, are also an indicator. Percent capture values over 5% indicate that performance-related problems may exist. Every sub-basin within the Alum Creek and Livingston tributary areas showed a 10% capture and greater. The sub-basins within the Gould Road tributary area showed percent capture values less than 5%, however, the flow monitoring was performed during dry conditions. It is suspected that the percent capture values will increase during more saturated periods.

If the tributary area is determined to have excessive I/I, or operational/performance-related issues are identified, then it is recommended that a detailed sanitary sewer evaluation survey (SSES) be performed to identify sources of I/I. Tributary areas which do not have excessive I/I are recommended to be integrated into a Capacity, Management, Operation and Maintenance (CMOM) program.

Table 4-18: Recommendation Summary

Sub-Basin	Sub-Basin Tributary Area (acres)	Exceed City of Columbus Design Standards	Operational or Performance-Related Issues Identified	Recommendation
Maryland Ave	97	No	Yes	SSES
Broad St	108	No	Yes	SSES
Main St	117	No	Yes	SSES
Powell Ave	52	Indeterminate	Yes	SSES
Livingston Ave	75	Yes	Yes	SSES
1	77	Indeterminate	Indeterminate	SSES
2/3	137	Yes	Yes	SSES
4	29	No	Yes	SSES
5	182	Yes	Yes	SSES
6	21	No	Yes	SSES
7	143	Yes	Yes	SSES
8	189	Yes	Yes	SSES
9	103	Yes	Yes	SSES
11	214	Yes	Yes	SSES
12	35	Yes	Yes	SSES

5.0 HYDRAULIC MODELING

Hydraulic modeling involves the development of a calibrated/verified computer model to simulate the hydrology and the hydraulic capacity of the sanitary sewer collection system and to identify deficiencies. The model is developed with the use of record plan information to determine the existing physical characteristics of the sewer collection system including: pipe material, size, and slope along with flow data collected during flow monitoring. The model will be utilized to evaluate the existing conditions and alternative proposed improvements in the sanitary sewer system.

A hydraulic and hydrologic model was created for Bexley's sanitary sewer system in the Alum Creek and Livingston Tributary Areas in order to further assess the wet weather capacity and performance of the existing sewer system and to evaluate alternative improvements to address its deficiencies. The US Environmental Protection Agency (EPA) Storm Water Management Model 5.0 (SWMM5) was utilized for this study.

5.1 Model Development

This section will describe the development and calibration of the hydraulic model for the City of Bexley's sanitary collection system in the Alum Creek and Livingston tributary areas. The system is modeled using the Storm Water Management Model (SWMM5).

5.1.1 System Model Configuration

The model for the Bexley's Alum Creek and Livingston tributary areas consists of all pipes that provide the main conveyance in the system. This generally includes pipes 12-in and larger and smaller pipes as needed to replicate the hydraulics of the system. Sewer sizes and slopes are based on record plan information.

All associated manholes are included and are numbered based on Bexley's manhole numbering system. Manhole inverts use NAVD 1988 datum.

There are five outfalls in the model as follows.

1. Outfall to Clifton Tributary Area at Clifton Avenue (CL-118)
2. Outfall to Alum Creek Trunk Sewer at Bryden Road (AL-240)
3. Outfall to Alum Creek Trunk Sewer at Main Street (AL-110)
4. Outfall to Alum Creek Trunk Sewer at Village Creek (AL-103)
5. Outfall to Alum Creek Trunk Sewer at Livingston Avenue (LI-100)

Figure 5-1 illustrates the conduits (pipes), junctions (manholes) and outfalls that comprise the modeled system for the City of Bexley.

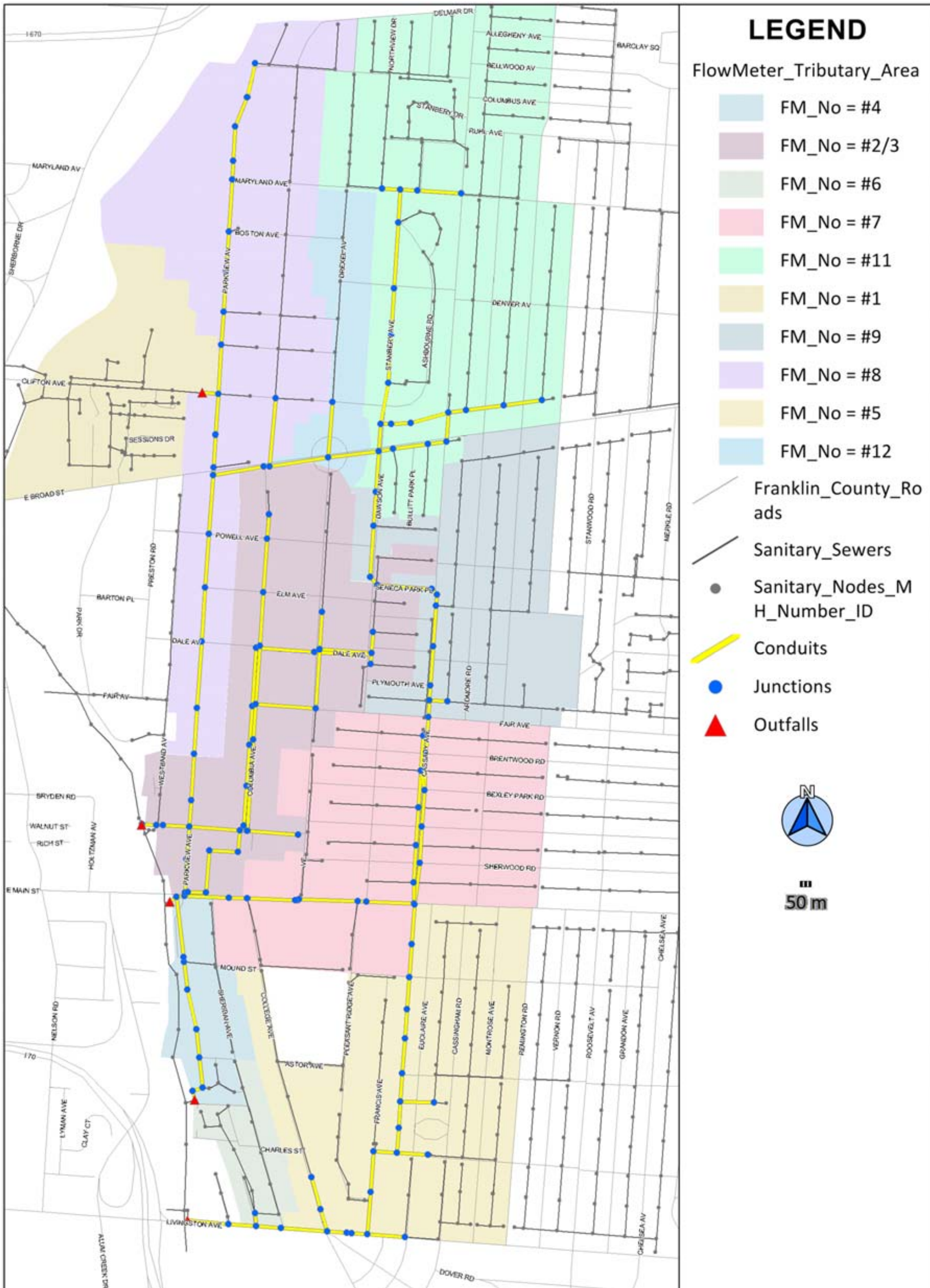

Figure 5-1: Modeled System for City of Bexley

5.1.2 Developmental Conditions

The 2011 developmental conditions were used in the model. The City of Bexley is fully developed and no future conditions are considered as a part of this study.

5.1.3 Model Calibration

Model calibration utilized flow monitoring and rain gage data from December 10, 2010 to April 1, 2011. This period represents winter and spring seasons, which tend to produce larger peak flow and percent captures than during the summer.

The one-month period from February 21, 2011 to March 19, 2011 was a very saturated period that produced particularly high peak flows and showed high infiltration. Five consecutive rainfall events occurred with a 2-month to 4-month return frequency totaling over 6 inches of rain. During this time, the flow did not return to dry weather flow levels due to long-term infiltration caused by saturated soils. This saturation period, which is representative of the worst-case conditions throughout the year, was the main focus for the calibration. **Figure 5-2** displays the rainfall and flow observed during the flow monitoring period used for model calibration.

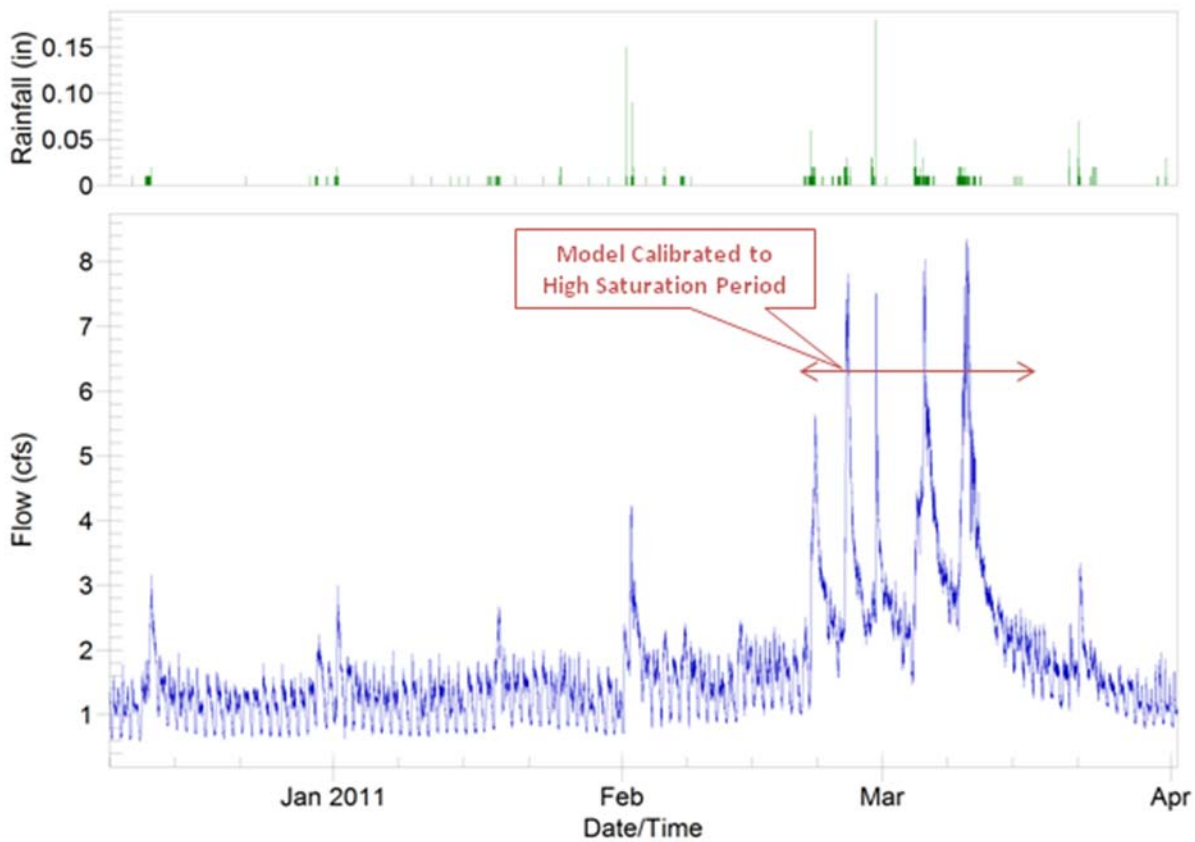

Figure 5-2: Calibration Period Rainfall and Flow Data

A continuous simulation over the flow monitoring period from December 10, 2010 to April 1, 2011was established. The estimated sewer flow in the model is generated from three flow components: groundwater infiltration, sanitary flow and RDII. In addition, initial abstraction parameters are added to account for antecedent moisture conditions. And the depth vs. velocity relationship in the pipe is calibrated to account for debris and blockages in the system. The following subsections discuss the calibration of each component to develop a well calibrated system model.

5.1.3.1 Groundwater Infiltration

Groundwater infiltration is entered into the model as a base flow at each input node with tributary area assigned. Estimated infiltration rates from the flow meter data is distributed evenly across each sub-basin per the unit groundwater infiltration rate. The groundwater infiltration is estimated to be 85% of the average dry weather flow. **Table 5-1** lists the estimated groundwater infiltration rate for each sub-basin.

5.1.3.2 Sanitary Flow

An average sanitary flow value is assigned to each input node with tributary service area in the model based on the per capita sanitary flow determined from the flow monitoring and the estimated population to each input node. **Table 1** lists the per capita sanitary flow estimated for each sub-basin.

Dry weather flow diurnal patterns determined from flow meter data are applied to the average sanitary flow.

Table 5-1: Dry Weather Flow Parameters

Sub-Basin #	Net Avg. Daily DWF (cfs)	Estimated Population (Capita)	Per Capita Sanitary Flow (gpdc)	Sub-Basin Tributary Area (ac)	Estimated Groundwater Infiltration (cfs/100ac)
2/3	0.300	1,308	50	137.3	0.144
4	0.018	467	11	21	0.049
5/7	0.374	3,641	45	297.9	0.041
6	0.045	498	38	20.7	0.078
8	0.088	564	48	193	0.024
9	0.458	1,221	67	103.4	0.321
11/12	0.348	2,292	58	244.4	0.058

5.1.3.3 Rainfall Derived Infiltration and Inflow

RDII is calculated in the model using the unit hydrograph method. The unit hydrograph contains three sets of RTK values representing the short term, medium-term and long-term response in the sewer. RTK values were calibrated to match the shape of the observed flow data.

- The R-value represents the fraction of rainfall that becomes RDII. This value corresponds to the percent capture of the system.

- The T-value is the time to peak in hours.

- The K-value is a constant that determines the receding limb of the triangle.

Table 5-2 lists the calibrated RTK values used for each sub-basin. The majority of the RDII volume is in the form of long-term infiltration, which indicates that the system is slowly draining the surrounding soil through either defects in the pipes and laterals or through connected foundation drains. It also shows that the sub-basins with the largest volume of rainfall entering the system are Sub-Basins #2/3, #6, #8 and #11/12.

Table 5-2: RDII Parameters

Sub-Basin #	Short-Term			Medium-Term			Long-Term			Total R-Value
	R1	T1	K1	R2	T2	K2	R3	T3	K3	
2/3	0.04	0.25	15	0.09	4	5	0.25	12	12	0.38
4	0.02	0.25	15	0.03	4	4	0.05	12	12	0.10
5/7	0.025	0.25	15	0.05	4	5	0.10	12	12	0.175
6	0.05	0.25	15	0.08	4	4	0.27	12	12	0.40
8	0.05	0.25	15	0.08	4	4	0.17	12	12	0.30
9	0.03	0.25	15	0.05	4	5	0.10	12	12	0.18
11/12	0.06	0.25	15	0.13	4	4	0.27	12	12	0.46

5.1.3.4 Sewer Blockages and Debris

Once the flow is calibrated, the depth and velocity in the pipe is calibrated by including pipe deficiencies that cause changes in depth and velocity. Pipe deficiencies are simulated in the model by increasing the manning's coefficient. The observed flow meter data and the age of the sewer pipe provide clues as to where these pipe deficiencies are.

One specific sewer blockage was found during the flow monitoring period. The blockage was found in the sewer segment in Main Street, between Drexel and College Ave (AL-157a:AL-156) in Sub-Basin #7. This blockage forced flow to back up and flow through the relief connection at the intersection of Main St and Cassady into Sub-Basin #5. The blockage was accounted for in the model by decreasing the diameter of the blocked pipe from 12 inches to 1.2 inches. It is necessary to include this blockage in the model for calibration; however, the blockage will be removed for system evaluation.

5.1.3.5 Calibration Plots

Calibration plots illustrating the observed vs. computed depth, velocity and flow at each meter location have been provided to the City in a detailed report. **Figure 5-3** illustrates the observed vs. computed peak flows plotted on a 45-degree line to reflect the overall accuracy of the calibrated model.

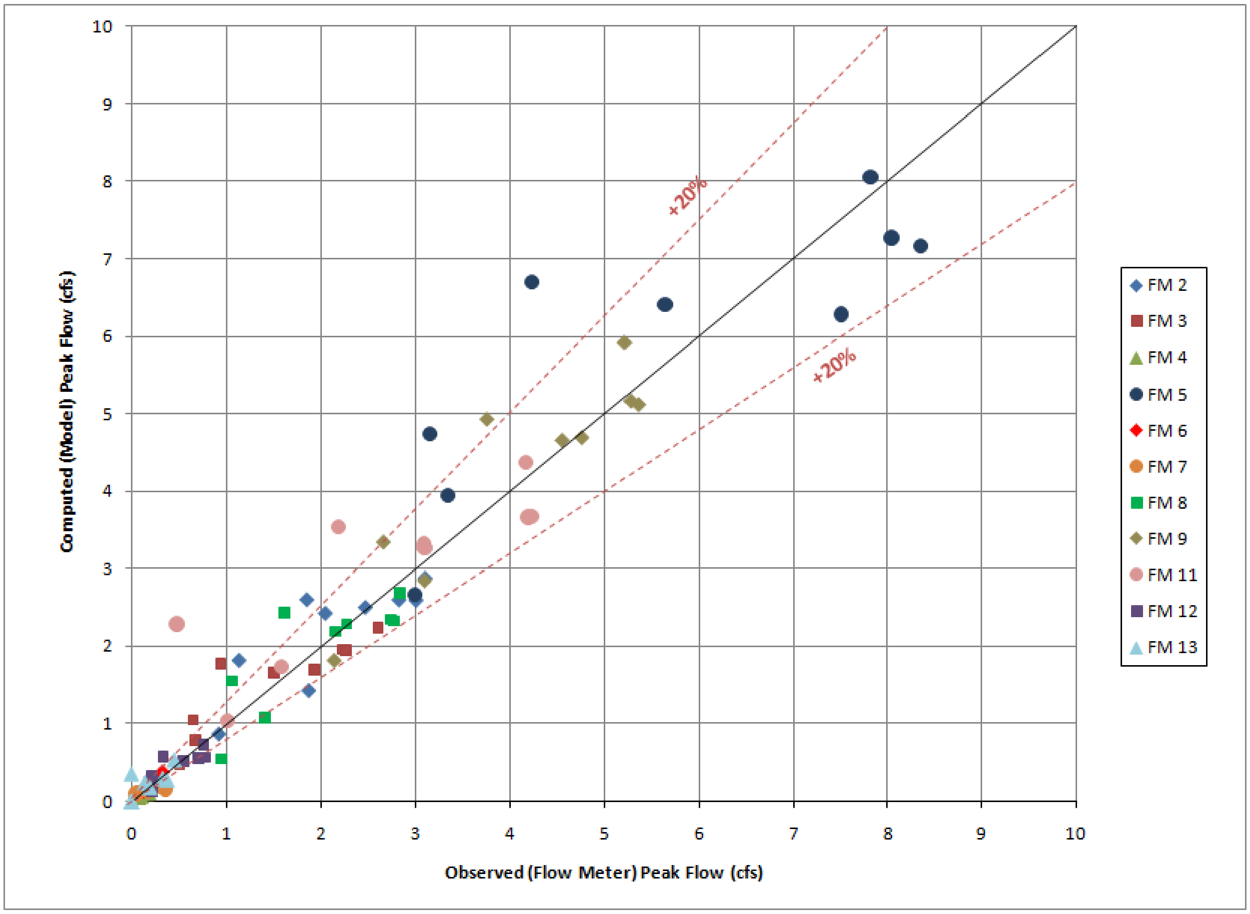

Figure 5-3: Observed vs. Computed Calibration Plot on 45-Degree Line

5.1.4 Boundary Conditions

The City of Bexley discharges directly to the Alum Creek Trunk Sewer at four locations. The Alum Creek Trunk Sewer, one of the main trunk sewers for the City of Columbus, is a 90-inch pipe and experiences frequent surcharge during wet weather. This study investigates the influence of any surcharge on the City of Bexley collection system.

The City of Columbus has monitored the flow along the Alum Creek Trunk Sewer for many years. The closest flow meter to Bexley is Flow Meter A2, located north of Bryden Road as shown in **Figure 5-4**. The past 10 years of flow data has been retrieved from the City of Columbus to investigate how high the surcharge in the trunk sewer has historically been. **Table 5-3** displays the highest recorded peak depths from the past 10 years of flow data at Flow Meter A2.

Figure 5-4: Location of Columbus Flow Meter A2

Table 5-3: Highest Recorded Depths at Flow Meter A2 (Alum Creek Trunk Sewer)

Rank	Date	Peak Recorded Depth (ft)	Corresponding Water Level (NAVD '88)
1	1/3/2005	15.4	744.93
2	12/5/2011	15.0	744.52
3	6/11/2004	14.7	744.31
4	1/12/2005	14.7	744.24
5	3/28/2005	13.9	743.48
6	1/27/2012	13.3	742.83
7	5/3/2011	13.2	742.78
8	5/18/2001	12.8	742.38
9	6/6/2002	11.5	741.09
10	1/4/2004	11.3	740.91

According to the flow meter data, the water elevation has not risen above elevation 745. The invert of the sewer system serving the City of Bexley near the Bryden Road and Main Street discharge locations are much higher than the Alum Creek Trunk Sewer and higher than elevation 745. The invert of MH# AL-237 on Bryden Road is at elevation 760.41 and the invert of MH# AL-111 on Main Street is at elevation 747.17. Therefore, the City of Bexley does not appear to be directly influenced by surcharge in the Alum Creek Trunk Sewer at these locations and no boundary condition was considered for this study.

5.1.5 Level of Service

The model was calibrated to the flow monitoring period through the winter and spring seasons with high saturation levels. A system response to rainfall varies throughout the year, as well as the rainfall patterns themselves. Therefore, it is important to consider the rainfall characteristics that are observed during that season. Most short-duration, high-intensity rainfall events occur during summer when the soil is dry, while mostly long-duration, low-intensity events are seen through the winter. To be consistent with the calibration, long-duration design storm events are selected to evaluate the system for a given level-of-service (LOS).

An 18-hour duration was selected with the 3rd Quartile Huff Distribution. From past studies, it is expected that a 2-year, 18-hour design storm can be expected to occur under winter conditions on average once in ten years, resulting in a 10-year LOS. The LOS is different from the rainfall frequency because we are considering only rainfall that occurs during the winter, not the entire year. **Table 5-4** provides the expected LOS for each of the design storm events used by the model to evaluate the system.

Table 5-4: Design Storm Events vs. Level-of-Service

Design Storm Event	Level-of-Service
2-Year, 18-Hour Design Storm 3rd Quartile Huff Distribution Total Rainfall = 2.54 inches	10-year LOS
1-Year, 18-Hour Design Storm 3rd Quartile Huff Distribution Total Rainfall = 2.04 inches	5-Year LOS
9-Month, 18-Hour Design Storm 3rd Quartile Huff Distribution Total Rainfall = 1.88 inches	2-Year LOS
6-Month, 18-Hour Design Storm 3rd Quartile Huff Distribution Total Rainfall = 1.65 inches	1-Year LOS
4-Month, 18-Hour Design Storm 3rd Quartile Huff Distribution Total Rainfall = 1.43 inches	Less than 1-Year LOS

5.2 Evaluation of Existing System

The Flow Monitoring Report evaluated the system capacity based on calculated design flows using the City of Columbus Sanitary Sewer Design Standards. The calculations were performed at each flow meter location and it was determined that the system should have enough carrying capacity to convey the theoretical peak flows. However, the peak flows observed during the flow monitoring were higher than the expected design flows in the system. Analysis of the observed wet weather flow shows that the system lets in a high amount of RDII, capturing up to

40% of the rainfall in the area. The calibrated hydraulic model was developed to predict the peak flows, evaluate the hydraulic performance and identify capacity issues of the existing system.

5.2.1 System Capacity

The existing system was evaluated with various design storms to determine where the capacity issues in the system are located and at what LOS the system can achieve. (The LOS is described in Section 2.5.) **Figure 5-6** illustrates the segments that have capacity issues and their expected LOS.

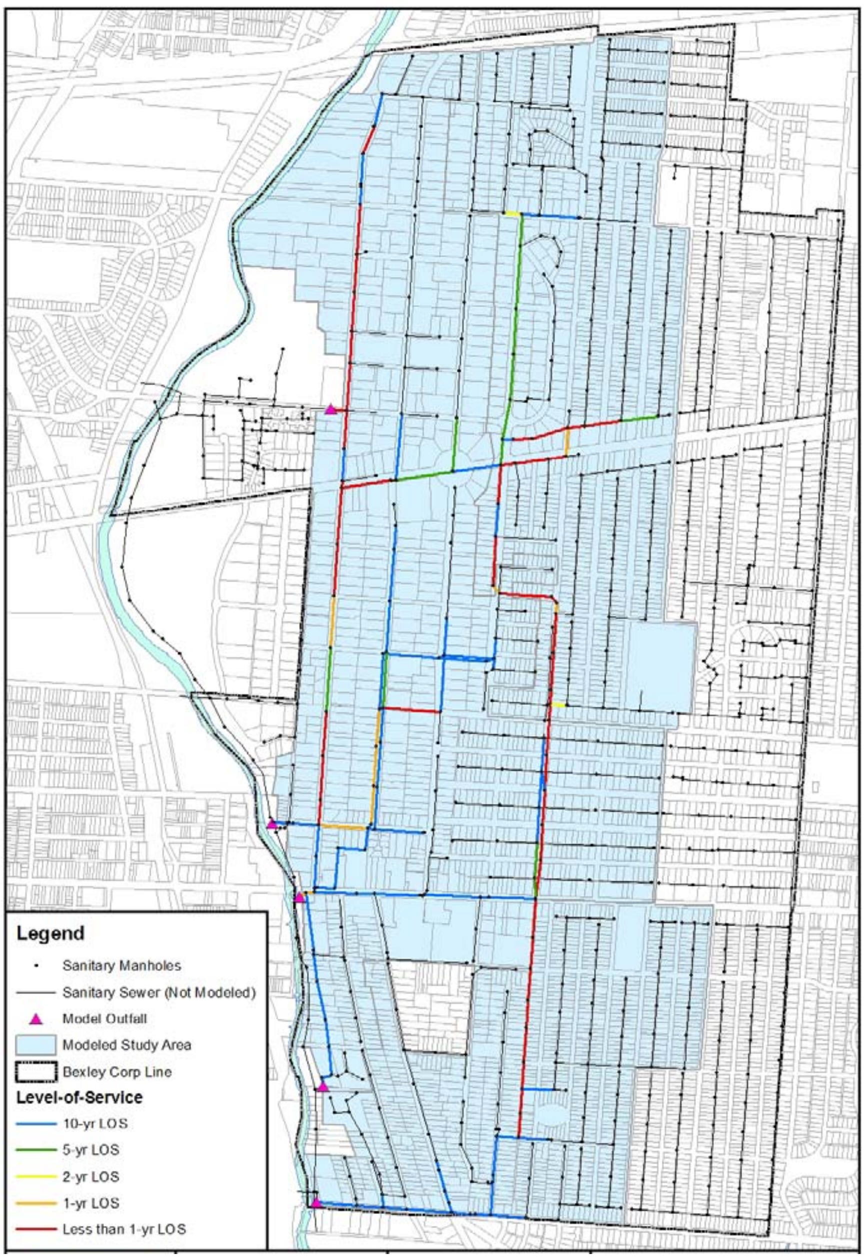

Figure 5-6: Existing Level of Service

There are three specific areas that show major capacity issues in the model and are as follows:

- Parkview Ave. (Bryden Rd. to Caroline Ave.) – This reach of sewer is a 12-inch pipe from Bryden Rd. to Broad St. and an 8-inch pipe from Broad St. to Caroline Ave. The area tributary to the sewer is among the highest RDII areas in the system and consumes the system capacity quickly. The sewer experiences high surcharge and backup, which activates a relief connection at Clifton Avenue and has potential for water-in-basements or flooding at low-lying manholes. A profile of the maximum hydraulic grade line for each LOS is shown in **Figure 5-7**.

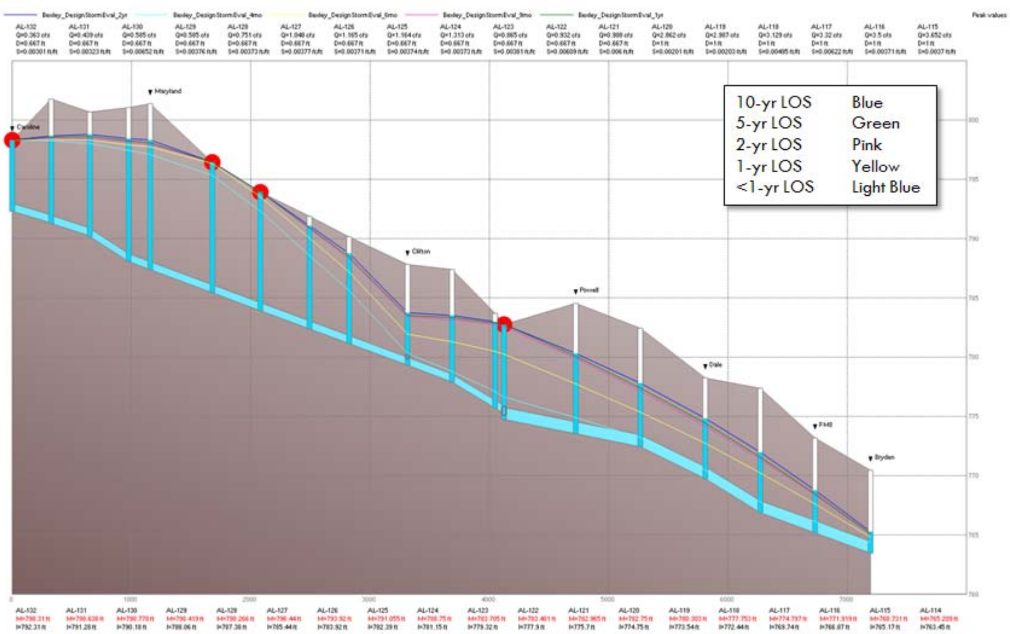

Figure 5-7: Hydraulic Profile of Parkview Avenue Sewer for Existing Conditions

- Cassady Ave. & Dawson Ave. (Charles St. to Broad St.) – This reach of sewer is an 18-inch to 20-inch pipe, which discharges into a 36-inch pipe. The sewer is deep and runs parallel to and below a large storm trunk sewer. Problems may arise at the 2-year LOS when the HGL comes within five feet of the ground elevation. A profile of the maximum hydraulic grade line for each LOS is shown in **Figure 5-8**.

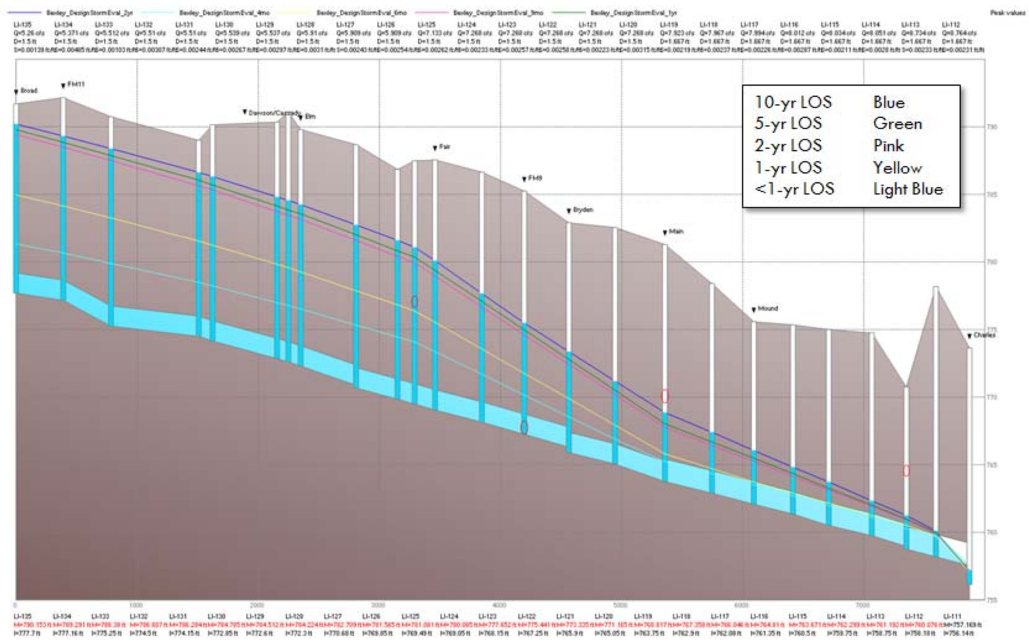

Figure 5-8: Hydraulic Profile of Cassady & Dawson Avenue Sewer for Existing Conditions

- Alley north of Broad St. (Stanberry Ave. to Cassingham Ave.) – This reach of sewer is an 8-inch pipe which has capacity problems due to high RDII and backwater from the 18-inch sewer in Dawson Avenue. The sewer splits at Cassady Avenue and flows south to Broad Street which provides some relief. There is potential for WIBs and manhole flooding at the 2-year LOS. A profile of the maximum hydraulic grade line for each LOS is shown in **Figure 5-9**.

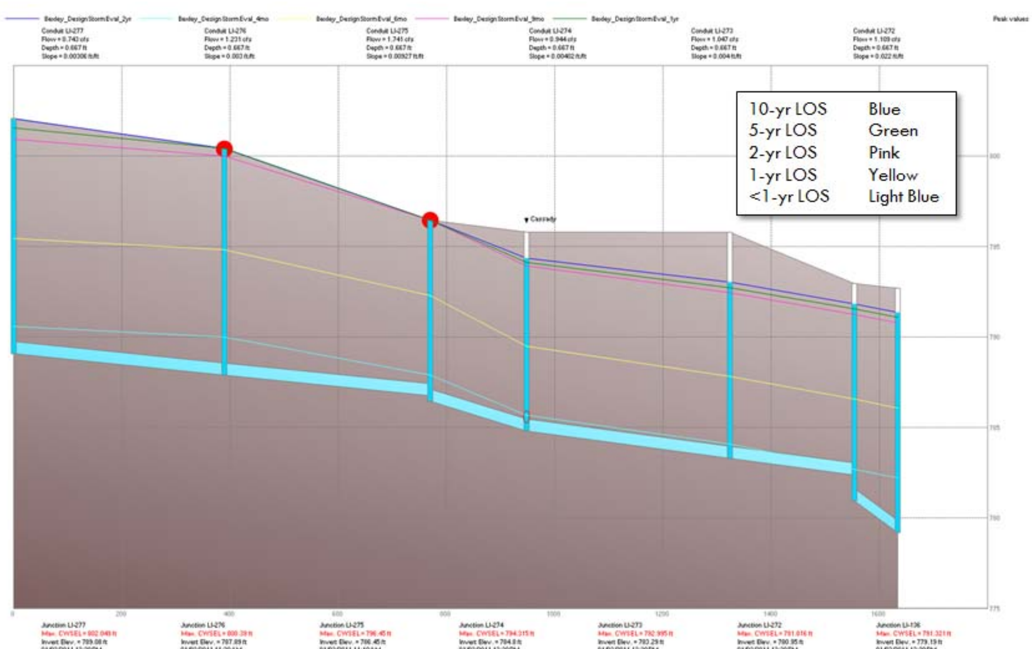

Figure 5-9: Hydraulic Profile of Alley n/o Broad St. for Existing Conditions

The remaining areas of the system perform well under the 10-year LOS with minor surcharge and capacity problems. The evaluation assumes the system is clean and clear of any restrictions, blockages or localized issues.

5.2.2 Potential for Water-in-Basement

The capacity issues in the system produce high surcharge that has the potential to cause water-in-basements. To determine where this potential exists, the highest hydraulic grade line (HGL) elevation in the model, which is estimated at each manhole, is compared to the ground elevation of the surrounding buildings. If the HGL is within 8 feet of the ground elevation, then potential for a WIB is considered. **Figure 5-10** illustrates the zones where there is potential for WIBs at each LOS.

The potential for WIBs mainly exists in the northern part of the City. This is due to the capacity issues that are found in the sewers along Cassady Ave. and Parkview Ave. This generates surcharging and backwater conditions in the upstream part of the system. The greatest potential for WIBs in the City is located along the west side of Parkview Avenue.

5.2.3 Potential for Manhole Flooding

The hydraulic model has identified 11 manholes that are susceptible to flooding due to the capacity issues and high surcharging in the existing system. **Table 5-5** lists the susceptible manholes, their location, and the frequency of occurrence. **Figure 5-11** illustrates the location of the flooded manholes.

The location most susceptible to flooding is at the intersection of Parkview Avenue and Caroline Avenue. This location has a low rim elevation relative to nearby manholes, and the depth of the manhole is approximately 6 feet. The flooding is a result of capacity issues in Parkview Avenue from Caroline Avenue to Clifton Avenue, where a relief connection exists.

Table 5-5: Manholes Susceptible to Flooding

No.	MH#	Location	Frequency of Occurrence	Potential Flooded Volume for 10-year LOS
1	AL-132	Parkview Ave. at Caroline Ave.	Less than 1-year	0.222 MG
2	AL-127	Parkview Ave. at Boston Ave.	2-year	0.049 MG
3	AL-126	Parkview Ave. south of Boston Ave.	2-year	0.018 MG
4	LI-275	Alley north of Broad St, between Cassady Ave. and Ardmore Rd.	2-year	0.144 MG
5	AL-242	Broad St. at Columbia Ave.	2-year	0.107 MG
6	LI-140	Stanberry Ave. at Ashbourne Rd.	5-year	0.131 MG
7	LI-139	Stanberry Ave. at Denver Ave.	5-year	0.018 MG
8	LI-137	Stanberry Ave. north of Clifton Ave.	5-year	0.068 MG
9	LI-276	Alley north of Broad St, between Ardmore Rd. and Cassingham Rd.	10-year	0.033 MG
10	AL-120	Parkview Ave. at Broad St.	10-year	0.014 MG
11	LI-308	Maryland Ave. at Northview Dr.	10-year	0.004 MG

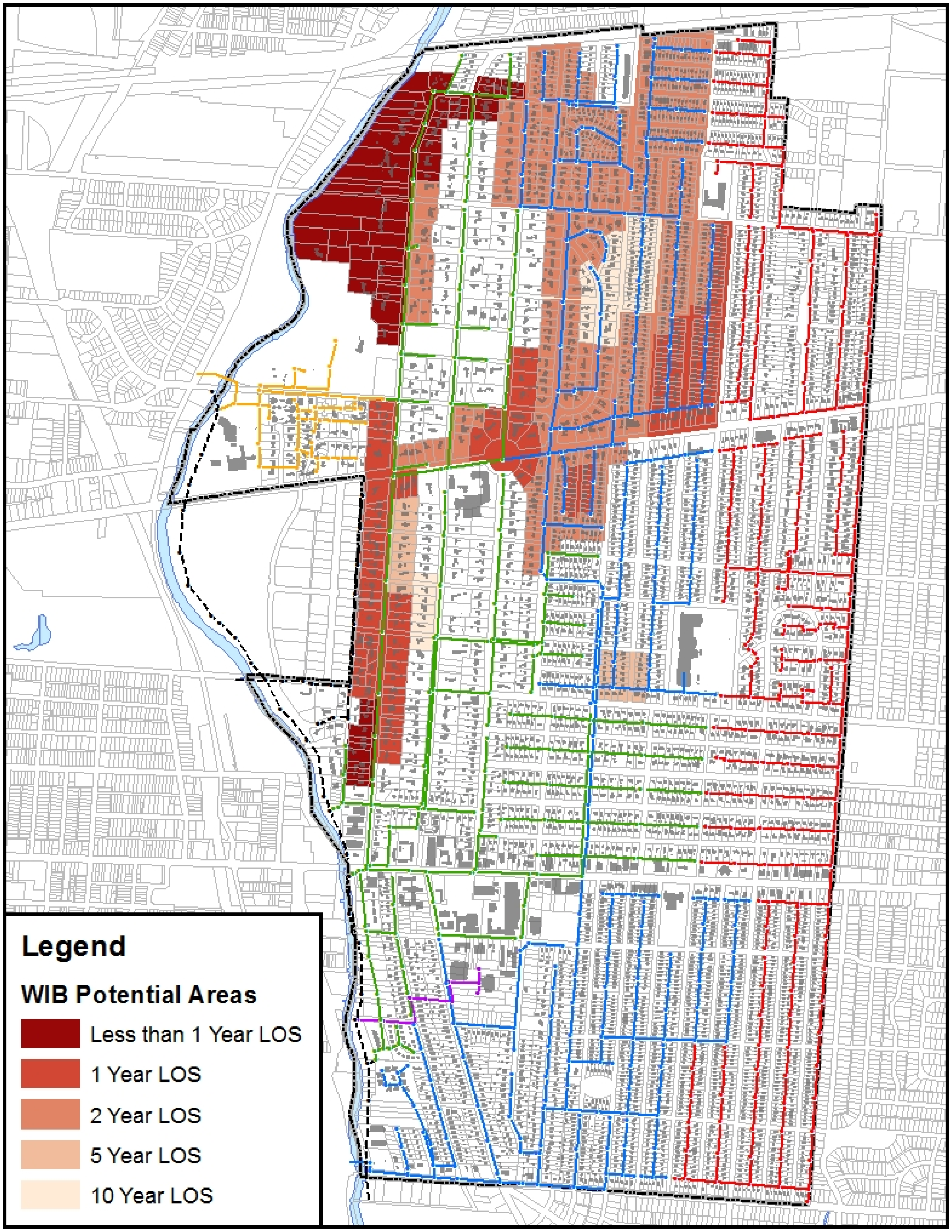

Figure 5-10: Existing System Potential for WIBs

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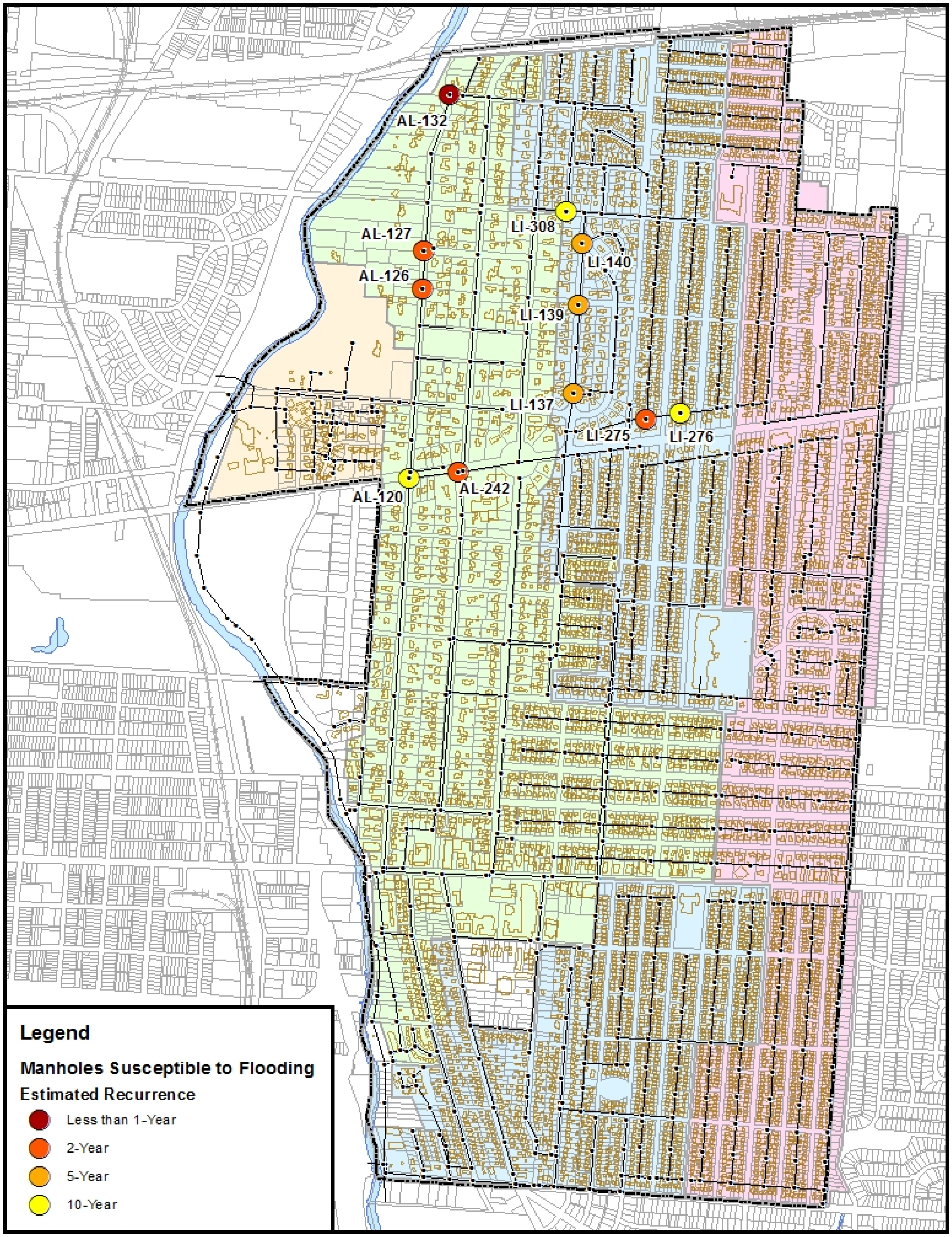


Figure 5-11: Existing System Potential for Manhole Flooding

5.3 Alternative Analysis

Hydraulic modeling was used to evaluate several alternatives to reduce the hydraulic deficiencies in the system. Hydraulically deficient areas within the system have been identified during the evaluation of the existing system. The following alternative solutions were applied to the model to determine their effectiveness in eliminating the capacity and surcharge issues.

- RDII Reduction
- Capacity Improvements
- Storage Facilities

The alternatives were evaluated for 1-, 2-, 5- and 10-year LOS. No surcharge conditions in the Alum Creek Trunk Sewer are assumed, therefore, free outfalls are utilized for the alternative simulations.

The following subsections provide general discussion on the feasibility and effectiveness of the alternatives as solutions to the hydraulic deficiencies.

5.3.1 RDII Reduction

It has been established that the sanitary collection system in the City of Bexley has high RDII. SSES investigations have identified various sources of public and private I/I including, directly-connected downspouts and foundation drains, leaky manholes and leaky joints and cracks in the mainline and lateral pipes. Specific recommendations to remediate these identified I/I sources are provided in the Recommendations section of this report. Hydraulic modeling only assumes a general percentage of RDII reduction based on the calibrated RTK values. It does not account for specific RDII remediation efforts.

5.3.1.1 Model Application

This alternative determines a target for RDII reduction to achieve the each LOS. It has been determined that RDII reduction is vital only in Sub-Basins #8, #9, #11 and #12 as these sub-basins not only show the highest I/I, but are tributary to the hydraulically deficient sewers. The remaining sub-basins, despite having high RDII, perform adequately up to a 10-year LOS.

5.3.1.2 Model Results

It is generally thought that most of the I/I enters the sewer system through the private laterals and connections. As a result, public improvements have a limited impact on RDII reduction. It is thought that the most I/I reduction that can be achieved through public improvements is roughly 20-30%. In order to achieve a 10-year LOS, RDII remediation efforts will need to target a 50% reduction in I/I in Sub-Basins #9, #11 & #12 and target a 65% reduction in I/I in Sub-Basin #8. With such high targets, aggressive RDII remediation efforts are needed and should include remediation of private I/I sources as well as public I/I sources. **Table 5-6** displays the amount of RDII reduction need to achieve each LOS.

Table 5-6: RDII Reduction Targets Needed to Achieve LOS

1-year LOS	1. Achieve 45% I/I Reduction in Sub-Basin #8
2-year LOS	1. Achieve 50% I/I Reduction in Sub-Basin #8 2. Achieve 15% I/I Reduction in Sub-Basins #9, #11 & #12
5-year LOS	1. Achieve 55% I/I Reduction in Sub-Basin #8 2. Achieve 35% I/I Reduction in Sub-Basins #9, #11 & #12
10-year LOS	1. Achieve 65% I/I Reduction in Sub-Basin #8 2. Achieve 50% I/I Reduction in Sub-Basins #9, #11 & #12

5.3.2 Capacity Improvements

Relief sewers that convey flow from a hydraulically deficient point to a downstream location with available capacity would help the performance of the system. There are many options and alignments available for this alternative, including constructing relief sewers that augment the existing sewer or increasing the size of an existing pipe through replacement. This study focuses on where the relief locations need to be and to which downstream location they can discharge to.

5.3.2.1 Model Application

Two relief sewers (both split into a north and south portion) were input into the model to relieve wet weather flow in Parkview Avenue and Cassady Avenue. These two main sewer lines have insufficient capacity to convey the 1-year LOS flows and cause significant surcharge and backwater. The relief sewers increase the system capacity to reduce the frequency and magnitude of surcharge and backwater affecting the upstream tributary areas.

- Parkview Avenue Relief Sewer (south portion) – This sewer would relieve the 12-in sewer in Parkview Avenue at the intersection with Broad Street (MH# AL-120) where the 10-in sewer in Broad Street connects. It conveys the relieved flow approximately 3,540 feet south in a 12-in pipe, paralleling the existing sewer, and discharges to the 15-in sewer in Bryden Avenue (MH# AL-113), which then discharges to the Alum Creek Trunk Sewer.

- Parkview Avenue Relief Sewer (north portion) – This sewer would relieve the 8-in sewer in Parkview Avenue at the intersection with Maryland Avenue (MH# AL-128). It conveys the relieved flow approximately 3,040 feet south in a 10-in pipe to the south portion of the Parkview Avenue Relief Sewer at Broad Street.

- Cassady Avenue Relief Sewer (south portion) – This sewer would relieve the 18-in sewer in Cassady Avenue at the intersection with Elm Avenue (MH# LI-128). It conveys the relieved flow approximately 6,680 feet south in a 15-in pipe, along Ardmore Road and Cassingham Road, and discharges to the 33-in sewer in Charles Street (MH# LI-111).

- Cassady Avenue Relief Sewer (north portion) – This sewer would relieve the 8-in sewer in the alley north of Broad street at the intersection with Ardmore Road. It conveys the relieved flow approximately 2,030 feet south in a 10-in pipe along Ardmore Road and discharges to the south portion of the relief sewer.

5.3.2.2 Model Results

The south portion of the Parkview Avenue Relief Sewer provides a 10-year LOS to the sewer south of Clifton Avenue. However, the relief sewer does not alleviate the capacity issues upstream, nor does it alleviate the manhole flooding at MH# AL-132 at the intersection of Parkview Avenue and Caroline Avenue. In order to address the capacity issues, the relief sewer is extended to Maryland Avenue as the north portion of the Parkview Avenue Relief Sewer. This relief sewer provides enough additional capacity to reduce the surcharge and prevent MH# AL-132 at the intersection of Parkview Ave and Caroline Ave from flooding.

The south portion of the Cassady Avenue Relief Sewer provides a 10-year LOS to the sewer south of Broad Street. However, the relief sewer does not alleviate the capacity issues north of Broad Street. The north portion relieves flow from the alley north of Broad Street, however, the far northern part of Sub-basin #11 near Maryland Avenue still has capacity issues with the 10-year LOS. RDII reduction is therefore needed achieve the 10-year LOS for the whole system. Capacity improvements in conjunction with I/I reduction is discussed as an alternative in the next section.

Another effect of increasing the conveyance capacity within the system is an increase in peak flow being discharged to the Alum Creek Trunk Sewer. The City of Columbus may require storage to reduce the peak flows being discharged.

Table 5-7: Resulting Flow Increase to Alum Creek Trunk Sewer from Capacity Improvements

	Flow Increase at Bryden Rd. Outfall	Flow Increase at Main St. Outfall	Flow Increase at Livingston Ave. Outfall	Total Increase in Flow to Alum Creek Trunk Sewer
1-year LOS	0.39 cfs	0.49 cfs	0.54 cfs	1.42 cfs
2-year LOS	0.56 cfs	0.40 cfs	0.72 cfs	1.68 cfs
5-year LOS	0.73 cfs	0.55 cfs	1.21 cfs	2.49 cfs
10-year LOS	1.19 cfs	0.89 cfs	2.74 cfs	4.82 cfs

5.3.3 RDII Reduction with Capacity Improvements

This alternative investigates combining RDII reduction with relief sewers to address the capacity issues in the system. As the previous sections detail, RDII reduction and relief sewers both greatly benefit the system, but are not sufficient on their own to achieve a 10-year LOS. Model simulations were completed to determine the combination of RDII reduction and sewer relief that would be needed to achieve each LOS. RDII was restricted to 15% reduction, which is a realistic target for the City. **Table 5-8** displays those improvements that are needed for each LOS.

Table 5-8: Capacity Improvements and RDII Reduction Needed to Achieve LOS

1-year LOS	1. Construct Parkview Ave. Relief Sewer from Maryland Ave. to Bryden Rd.
2-year LOS	1. Perform 15% I/I Reduction in Sub-Basin #9, #11 & #12 2. Construct Parkview Ave. Relief Sewer from Maryland Ave. to Bryden Rd.
5-year LOS	1. Construct Parkview Ave. Relief Sewer from Maryland Ave. to Bryden Rd. 2. Construct Cassady Ave. Relief Sewer from Alley north of Broad St. to Charles St.
10-year LOS	1. Perform 15% I/I Reduction in Sub-Basins #8, #11 & #12 2. Construct Parkview Ave. Relief Sewer from Maryland Ave. to Bryden Rd. 3. Construct Cassady Ave. Relief Sewer from Alley north of Broad St. to Charles St.

5.3.4 Localized Storage Facilities

Storage refers specifically to the storage of excess flow generated during a wet weather event followed by the release of stored flow when system capacity becomes available. The goal of the storage is to attenuate the peak flow, which can help resolve capacity issues in the system.

Potential locations for localized storage facilities were investigated within the City. The City is fully development with very few vacant or undeveloped parcels. One potential location is an apparent vacant parcel of land at the intersection of Parkview Avenue and Caroline Avenue in the northwest corner of the City. An off-line storage facility would connect to MH# AL-132, which frequently floods according the model simulations. The storage facility would store the excess flow to prevent sanitary sewer overflow. The storage volume needed to prevent any overflow for the 10-year LOS is 0.25 MG. A pump would also be required to release flow back into the system. This alternative could be used in replace of the north portion of the Parkview Avenue Relief Sewer to achieve the 10-year LOS. After discussion with the City, this parcel would not be available for purchase.

6.0 DETAILED SSES FINDINGS

Per an assessment of the tributary sub-basins defined by the System-Wide Flow Monitoring Program, it was recommended to perform detailed SSES investigations over the entire sewer system. The primary focus of the detailed SSES is to

- Identify specific sources of I/I entering the collection system
- Identify structural defects
- Identify any operation and maintenance issues

The SSES investigative methods utilized include: manhole inspections, smoke testing, dyed water testing, and CCTV inspection. The study was performed in two phases as shown in the following **Figure 6-1**.

1. SSES Phase 1 – This phase studied the area north of Fair Avenue.

2. SSES Phase 2 – This phase studied the area south of Fair Avenue.

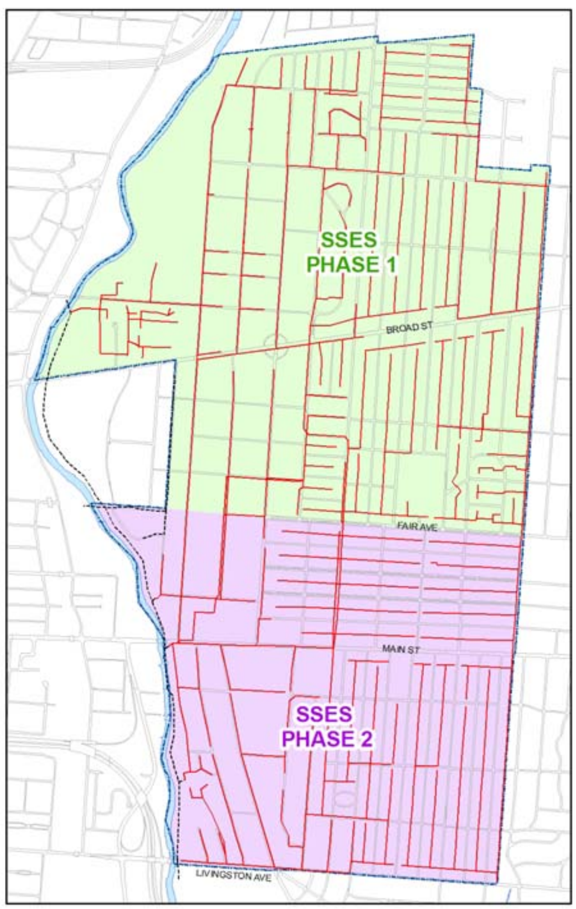


Figure 6-1: SSES Phases

6.1 Manhole Inspection

Manhole inspections were completed on all located manholes in the City to assess the structural condition of the manhole and examine manholes for evidence of high I/I. The City of Bexley's sanitary sewer system consists of approximately 737 manholes. The inspection status of the system's manholes is as follows:

- 615 manholes were located, opened and visually inspected
- 32 manholes were located but could not be opened for inspection
- 90 manholes were not located in the field

The manholes in the study area are mostly brick manholes. Many of the sanitary sewers were constructed next to or under storm sewers, and as a result, manhole walls and benches were formed around storm sewers. In some cases, the invert of the manhole could not be visually inspected due to the storm sewer above.

The manholes inspections followed NASSCO MACP standards. The condition of the manholes was evaluated on a 1-5 scale for six distinct inspection components. **Table 6-2** shows the condition assessment scale.

Most of the manholes in the study area are in poor condition and in need of some form of rehabilitation. Out of the 615 manholes that were inspected, rehabilitation was recommended for 538 manholes (87%), as distinguished by a rating of (3) or higher in at least one category (excluding maintenance).

Figure 6-2 shows the inspected manholes and their highest condition rating for each inspection component. **Table 6-1** lists the total number of condition ratings in each category.

Table 6-1: Manhole Condition Assessment Results

Inspection Component	**(1)** Good Condition	**(2)** Fair Condition	**(3)** Low-Priority Rehabilitation	**(4)** Med-Priority Rehabilitation	**(5)** High-Priority Rehabilitation
Site	591	19	5	6	0
Frame/Cover	564	42	6	4	0
Shaft/Chimney	45	92	377	93	8
Chamber/Wall	58	57	446	42	12
Bench/Channel	90	410	58	22	9
Maintenance	363	185	42	16	3
Overall (Highest Rating)	32	54	376	136	26

Table 6-2: Manhole Condition Assessment Description

Inspection Component	(1) Good Condition	(2) Fair Condition	(3) Low-Priority Rehabilitation	(4) Medium- Priority Rehabilitation	(5) High-Priority Rehabilitation
Site	Site is in good condition.	Manhole is buried/ covered or site has potential for erosion.	Manhole could not be opened or site has potential for future structural or I/I problems.	Site causing structural or I/I problems in the manhole.	Site in critical condition and causing structural or I/I problems.
Frame/ Cover	Frame/cover is in good condition. No evidence of I/I.	Frame/cover is chipped, cracked or offset.	Frame/cover is loose or poorly fit. Vent holes in cover have low potential for I/I.	Frame/cover is broken or severely offset. Vent holes in cover have high potential for I/I.	Frame/cover is defective or exhibits high I/I.
Shaft/ Chimney	Chimney is in good condition. No evidence of I/I.	Chimney shows signs of defects, has light cracks or water marks.	Chimney has water marks, deposits, cracks, displaced bricks, surface damage, light roots or defective seal.	Chimney has heavy deposits or signs of I/I, broken pieces, voids, roots or defective seal.	Chimney has severe deposits, deterioration, voids or roots exhibiting high I/I.
Chamber/ Wall	Chamber is in good condition. No evidence of I/I.	Chamber shows signs of defects, has light cracks or water marks.	Chamber has water marks, deposits, chips, cracks, displaced bricks, or surface damage.	Chamber has heavy deposits or signs of I/I, broken pieces, voids, or roots.	Chamber has severe deposits, deterioration, voids or roots exhibiting high I/I.
Bench/ Channel	Bench/ channel is in good condition.	Bench/channel has light cracks, deposits, or surface damage.	Bench/channel has chips, cracks, deposits, or surface damage. Flow through channel affected.	Bench/channel broken, heavy surface damage, or dysfunctional (flat-bottom).	Bench/channel is broken or defective, voids visible, or exhibits high I/I.
Maintenance	Channel and bench are clean of debris.	Debris noted, but not a concern for cleaning.	Sewer/manhole should be considered for future cleaning.	Sewer/manhole should be cleaned, potential for problems exist.	Sewer/manhole should be cleaned, sewer performance is affected.

6.2 Smoke Testing

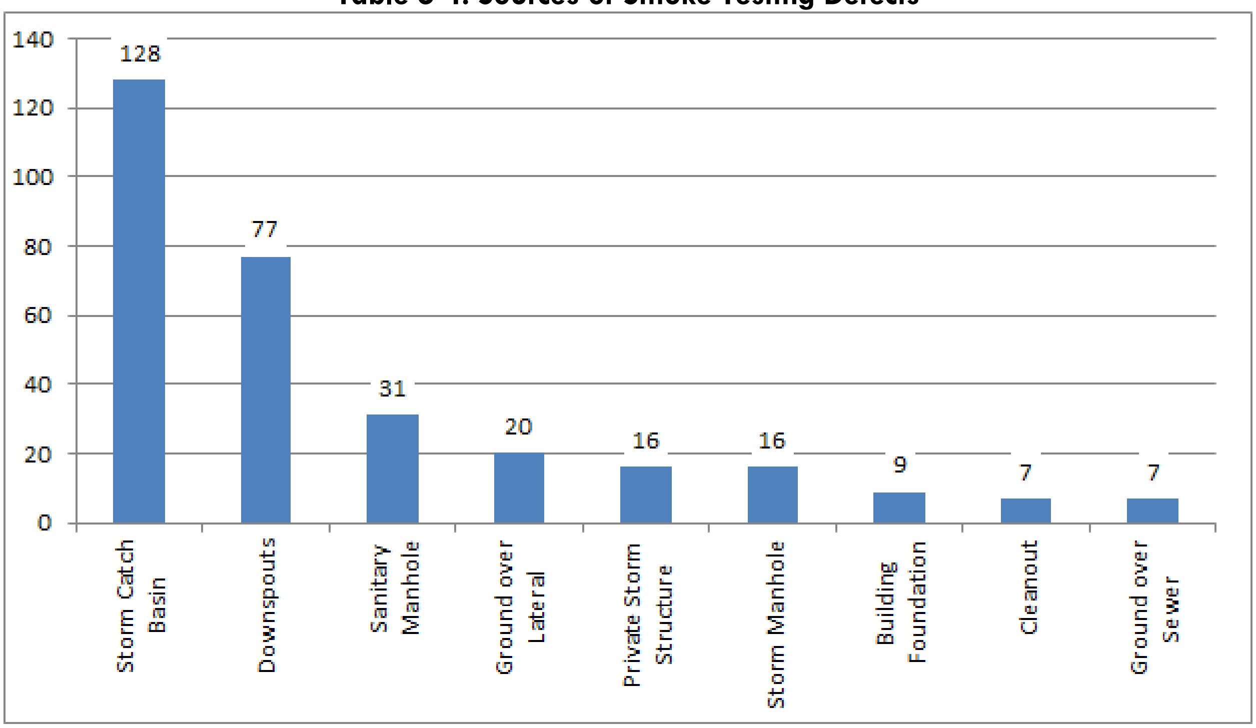
Smoke testing was completed to identify sources of RDII by forcing non-toxic smoke into the sewer lines. Smoke will escape through the sewer system at locations that are susceptible to RDII. Locations are noted as either public or private. Public defects that exhibit smoke include cracks in the mainline sewer, vented manhole covers, offset frames, etc. Private defects that exhibit smoke include cracks in the sewer lateral, broken clean-outs, downspout connections, etc. The following table lists the total defects found in each phase of the SSES.

Table 6-3: Public/Private Smoke Testing Defects

	Total Defects	Public Defects	Private Defects
Phase 1	201	115	86
Phase 2	110	64	46
SSES Study Area Total	311	179	132

Refer to **Figure 6-3** for the locations of observed smoke and type of defect. The following table illustrates the types and number of defects found.

Table 6-4: Sources of Smoke Testing Defects



The stormwater system exhibited the most smoke with 128 catch basins, 16 storm manholes and 16 private storm structures. Smoke emanating from these structures indicates direct/indirect connections between the storm and sanitary sewer systems. The means of the connection cannot be determined solely by smoke testing. Therefore, dye testing is recommended to further investigate the I/I source and determine the manner of connection between the two systems.

Smoke can be found emanating from the frame, cover, or ground to identify leaking manhole structures, and their potential points of leakage, some of which may not be readily apparent during manhole inspections. The smoke testing revealed 31 sanitary manholes emitting smoke. Manhole defects found with the smoke testing, in conjunction with the manhole inspections, are used to determine courses of rehabilitation.

Smoke emanating through the ground above the sanitary sewer or lateral usually indicates broken pipe or open joints. There were 30 ground locations above private laterals and 7 ground locations above mainline sewers that were emitting smoke. Buried cleanouts or manholes are also possible sources of ground smoke. Dye testing or CCTV is completed to further investigate the cause of the smoke.

Downspouts and cleanouts are private property items that can be a source of I/I. There were 77 downspouts and 7 cleanouts found to be emitting smoke. These sources were not investigated any further due to being on private property. It has been recommended that the residents be notified of the potential defect.

Smoke found along the foundations of buildings indicates potential connection of footer drains and sump pumps or buried/hidden cleanouts. There were 9 instances of smoke found along the foundations of buildings and houses. These sources were not investigated any further due to being on private property. It has been recommended that the residents be notified of the potential defect.

6.3 Dyed Water Testing

Dye testing was performed to locate sources of I/I through direct/indirect connections with the stormwater system. The selected locations were identified through smoke testing as structures with possible connections to the sanitary sewer system. Dyed water is injected into the structure that was emitting smoke and CCTV is then utilized to detect the source and rate of dyed water entering the sanitary sewer. The rate of I/I can be categorized as a weeper, dripper, runner or gusher.

Smoke testing identified 37 general areas to perform dye testing in Phase 1 and 14 general areas in Phase 2. Some of the tests could not be performed due to the configuration of sewers or manhole access. A total of 41 dye tests were competed.

The dye testing revealed several critical sources of indirect connections with the stormwater system. The dye testing found many locations where storm sewer flow was entering the sanitary system through joints and cracks in the pipe, service laterals or connections, and manholes. The following tables summarize the findings observed by CCTV. The estimated I/I rate is based on the visual observations of dye entering the sewer from the CCTV videos and is used to categorize the severity of I/I.

Table 6-6: Dye Test Findings – I/I through Pipe Joints and Wall

SSES Phase	Dye Test #	Sewer Segment	Number of Joints Leaking	Comment	Max I/I Rate
1	2	LI-256 : LI-255	1	Leaking though one offset joint	Gusher
1	3	LI-125 : LI 124	8	Leaking at joints	Gusher
1	4/5	LI-127 : LI-126	14	Leaking at joints	Weeper
1	7	LI-133 : LI-132	65	Leaking at joints	Runner
1	7	LI-132 : LI-131	10	Leaking at joints	Runner
1	8	AL-227 : AL-226	1	Leaking at joint	Gusher
1	9	AL-228 : AL-227	3	Leaking at joints	Runner
1	12/13	LI-262 : LI-133	5	Cracks and deposits at joints	Runner
1	14	AL-222 : AL-221A	5	Leaking at joints	Gusher
1	16a	AL-132 : AL-131	4	Leaking at joints	Runner
1	19	AL-254 : AL-253	2	Leaking at joints	Gusher
1	20	AL-250 : AL-249	2	Leaking at joints	Runner
1	21	LI-317 : LI-308	3	Leaking at joints	Runner
1	22	AL-249 : AL-248	3	Leaking at joints	Runner
1	27	LI-303 : LI-302	1	Leaking at joints	Weeper
1	27	LI-302 : LI-301	6	Leaking at joints	Runner
1	28	LI-300 : LI-299	2	Leaking at joints	Runner
1	29/30	LI-141 : LI-140	Continuous for 10 ft	Leaking through longitudinal cracks with deposits.	Gusher
1	31	LI-139 : LI-138	29	Leaking at joints	Gusher
1	31	LI-138 : LI-137	20	Leaking at joints	Gusher
1	32	LI-137 : LI-136	8	Leaking at joints	Runner
1	32	LI-136 : LI-135	8	Leaking at joints	Runner
1	33	LI-320 : LI-319	2	Leaking at joints	Gusher
1	30/35	LI-308 : LI-141	5	Leaking at joints	Runner
2	1	AL-225 : AL-219	3	Leaking at joints	Gusher
2	2	AL-165 : AL-164	3	Leaking at joints	Runner
2	3	AL-186 : AL-162	1	Leaking at joint	Weeper
2	3	AL-162 : AL-161	5	Leaking at joints and crack in pipe	Gusher
2	4	LI-164 : LI-164a	2	Leaking at joints	Weeper
2	5	LI-221 : LI-220	4	Leaking at joints and cracks in pipe	Runner
2	8	LI-169 : LI-163	4	Leaking at joints	Weeper
2	12	GU-154 : GU-186	3	Leaking at joints, severe I/I at one joint	Gusher

Table 6-7: Dye Test Findings – I/I through Service Connections and Taps

SSES Phase	Dye Test #	Sewer Segment	Distance	Apparent Property Address Served	Dyed Water Entry Point	Max I/I Rate
1	1	GU-257 : GU-256	44.6' D	2772 Powell Ave	Severe I/I, can't see entry point.	Gusher
1	1	GU-257 : GU-256	45.6' D	2775 Powell Ave	Connection and possibly lateral	Gusher
1	1	GU-257 : GU-256	98.6' U	2796 Powell Ave	Connection	
1	2	LI-256 : LI-255	193.1' D	138 Cassady Ave	Severe I/I, can't see entry point	Gusher
1	2	LI-256 : LI-255	245.1' D	144 Cassady Ave	Connection with roots (5%) and possibly lateral	Gusher
1	2	LI-256 : LI-255	295.1' D	150 Cassady Ave	Connection and lateral	Gusher
1	12	LI-262 : LI-133	540.5' D	104 Dawson Ave	Lateral	Gusher
1	17	AL-130 : AL-129	314.2' U	445 Parkview Ave	Connection with roots (100%)	Runner
1	18	AL-126 : AL-125	173.4' D	239 Parkview Ave	Connection	Runner
1	18	AL-126 : AL-125	343.5' D	215 Parkview Ave	Offset connection with roots (5%)	Gusher
1	28	LI-300 : LI-299	141.2' D	107 Ashbourne Rd	Offset connection with roots (5%)	Runner
1	29	LI-141 : LI-140	192.7' D	297 Stanberry Ave	Connection with roots (30%) and deposits	Runner
1	29	LI-141 : LI-140	212.2' D	296 Ashbourne Pl	Connection and possibly lateral	Runner
1	29	LI-141 : LI-140	276.3' D	297 Stanberry Ave	Connection with roots (50%)	Gusher
1	31	LI-139 : LI-138	270.3' D	166 Stanberry Ave	Offset Connection	Runner
1	32	LI-137 : LI-136	60.0' U	41 Clifton Ave	Connection with roots (10%)	Runner
1	32	LI-136 : LI-135	135.1' D	17 Stanberry Ave	Connection	Runner
1	35	LI-308 : LI-141	3' U	2538 Maryland Ave	Connection with roots (5%)	Runner
1	35	LI-308 : LI-141	64.4' U	2520 Maryland Ave	Connection and possibly lateral	Gusher
1	35	LI-141 : LI-140	2' D	Unknown	Offset connection	Runner
1	35	LI-141 : LI-140	3' D	Unknown	Offset connection	Gusher
2	1	AL-225 : AL-219	38.8' U	Unknown	Unable to determine	Gusher
2	4	LI-164 : LI-164a	70.6' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Runner
2	4	LI-164 : LI-164a	80.8' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Gusher
2	4	LI-164 : LI-164a	121.0' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Gusher

Table 6-7 Continued						
SSES Phase	Dye Test #	Sewer Segment	Distance	Apparent Property Address Served	Dyed Water Entry Point	Max I/I Rate
2	4	LI-164 : LI-164a	179.7' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Gusher
2	4	LI-164 : LI-164a	256.6' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Gusher
2	4	LI-164 : LI-164a	336.9' U	Pleasant Ridge Ave Parking lot	Connection and possibly lateral	Gusher
2	6	LI-167 : LI-161	130.5' U	761 College Ave	Lateral	Runner
2	6	LI-167 : LI-161	316.1' U	733 College Ave	Lateral	Runner
2	6	LI-167 : LI-161	514.6' U	Capital Univ, Schaaf Hall	Lateral	Gusher
2	6	LI-167 : LI-161	563.7' U	Capital Univ, Schaaf Hall	Lateral	Gusher
2	7	LI-161 : LI-160	26.9' D	783 College Ave	Unable to determine	Gusher (Severe)
2	9	LI-159 : LI-160	319.6' U	845 College Ave	Lateral	Gusher
2	9	LI-158 : LI-159	34.9' D	879 College Ave	Unable to determine	Gusher (Severe)
2	9	LI-158 : LI-159	83.3' D	885 College Ave	Unable to determine	Gusher (Severe)
2	9	LI-158 : LI-159	131.9' D	887 College Ave	Connection and possibly lateral	Gusher

Table 6-8: Dye Test Findings – I/I through Manholes

SSES Phase	Dye Test #	Manhole ID	Dyed Water Entry Point	Comment	Max I/I Rate
1	23	AL-247	Pipe Seal	Incoming pipe from MH AL-248	Weeper
1	29	LI-140	Wall	Above pipe entering MH from northeast	Runner
1	30	LI-141	Wall	Through bricks at the bottom of manhole wall	Gusher
2	1	AL-219	Wall	Through bricks	Gusher
2	8	AL-163	Pipe Seal	Around pipe and cracked channel	Runner

6.4 CCTV Inspection

CCTV was completed on approximately 11,000 LF of sanitary sewer (36 pipe segments) in the Phase 1 study area. During Phase 2, CCTV was completed on approximately 5,300 LF of sanitary sewer (13 pipe segments). The CCTV focused mainly on the trunk sewers and capacity deficient segments.

CCTV procedures and grading followed NASSCO's Pipeline Assessment and Certification Program (PACP) standards. Pipe defects were recorded by the operator as the sewer was televised, including the type of defect and its distance from the entry manhole. Pipe defects are graded 1-least severe through 5-most severe under either an Operation & Maintenance (O&M) or Structural scoring. The Total Rating, which is the sum of all defect grades in the pipe, are then given for both O&M and Structural.

6.4.1 Structural Component

Structural ratings take into account cracks, fractures, holes, broken or collapsed pipe, deformed pipe, and offset joints.

Many of the structural defects found in the televised sewers were located at the joints. Cracks, which were seen prevalently throughout the televised sewers, were mostly small longitudinal or circumferential cracks at the joints. Many of the fractured and broken sections were also along the joints in the pipe. As these broken and fractured sections deteriorate, holes will be created. Many existing holes at the joints have been identified already. Although the structural integrity of the pipe as a whole is still good, these defects at the joints allow I/I to enter the sewer.

CCTV also found that a few sections of pipe were fractured or broken longitudinally from joint to joint, particularly in the sewers from LI-131 to LI-124. These defects are more severe as the structural integrity of the pipe is compromised and the pipe can become deformed or collapsed upon further deterioration. No severe structural defects restricting flow were found in the televised sewers.

Two occurrence of severe surface damage was identified. The sewers from AL-121 to AL-120 and from AL-171 to AL-170 had severe surface damage in the pipe, which caused the survey to be abandoned.

Notable structural defects were found in 19 sewer segments of the 51 segments televised. These defects include severe cracks, fractures, holes and broken pipe that can lead to pipe failure, restrictions, and/or increased I/I. The PACP Structural Rating and number of defects found for each sewer segment that has notable structural defects are displayed in **Table 6-9.**

Table 6-9: Pipes with Notable Structural Defects

Rank	Sanitary Sewer Segment	Surveyed Length (ft)	# of Cracks	# of Fractures	# of Pipe Broken	# of Holes	PACP Structural Rating	Description of Defects
1	AL-123 : AL-122	409.1	36	21	1	1	185	Cracks, Fractures and Holes at Joints
2	AL-127A : AL-126	156.0	63	17	0	2	229	Cracks, Fractures and Holes at Joints
3	AL-132 : AL-131	376.4	15	11	1	3	68	Cracks, Fractures and Holes at Joints
4	AL-128 : AL-127	335.6	40	10	2	1	133	Severely Broken Pipe
5	AL-126 : AL-125	545.0	55	9	0	3	162	Cracks, Fractures and Holes at Joints
6	LI-131 : LI-130	414.2	107	9	1	0	240	Longitudinal Cracks, Fractures and Broken Pipe
7	LI-264 : LI-263	158.6	36	5	0	2	93	Cracks, Fractures and Holes w/Soil Visible at Joints
8	LI-125 : LI-124	383.1	36	6	0	0	85	Longitudinal Cracks and Fractures
9	AL-125 : AL-124	526.4	49	1	2	2	149	Hole w/Soil Visible and Joint Offset
10	AL-171 : AL-170	237.7	4	1	1	2	28	Holes w/ Soil Visible, Encrustation (possible material change) – Survey Abandoned
11	AL-124 : AL-123	344.4	59	3	1	0	171	Cracks and Fractures at Joints
12	LI-128 : LI-127	372.9	55	3	0	0	125	Longitudinal Cracks and Fractures
13	AL-219 : AL-212	502.5	29	1	0	1	89	Cracks and Fractures at Joints
14	LI-126 : LI-125	462.0	24	2	0	0	55	Cracks and Fractures at Joints
15	LI-127 : LI-126	498.7	52	2	0	0	111	Longitudinal Cracks and Fractures
16	AL-162 : AL-161	378.4	50	7	0	0	137	Longitudinal Cracks and Fractures
17	LI-276 : LI-275	57.1	49	1	0	0	126	Cracks and Fractures at Joints
18	LI-133 : LI-132	502.5	72	1	0	0	146	Longitudinal Cracks and Fractures
19	AL-121 : AL-120	14.2	1	0	0	0	3	Severe Surface Damage – Survey Abandoned

6.4.2 Operation and Maintenance Component

O&M ratings take into account roots, deposits, defective or intruding taps, obstacles/obstructions and observed infiltration. The following subsections describe the O&M defects found in the system.

6.4.2.1 Deposits

Attached encrustation from groundwater infiltration was found extensively in the televised sewer segments. The deposits were located at joints, cracks in the pipes, and within service taps. Most of the deposits found are not reducing the cross-sectional area of the pipe and are not affecting the flow. However, there are a few accumulations that may restrict flow in the main pipe or service lateral.

Attached grease was found at only a couple locations. Additionally, a couple sewers with low flow had settled deposits and debris along the bottom of the pipe.

6.4.2.2 Obstacles/Obstructions

Poles were found protruding through the top of the pipe at two different locations. These locations are both found in the sewer that runs west along the south side of East Broad Street, and the locations appear to be directly under street lamps. Debris has accumulated on the poles, resulting in blockages of 30%-50%.

6.4.2.3 Roots

Roots were mainly found in 14 of the 51 televised sewer segments. Root cutting was performed in two segments. **Table 6-10** lists the sanitary sewer segments with root intrusion observed by the CCTV.

6.4.2.4 Infiltration Found

Any groundwater seen infiltrating into the sewer during the CCTV is noted as an O&M defect. The infiltration is defined by the rate it is entering and tagged as either a weeper, dripper, runner or gusher. Infiltration found during the CCTV investigation can be an indication of a more serious I/I problem in the sewer during wet weather.

6.4.2.5 Service Taps

Defective taps, whether factory made or break-in/hammer, are denoted when the tap or sewer immediately around the tap is structurally damaged (fractured, broken, or separated) or is leaking infiltration. Intruding break-in/hammer taps are denoted when the connection intrudes into the sewer. CCTV investigations identified 7 instances of defectives taps and 5 instances of intruding taps in the televised segments.

Table 6-10: CCTV Root Defects

Rank	Sanitary Sewer Segment	Root Cut Performed	Total Rating of Root Defects	Comments
1	LI-135 : LI-134	No	40	Many instances of fine roots at joints. Survey abandoned by root ball at joint and root ball at connection causing a blockage of flow.
2	LI-275 : LI-274	Yes	38	Many instances of fine and medium roots at joints after root cut. Two laterals with root balls.
3	LI-131 : LI-130	No	34	Many instances of fine and medium roots at joints.
4	AL-162 : AL-161	Yes	14	Many instances of fine and medium roots at joints after root cut.
5	AL-219 : AL-212	No	27	Many instances of fine roots at joints. One root ball at connection.
6	LI-273 : LI-272	No	25	Many instances of fine roots at joints.
7	AL-126 : AL-125	No	22	Many instances of fine roots at joints. One lateral with root ball.
8	AL-164 : AL-163	No	42	Many instances of fine roots at joints.
9	AL-163 : AL-162	No	38	Many instances of fine roots at joints.
10	LI-274 : LI-273	No	21	Many instances of fine roots at joints.
11	LI-276 : LI-275	No	17	Many instances of fine roots at joints.
12	LI-128 : LI-127	No	16	Many instances of fine roots at joints.
13	LI-125 : LI-124	No	7	Many instances of fine roots at joints.
14	LI-124 : LI-123	No	10	Many instances of fine roots at joints.

7.0 SEWER SYSTEM EVALUATION

The primary focus of this SSES is to identify sources of I/I entering the collection system along with defects and deficiencies that affect the performance of the collection system. This section summarizes the findings of the field investigations and evaluates the performance of the system with regards to the structural condition of the pipes and manholes, susceptibility to I/I, and operation and maintenance issues.

7.1 Structural Condition

The sewer system in Bexley consists mostly of brick manholes and vitrified clay pipe constructed in the 1920s through 1940s. Despite the age of the pipe, no major defects that restrict the capacity or compromise the structural integrity of the pipe through substantial deformation or collapse were identified in the system by the field investigations.

The majority of structural defects identified in the pipes were cracks and fractures. Although these defects have the potential to deteriorate further, the pipes generally have a long remaining useful life before further deterioration occurs. Several holes and broken sections of pipe were found in the system. Most of these holes and broken pipe were small, typically only an inch or two in diameter, and located along the joints of the pipe. They do not affect the structural integrity of the pipe as a whole, but as with cracks and fractures, can be a generous source of I/I. A few sections of broken pipe were found in the televised segments. These broken sections show only a small deformity but have potential to deteriorate and collapse in the future.

Many of the inspected manholes showed signs of deterioration in the chimney, wall, bench and channel components. In particular, there were many brick rings in the chimneys which were completed deteriorated with bricks broken or missing. Some of the manholes have broken or dysfunctional bench and channels, which disrupt the flow through the manhole and can cause debris to collect. In a few cases, the bench and channel was broken with soil exposed.

7.2 Infiltration and Inflow

According to the flow monitoring program completed in August 2011, the basins north of Fair Avenue perform within acceptable I/I ranges during less saturated periods, and show excessive I/I during more saturated conditions. The percent capture, which is the percentage of rainfall that enters the sanitary sewer for a storm event, ranged from 34% to 43% during one particular storm event on March 4, 2011 (1.71", 39 hours, 4-month recurrence). Percent captures for acceptable I/I levels are generally under 5%. The long-term rainfall derived infiltration that occurs in the sewer system can last for 2-7 days after the rainfall event. It is evident that saturated ground conditions cause much of the I/I in the sanitary system.

According to the Franklin County Soil Survey maps, the soils in the City of Bexley are mostly Bennington-Urban Land Complex (Bf). Bennington is a somewhat poorly-drained soil with slow permeability. It is also characteristic of having seasonal high water tables, generally at a depth of 12 inches. The soil characteristics fall right in line with I/I observations.

In summary, the sanitary sewer system is prone to excessive I/I during periods of high soil saturation due to the soil characteristics in the study area. These conditions commonly occur in the spring and winter time or after any significant period of rainfall. The I/I during this time can enter the sanitary sewer system mainly through leaky pipes and manholes, or directly-connected foundations drains.

The completed SSES field investigations have led to several conclusions regarding how the I/I is entering the sanitary system in the basins studied. The following subsections discuss the nature of public and private I/I sources in detail.

7.2.1 Public Source I/I

No direct connection with any public stormwater inlet was identified during the field investigations. However, a connection with the stormwater sewer system was identified inside MH LI-273 located in the backyard of 2500 E. Broad Street, south of Ashbourne Road. A sanitary and a stormwater sewer run adjacent to each other through this manhole. Inside the manhole, both pipes are open allowing flow to pass from one pipe to the other when surcharged.

All public source I/I observed entering the sanitary sewer systems in these basins appear to be the result of leaky pipes and manholes. Leaky sanitary pipes that cross under or run nearby a storm sewer can accumulate additional I/I from stormwater that exfiltrates the storm system. It has been determined that over 25,000 LF (4.7 miles) of storm sewer pipe lies within 10 feet of a sanitary sewer (centerline to centerline), and over 10,000 LF (1.8 miles) of storm sewer pipe lies within 5 feet of a sanitary sewer.

The main sources of public source I/I identified by the SSES field investigations are as follows:

- Infiltration through pipe joints and cracks/holes in the pipe wall
- Infiltration through defective service connections
- Infiltration through sanitary service laterals that lie under stormwater sewers in the right-of-way
- Infiltration through brick manhole walls and chimneys

7.2.2 Private Source I/I

Smoke testing and resident questionnaires were the main investigative procedures to identify the private sources of I/I. The individual results of these tests are not definitive and require further investigations to confirm findings. However, the results do provide a general understanding of how the private source I/I is entering the system. The main sources of private source I/I identified by the investigations are as follows:

- Inflow through directly-connected downspouts
- Inflow through suspected connections with private drains in driveways, yards, and basement stairwells

- Infiltration through directly-connected foundation perimeter drains

- Infiltration through leaky sanitary service laterals in yards

The 2004 resident questionnaires were utilized to determine the amount of directly-connected downspouts and foundations drains in the study area. The questionnaire form asked residents about certain property characteristics and to check a box for a "yes" response if the characteristic applied to them. **Table 7-1** displays the total number of "yes" responses to the property characteristics regarding downspout and foundation drain connections.

Table 7-1: Property Characteristics from Resident Questionnaires

Property Characteristic	Total "Yes" Responses	"Yes" Responses in SSES Phase 1 Study Area
Foundation perimeter drains connected to the sanitary sewer (drains through basement drains)	111 (12%)	57 (11%)
Foundation perimeter drains connected to the storm sewer (usually drains to curb)	371 (38%)	215 (41%)
Roof and gutter drains connected to the sanitary sewer	51 (5%)	38 (7%)
Roof and gutter drains connected to the storm sewer	445 (46%)	251 (48%)

Smoke was found emitting from building foundations on 7 properties during the smoke testing investigations. It can be difficult to determine from smoke testing how many houses have foundation drains connected due to existence of sump pumps, p-traps, and other internal plumbing or lateral defects that can block smoke. None of the properties identified by the smoke testing had responded to the questionnaire. Based on results from the questionnaire, it is estimated that 10% to 20% of the properties in the study area may have perimeter foundations drains directly connected to the sanitary sewer.

Smoke testing identified 54 locations where smoke was emitting from downspouts or gutters. Smoke will not identify all houses due to any lateral defects or other issues that may block smoke. The resident questionnaires identified 38 properties that have connected downspouts, 7 of which also emitted smoke during the smoke test. It has also been observed that curb outlets are in place for most of the properties in the study area. From these results, it is estimated that 5% to 10% of the properties in the study area may have downspouts directly connected to the sanitary sewer.

7.3 Operation and Maintenance

The inspected portions of the sanitary sewer system appear to be well maintained and operational, with only a few blockages found. Surcharge found during manhole inspections were reported to the City immediately after the inspection. The following O&M conditions were found in the televised portions of the sanitary sewer system:

- Roots – Roots were found in 10 televised segments. The noted roots were mostly fine roots at joints. Medium to large roots that reduce the cross-sectional area were found in only 5 televised segments.

- Attached Encrustation – Encrustation from groundwater infiltration was found throughout the system. The encrustation was found at joints, cracks and from within the service lateral. Only a couple instances resulted in a decreased cross-sectional area.

- Obstructions –Two poles were found protruding into the pipe, causing a partial blockage of flow.

7.4 Water-in-Basements

The 2004 resident questionnaires were utilized to investigate the frequency and locations of WIB occurrences in the study area. **Table 7-2** displays the WIB responses from the resident questionnaires.

Table 7-2: WIB Responses from Resident Questionnaires

Property Characteristic	Total Responses	Responses in SSES Phase 1 Study Area
Number of responses reporting some form of basement flooding	694 (72%)	376 (71%)
Entering through toilet/sink	3 (0%)	2 (0%)
Entering through floor drains	340 (35%)	196 (37%)
Entering through cracks in floors/walls	180 (19%)	86 (16%)
Entering through windows/doors	21 (2%)	9 (2%)
Don't know or did not answer	149 (15%)	83 (16%)

When asked when the last occurrence of basement flooding was, the majority of responses listed a date between 8/13/2003 and 9/1/2003. This was a very wet period with 5"-7" of rain falling between those dates.

The respondents who reported basement flooding due to an apparent sanitary backup are scattered across the City. The Livingston Avenue tributary area contains almost half (46%) of the all the basements with apparent sanitary backups. The Gould Road tributary area contains 35% and the Alum Creek tributary area contains 18% of the apparent sanitary backups.

8.0 SYSTEM IMPROVEMENTS

Hydraulic modeling investigated various alternatives to reach a 10-year level-of-service for the sanitary collection system. The City has chosen to pursue aggressive RDII reduction to improve the capacity of their system and eliminate system overflows and water-in-basement complaints. Aggressive RDII reduction will include the following:

- Complete sanitary sewer rehabilitation and repairs in sub-basins #8, #9, #11 and #12. These sewers are tributary to the Parkview and Cassady Avenue sewers were identified to have capacity restrictions.
- Complete storm sewer system rehabilitation and repairs in sub-basins #8, #9, #11 and #12.
- Complete recommendations considered high priority that were not included in sub-basins #8, #9, #11 and #12. The high-priority recommendations will also be evaluated by the maintenance staff to determine if repairs need to be expedited under the CMOM program.
- Complete recommendations considered medium priority that were not included in sub-basins #8, #9, #11 and #12.
- City crews will investigate the 77 properties that have suspected downspouts connected to the sanitary sewer system. Property owners will be notified to correct positive direct connections.

The City will proceed first with sanitary and storm sewer rehabilitation in Sub-Basin #8. Upon the completion of sewer rehabilitation in Sub-Basin #8, the City will provide post-construction flow monitoring and hydraulic modeling to determine the amount of I/I reduction achieved by the completed improvements and the corresponding level-of service the system provides in that sub-basin. The evaluation will verify the City's approach is valid and the goal can be achieved. In the event that sufficient I/I reduction is not obtained, the City will reevaluate the need for the relief sewers and storage options. Additionally, the City will prepare a revised project schedule and submit to the OEPA for review and approval.

The following subsections detail specific sewer system improvements and assign a priority status.

8.1 Sanitary Sewer Rehabilitation

The City's plan for sanitary sewer rehabilitation is considers both recommendations from detailed SSES findings and the hydraulic modeling.

8.1.1 Target RDII Reduction Rehabilitation

The City will proceed with a rehabilitation program to install a liner in all sanitary sewer segments, excluding previously rehabilitated and newly-constructed segments. Based on findings from the hydraulic modeling, the City will first perform sanitary sewer rehabilitation within Sub-

Basins #8, #9, #11 and #12 to address capacity issues in Parkview and Cassady Avenues due to excessive I/I. **Table 8-1** displays the priority status of the sub-basins and total length of sewer to be rehabilitated within each.

Table 8-1: Target RDII Reduction per Hydraulic Modeling

Priority	Sub-Basin	Target RDII Reduction	Length of Sewer to be Rehabilitated
1	8	65%	15,522 L.F.
2	11	50%	31,055 L.F.
3	12	50%	3,822 L.F.
4	9	50%	14,209 L.F.

8.1.2 SSES Recommended Sanitary Sewer Rehabilitation

Recommendations for sewer rehabilitation are provided for sewers that were televised through CCTV or dye test investigations. The sewers identified for rehabilitation have severe defects that may include leaky joints, roots and/or structural defects that may lead to increased I/I, capacity restrictions, sink holes and/or pipe failure. Future CCTV efforts may identify further severe defects in the system and rehabilitation needs.

In addition to the defects found by CCTV, recommendations are provided for rehabilitation of sewers that are suspected to contribute large amounts of I/I. It is recommended that sanitary sewers that are in close proximity to stormwater systems by running parallel to storm sewers with less than 10 feet of separation be rehabilitated. Exfilitration from a storm sewer may pass through the granular backfill and through leaky joints in the sanitary sewer and laterals and increase the I/I entering the sanitary sewer.

The sewers recommended for rehabilitation through SSES investigations and proximity to storm sewers are shown in **Figure 8-1**. High priority is noted for segments that contain severe (rating of "5") structural defects per PACP coding during CCTV investigation or severe infiltration (gushers) through cracks and joints from dye testing. **Table 8-2** lists the total length of sewer recommended for rehabilitation.

Table 8-2: Quantity Table for Recommended Sanitary Sewer Rehabilitation

Pipe Diameter	High Priority	Medium Priority
8"	6,245 L.F.	10,205 L.F.
10"	220 L.F.	703 L.F.
12"	0 L.F.	1,900 L.F.
15"	1,983 L.F.	859 L.F.
18"	1,695 L.F.	1,529 L.F.
Total	10,143 L.F.	15,196 L.F.

High and medium priority rehabilitation segments that lie within Sub-Basins #8, #9, #11 and #12 will be the first to be addressed, as discussed in Section 8.1.1. The sewers that are not included in those sub-basins will be completed as a separate project after completion of Sub-Basins #8,

#9, #11 and #12. The high-priority recommendations will also be evaluated by the maintenance staff to determine if repairs need to be expedited under the CMOM program.

8.2 Sanitary Sewer Repair

Two obstructions were identified by the CCTV investigation that will require a pipe repair. Poles are observed projecting through the pipe at two locations on East Broad Street. The locations appear to be directly under street lamps and debris has accumulated on the poles, resulting in blockages of 30%-50%. It is recommended to repair the pipe through open-cut methods and reinstall the street lamps without damaging the sewer. The pipe repair locations are shown in **Figure 8-1**. The pipe repairs will be completed in conjunction with the rehabilitation in Sub-Basins #8, #9, #11 and #12.

8.3 Manhole Rehabilitation

Manholes that are recommended for rehabilitation in this study were identified through manhole inspections, smoke test findings and dye test findings. A manhole is recommended for rehabilitation if it showed evidence of I/I or has structural defects. A priority of high, medium or low is provided for each manhole recommended for rehabilitation based on its worst score from the manhole inspections and findings from smoke and dye testing.

Rehabilitation of sanitary manholes consists of applying a cementitious grouting to the chimney, cone and wall areas of the manhole, including the frame and pipe seals. The grouting aims to improve the structural integrity and prevent I/I from entering the manhole. Many manholes have dysfunctional and broken bench and channels. These should be re-formed to establish proper flow and prevent debris build-up. Any offset, buried or loose frames should be reset or raised.

A total of 29 manholes are given high priority for rehabilitation and 135 manholes are medium priority. **Figure 8-1** shows the locations of the manholes recommended for rehabilitation.

8.4 Notification of Private Property Issues

Smoke testing identified 77 properties that had suspected downspout connections. The City will investigate each property and if direct downspouts connections are confirmed, the property owner will be notified to disconnect the downspout.

Dye testing identified 37 service laterals that collect a significant amount of I/I due to indirect connections with the storm sewer above the lateral. The City has decided at this time to correct the public infrastructure issues identified in this report. Upon completion of these activities the City will evaluate the need for additional I/I reduction and notify the property owner if required. The property addresses which appear to be associated with the leaky laterals are listed in **Table 6-7**.

8.5 Storm Sewer Rehabilitation

As an alternative to rehabilitating sanitary sewer laterals, the City will rehabilitate their storm sewer system in the area of defective laterals. Many mainline sewers and service laterals cross or run parallel to storm sewers, posing a risk for I/I. **Figure 8-2** displays these storms sewers and categorizes them as medium priority for rehabilitation. Dye testing identified a number of storm sewers that cross over sanitary lateral and indirectly contribute a significant amount of I/I into the sanitary sewer system. These storm sewers are categorized as high priority for rehabilitation. There is approximately 130,500 L.F. of storm sewer within the City of Bexley. **Table 8-3** displays the length of storm sewer that is given priority for rehabilitation. The pipe diameters are unknown.

Table 8-3: Quantity Table for Recommended Storm Sewer Rehabilitation

	High Priority	Medium Priority
Storm Sewer Rehabilitation	5,034 L.F.	32,684 L.F.

In conjunction with sanitary sewer rehabilitation for target RDII reduction, the City has elected to rehabilitate the storm sewers located in Sub-Basin #8, #9, #11 and #12 as well. Highest priority will be giving to the storm sewers that are rated in Table 8-3.

8.6 Operation and Maintenance

The SSES investigations have identified various pipes and manholes that need cleaning and/or root cutting. The City will address these needs through their CMOM program.

Upon completion of the recommendations outline in this section of the report, the City's goal is to continue to inspect, evaluate and rehabilitate the sanitary and storm sewers that are not specifically addressed in this report. The City understands the importance of renewing the existing sewer system and plans to make an annual investment for this effort.

9.0 IMPLEMENTATION PLAN

The City of Bexley has developed an implementation program to complete the recommended improvements over the next 26 years. **Table 9-1** provides the summary of the schedule for the Ohio EPA's review. Please refer to **Appendix B** for detailed cost estimates.

Table 9-1: City of Bexley DFFO Implementation Schedule

Project Name	Year					Project Total
	2015-2018	**2019**	**2020-2035**	**2036-2037**	**2037-2040**	
Capacity Improvements						
Parkview Relief Sewer						TBD
Cassady Relief Sewer						TBD
Storage						TBD
					New Infrastructure Construction Projects =	**TBD**
Post Construction Monitoring and Evaluation						
Post Construction Monitoring and Evaluation		$ 125,000.00				$ 125,000.00
Rehabilitation and Repair Project						
Sub-basin #8 (4 year program)	$1,670,105.00					$ 1,670,105.00
Sub-basin #11 (16 year program)			$6,596,945.00			$ 6,596,945.00
Sub-basin #12 (2 year program)				$ 635,785.00		$ 635,785.00
Sub-basin #9 (5 year program)						$ 2,254,695.00
High Priority (2 year program combined with sub-basin #12)				$ 136,460.00		$ 136,460.00
Medium Priority (4 year program)					$1,570,830.00	$ 1,570,830.00
					Rehabilitation of the Existing Infrastructure =	**$ 12,989,820.00**
Yearly Total Spending =	**$1,670,105.00**	**$ 125,000.00**	**$6,596,945.00**	**$ 772,245.00**	**$1,570,830.00**	

APPENDIX A:

5-Year SSES Schedule Submitted August 10, 2009

APPENDIX B:

Detailed Cost Estimates