Hydraulic Model Report

Lexington-Fayette Urban County Government

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7-8-08

(Date)

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Acronyms/Definitions

CAP = Capacity Assurance Program

Correctable/Corrected Recurring SSOs = one of the Recurring SSOs that can be corrected by maintenance measures instead of related to capacity deficiencies.

H&H = hydrologic and hydraulic

HGL = hydraulic grade line

HMR = Hydraulic Model Report

LFUCG = Lexington-Fayette Urban County Government

Recurring SSO = an SSO that occurs in the same location more than once per twelve (12) month rolling period.

SSO = Sanitary Sewer Overflow

Trunk Sewers = the “Major Gravity Lines” as defined in the Consent Decree, which are gravity sewer lines that are 12 inches in diameter or larger.

Section 1 – Introduction

The Lexington-Fayette Urban County Government (LFUCG) is initiating the development of a hydrologic and hydraulic (H&H) computer model of its wastewater collection system that will become a critical tool in assisting LFUCG in meeting a variety of objectives. A team of experienced modeling professionals will be applying sound modeling techniques and approaches that will lead to the development of a reliable H&H model that will enable its application for the evaluation of various planning scenarios.

Through LFUCG's H&H computer model, a long-term investment is being made in a sophisticated tool that will assist LFUCG in better managing the large sewer system under its control. This investment leverages LFUCG's existing system data and knowledge and builds upon previous modeling efforts of LFUCG's wastewater collection system. Once developed, the H&H model will provide LFUCG with a tool to support a variety of sewer system management functions, which include sanitary sewer overflow (SSO) control planning, improved operations, enhanced maintenance planning and evaluation, and capacity assurance evaluations.

The H&H computer model will be developed in phases that will enable the timely development of the model datasets. The corresponding field data collection programs (e.g., field survey, flow monitoring, rainfall monitoring) will be coordinated with their respective portions of the collection system.

The purpose of this Hydraulic Model Report (HMR) is to define how the model will be developed to support the Consent Decree requirements. The report focuses on the technical activities necessary to achieve this objective. This report is intended to satisfy Section VII, Paragraph 15, E, ii of the LFUCG Consent Decree which identifies the following to be included in the HMR:

- A description of the Model which shall be a widely accepted model,
- Digitized maps and schematics that identify and characterize the portions of the Sanitary Sewer System that shall be included in the Model,
- Identification of input data,
- Configuration of the Model,
- Procedure and protocols for performance of sensitivity analyses,
- Procedures for calibrating the Model, and
- A schedule for complete implementation of the Model.

Section 2 – Project Goals and Schedule

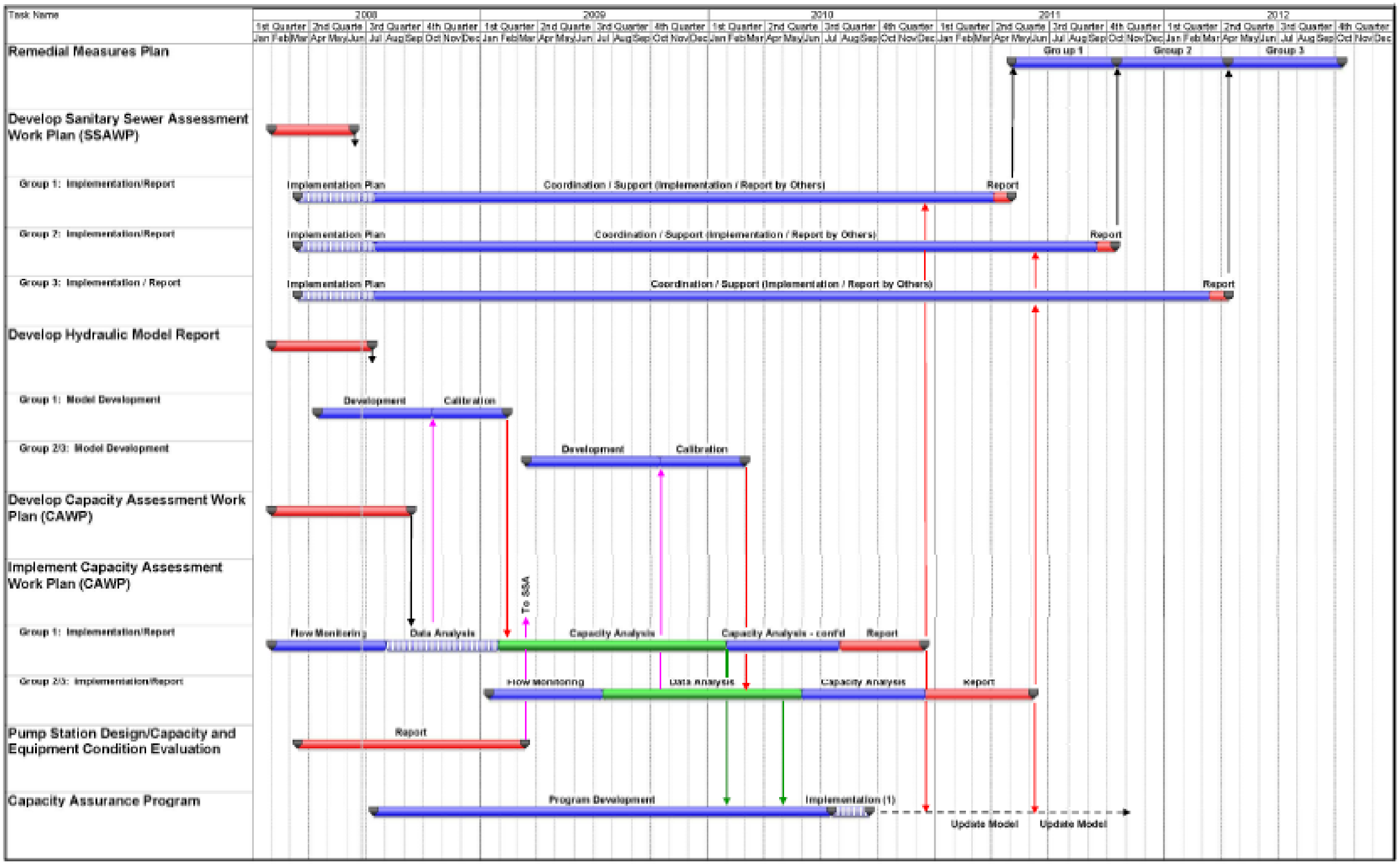
The investment in a reliable H&H computer model of the LFUCG's Sanitary Sewer System will benefit a variety of both short and long-term goals and objectives. The primary objective for developing the H&H computer model is to satisfy current Consent Decree requirements. LFUCG is also developing the H&H computer model to support other internal agency objectives as well as to provide a sustainable tool that can be applied to support LFUCG's long-term commitment to providing reliable sanitary sewer service to its customers.

The goal is to develop a reliable H&H model acceptable to the EPA that adequately supports LFUCG's short and long-term needs. The H&H model will be used to meet the following Consent Decree requirements:

1. Assess the hydraulic capacity of the sewer system (support capacity assessment work plan implementation)
2. Identify causes of known Recurring SSOs
3. Assess proposed remedial measures with the goal to eliminate the Recurring SSOs
4. Evaluate alternatives to develop a Capacity Assurance Program (CAP)
5. Support the Sanitary Sewer Assessment (SSA) program
6. Perform post-construction performance validation of system improvements

The H&H model is scheduled to be developed in two phases in order to have model datasets available to support the Consent Decree schedule. The Group I Sewersheds is scheduled to be developed first followed by the development of Groups II and III. In short, the Group I Sewersheds are scheduled to be developed and calibrated in 2008 while Group II is scheduled to be developed and calibrated in 2009. It is desirable that the Group III Sewersheds be developed along with Group II Sewersheds. **Figure 2-1** illustrates the schedule of development of the H&H models corresponding to the three different Sewershed Groups in relation to other Consent Decree programs.

Figure 2-1 Schedule for H&H Computer Model Development and Implementation



(1) CAP submittal is due to EPA within 2 years of Effective Date; implementation due 30 days after approval.

Fast Track Activities for CAP Implementation Support

CDM

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Section 3 – Summary of Existing Information

A variety of types of existing data are available to assist with the development of LFUCG's H&H computer model. These resources are discussed below.

3.1 Sewer Network Data

The representation of the physical wastewater collection system in the H&H computer model is a fundamental component of developing a reliable model. The accurate and up-to-date representation of the collection system physical attributes is important in order to ensure that the simulated flow rates and water depths represent real-world conditions. The sewer system network data is comprised of the following attribute data:

1. connectivity of the pipes and manholes,
2. sewer sizes,
3. sewer shapes,
4. sewer material,
5. invert elevations of the pipes at the manholes, and
6. manhole rim elevations.

The sewer network data will be developed first based on currently available information and only followed by field investigation work if deemed necessary. Below is a discussion of available resources available to assist with the sewer network.

3.1.1 GIS and Other Digital Data

LFUCG has a geographic information (GIS) database with sewer system attributes. The GIS database includes important information such as all gravity pipe IDs, force main IDs, manhole IDs, the pipe connectivity, the locations of Recurring SSOs, pump stations, as well as the X and Y coordinates of all listed items.

3.1.2 Paper-based Sewer Mapping

Paper-based record drawings for pipes and sewer appurtenances are available as a resource if other existing digital data does not prove adequate to resolve sewer system attribute data. LFUCG has drawings for the replacement of trunk sewers that occurred since the development of the trunk sewer models under what was known as the "Bond Projects." These are important in order to have a model that is up-to-date and represents real-world conditions. The paper maps that are not certified to represent "as-built" or "record" conditions will be confirmed prior to inclusion in the model. These projects are listed below.

1. Winburn Estates Sanitary Sewer Rehabilitation
2. Phase 1 and Phase 2, Elkhorn Park & Radcliff Neighborhood Sanitary and Storm Improvements
3. West Hickman Watershed Sub-Area, Lansdown Trunk, Zandale Drive Sanitary Sewer Improvements
4. New Dixie Trunk Sewer Rehabilitation
5. Upper Wolf Run/Picadome Pumping Station

3.1.3 Sewer System Studies

LFUCG has conducted a number of sewer system studies over the years and they are available in hard-copy with some available in digital format. Trunk sewer studies corresponding to the seven Sewersheds were conducted between 1998 and 2002. The reports associated with these studies are available as resources to understand the historical hydraulic performance of the collection systems and how the models were developed to support the specific studies.

3.2 Sewershed Characteristics Data

Sources for understanding the sewershed characteristic data were also investigated. The key sewershed data to assist in the H&H computer model development include sewershed delineations and areas, land use, zoning, parcels, population, ground contours, and aerial photographs.

3.2.1 GIS and Other Digital Data

Within LFUCG's GIS are ArcGIS shapefiles that contain information regarding sewershed delineations, land use, parcels, and ground contours. These are valuable resources currently available that will assist in characterizing the characteristics for each of the seven Sewersheds. The GIS data is anticipated to be the primary source for information that will be used to characterize the Sewersheds.

3.2.2 Paper-based Sewershed Mapping

Paper-based sewershed mapping products are available for some of the trunk sewers. Existing paper-based sewershed mapping are largely based on LFUCG's information from LFUCG's GIS.

3.2.3 Studies and Reports

The trunk sewer studies are resources available to help understand the historical sewershed characteristics. They are available as a secondary source to the GIS data.

3.3 Existing Sanitary Sewer System Models

A number of existing hydraulic computer models related to portions of LFUCG's wastewater collection system have been identified as important resources for the development of LFUCG's H&H computer model. All of the hydraulic models are models based on the EPA SWMM software. They include:

1. trunk sewer models for each of the seven Sewersheds,
2. the Downtown Collector Sewer Study model related to the downtown Lexington area,
3. a more recent hydraulic model of a portion of the North Elkhorn Sewershed pumping systems.
4. WH7 re-calibration effort

LFUCG has had hydraulic computer models developed for each of the seven sewershed trunk systems spanning a period of time dating back approximately ten years. These hydraulic models are a key resource for developing the sewer system network for the new H&H computer models. The models do not contain data related to the hydrology of their respective Sewersheds. Hydraulic loads to the models were developed outside of the existing trunk sewer models and input directly. **Table 3-1** lists the trunk sewer studies and summary information related to each.

Table 3-1 Summary of Sewershed Trunk Sewer Models

Sewershed	Period of Development	Consent Decree Sewershed Group	No. Modeled Pipes
Wolf Run	2002	I	428
East Hickman	2002	I	303 [1]
West Hickman	2001	I	617
Cane Run	2001	II	164
Town Branch	2002	II	528
South Elkhorn	2001	III	318
North Elkhorn	2002	III	303 [1]

[1] The number of pipes is based on the hydraulic model where the East Hickman and North Elkhorn Sewersheds are modeled together, in one model.

The model of the downtown area represents a model with more recent information than the Town Branch trunk sewer model. Information from this model will be reviewed to determine how to use the more detailed information.

The recent North Elkhorn study includes a hydraulic model that includes additional features and accounts for new development beyond its trunk sewer study and focuses on the force mains.

3.4 Other Existing Data

Other existing data were identified that may assist with the development of the H&H computer model of LFUCG's wastewater collection system. These data are summarized below.

3.4.1 Flow Monitoring

Water depth flow monitoring data are available in electronic format at the five cross-connections between the sanitary and storm sewer systems in the Sanitary Sewer System. The recorded water depth data are used to estimate when flow occurred through these cross-connections. The flow rates and volumes through the cross-connections are estimated based an estimated depth of flow in the cross-connection. The reliability of the flow monitoring data will be assessed and the data will be utilized accordingly during the model development and calibration. The five cross connections are listed below.

1. MH CR3_51, 772 N Broadway
2. MH TB2_33, 648 S Broadway

3. MH TB5_14, 441 Park Ave.
4. MH TB5_17, 443 Oldham Ave.
5. MH WR5_9, 782 Allendale Dr.

Flow monitoring data from previous studies may be useful to understand the historical performance of the Sanitary Sewer System.

3.4.2 TV Inspections

Recent CCTV records available in the West Hickman Sewershed (WH1, WH2, and WH7 sub-sewersheds) are available to assist with the model development as well as data from the previous trunk sewer studies. Understanding the condition of the sewers will help in model calibration.

3.4.3 WWTP Effluent Flow Records

Existing effluent flow rates at the West Hickman and Town Branch wastewater treatment plants will be used to assist with the model calibration. The effluent flow data will be used in conjunction with the flow data from the temporary flow monitoring program specific to the model development and calibration (See Section 5).

3.4.4 Pump Station Data

LFUCG maintains information related to the pump stations within its collection system. **Table 3-2** below lists the pump stations within the LFUCG collection system and flow meter types. **Figure 3-1** illustrates the LFUCG pump station locations which are labeled according to the "No." column in Table 3-2. LFUCG performs pump drawdown tests on each of the pump stations annually. Results from the drawdown tests are available in electronic format and will be important for accurately modeling the pump stations. Also available in electronic format are the estimated pump station overflow rates and descriptive information about the pumps at each pumping station.

Table 3-2 Pump Station Metering Summary

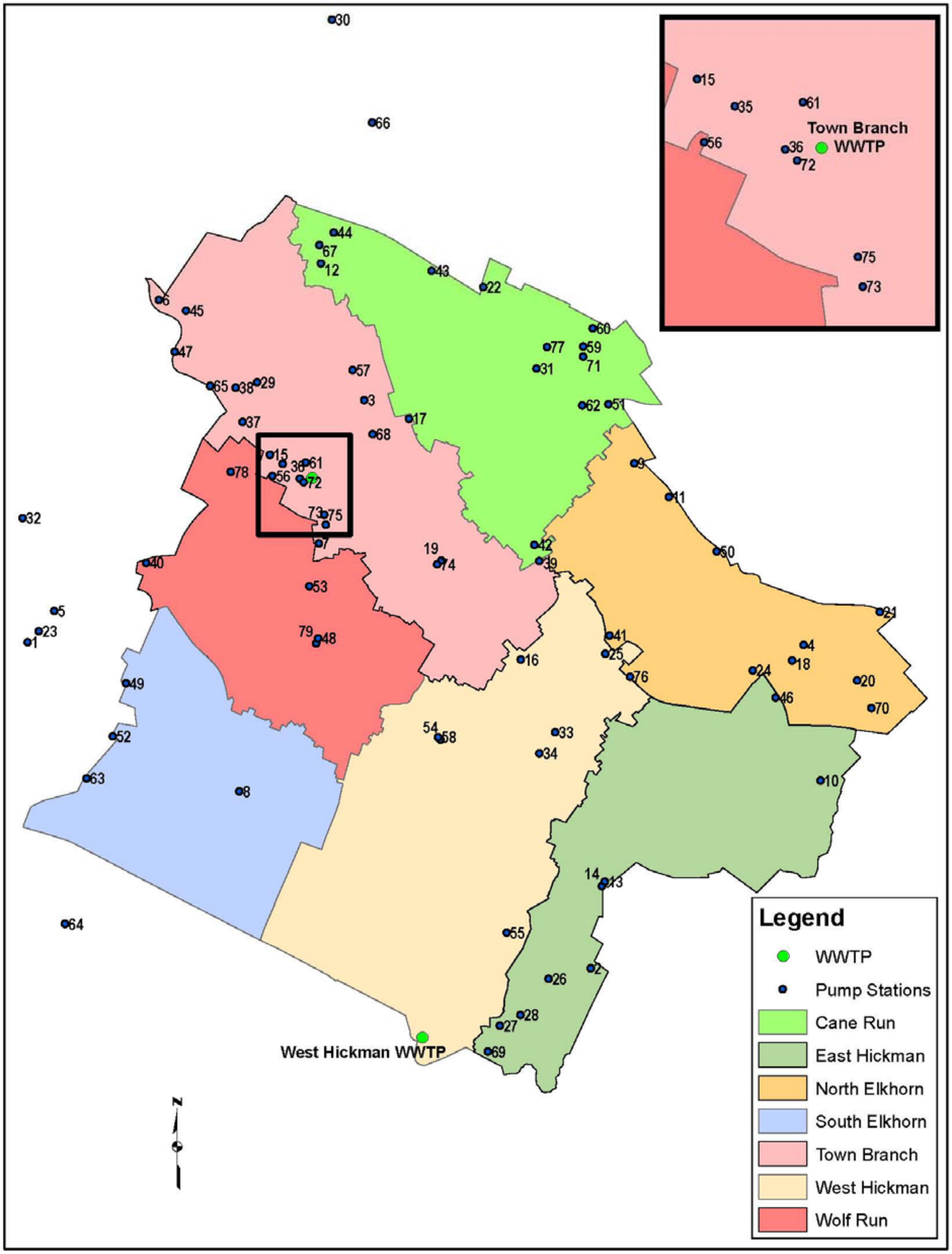
No.	Station Name	Station Address	Flow Meter Type	Comments
1	Armory	4309 Airport Rd	Note 1	
2	Armstrong Mill Road	2755 Armstrong Mill Rd	Note 1	
3	Baker Court	1331 Baker Ct	Note 1	
4	Blackford Property	3200 Mahala Cv	Note 1	
5	Blue Grass Field	1031 Air Frieght Dr	Note 1	
6	Bracktown	210 Betty Hope Ln	Note 1	
7	Cisco Road	109 Cisco Rd	Note 1	
8	Clays Mill	3330 Clays Mill Rd	Note 1	
9	Deep Springs	469 Anniston Dr	Note 1	
10	Deer Haven	1220 Deer Haven Ln	Note 1	
11	Dixie	1459 Huntsville Dr	Note 1	
12	Dotson Property	2828 Spurr Rd	Note 1	
13	East Hickman	3316 Buckhorn Dr	Flow meter in the inflow channel	

No.	Station Name	Station Address	Flow Meter Type	Comments
14	East Lake	1326 Fenwick Rd	Note 1	
15	Electronics Park	609 Bizzel Dr	Note 1	
16	Fincastle	1711 Clays Spring Ln	Note 1	
17	Georgetown Fire	1136 Finney Dr	Note 1	
18	Gleneagle	3095 Caversham Park Ln	Note 1	
19	Government Bld.	200 E Main St	Note 1	
20	Greenbrier # 1	3770 Katkay Dr	Note 1	
21	Greenbrier # 2	3592 Winchester Rd	Note 1	
22	Griffin Gate	1960 Stanton Way	Note 1	
23	Grinder	4260 Airport Rd	Note 1	
24	Hamburg Place	1936 Pavilion Way	Note 1	
25	Harbor Freight	1393 E. New Circle Rd	Note 1	
26	Hartland # 1	3630 Timberwood Ln	Note 1	
27	Hartland # 2	2140 Leafland Pl	Note 1	
28	Hartland # 3	4904 Hartland Pkwy	Note 1	
29	Hillenmeyers	2459 Leestown Rd	Note 1	
30	Horse Park	4020 John Henry Ln	Flow meter in the inflow channel Inaccurate at Higher Flows	Recorder not functioning
31	Johnson Property	1860 Millbank Rd	Note 1	
32	Keeneland	4091 Versailles Rd	Dopler in the force main	
33	Lake Tower	543 Laketower Dr	Note 1	
34	Lakeshore Drive	550 Lakeshore Dr	Note 1	
35	Landfill #1	1765 Old Frankfort Pike	Note 1	
36	Landfill #2	315 Jimmie Dr	Note 1	
37	Leestown Industrial	168 Trade St	Note 1	
38	Leestown West	150 Venture Ct	Note 1	
39	Lexington Manor	850 Byars Ave	Note 1	
40	Lexingtonian Estates	3300 Versailles Rd	Note 1	
41	Liberty Road	2101 Liberty Rd	Note 1	
42	Loudon	682 E Loudon Ave	Note 1	
43	Lower Cane Run	1760 Mcgrathiana Pkwy	Mag. Meter in the force main	
44	Lower Cane Run # 2	2908 Sullivans Trce	Mag. Meter in the force main	
45	Lower Town Branch	3231 Leestown Rd	Transient response meter in the force main Not Consistent Readings	Recorder not functioning
46	Man O War	2079 Bryant Rd	Note 1	
47	Marshall	249 Long Branch Ln	Note 1	
48	Mccubbin	526 Mccubing Dr	Note 1	
49	Mint Lane	1510 Man O War	Note 1	
50	North Elkhorn	2201 Elkhorn Rd	Flow meter in the	

No.	Station Name	Station Address	Flow Meter Type	Comments
			inflow channel	
51	Old Paris Pike	2138 Old Paris Rd	Note 1	
52	Palomar Hills	2212 Silktree Ct	Note 1	
53	Picadome	495 Parkway Dr	Mag. Meter in the force main	
54	Pizza Hut	2920 Tates Creek Rd	Note 1	
55	River Park	1419 Trent Blvd	Note 1	
56	Roll Call Center	1793 Old Frankfort Pike	Note 1	
57	Sandersville Road	1673 Jaggie Fox Way	Note 1	
58	Shadeland	857 Glendover	Note 1	
59	Shandon Park # 1	2335 Pierson Dr	Note 1	
60	Shandon Park # 2	765 Kingston Dr	Note 1	
61	Sharkey Property	315 Lisle Industrial Ave	Note 1	
62	Sharon Village	1985 Haggard Ct	Note 1	
63	South Elkhorn	2500 Bowman Mill Rd	Mag. Meter in the force main	
64	Southland Christian	4343 Harrodsburg Rd	Note 1	
65	Spicewood	253 Chestnut Ridge Dr	Note 1	
66	Spindle Top	2330 Research Dr	Mag. Meter in the force main	Recorder not functioning
67	Spurr Rd	3316 Sandersville Rd	Note 1	
68	St. Martins	959 St Martins Ave	Note 1	
69	The Reserve	5399 Tates Creek Rd	Note 1	
70	Thompson Property	2209 Walnut Grove Ln	Note 1	
71	Thoroughbred Acres	619 Parkside Dr	Note 1	
72	Town Branch	335 Jimmie Dr	Note 1	
73	Trafton	150 Trafton St	Note 1	
74	Transit Center	220 East Vine St	Note 1	
75	Vaughan	255 S Forbes Rd	Note 1	
76	Wilderness Trace	535 Wilderness Rd	Note 1	
77	Winburn	1985 Russell Cave Rd	Note 1	
78	Wolf Run	755 Enterprise Dr	Note 1	
79	Woodbine	525 Woodbine Dr	Note 1	

Note 1: These pump station flows are measured by the use of pump run time hour meters located at the pump stations, elapsed run times recorded by the pump station telemetry system, and individual pump draw-down records.

Figure 3-1 Locations of LFUCG Pump Stations



Section 4 – Model Selection

A key component of the Hydraulic Model Report and LFUCG's short and long-term wet-weather flow program is the selection of a hydraulic modeling software package. The process that led to the selection of the hydrologic/hydraulic modeling software package is described below.

4.1 Model Selection Process

The software selection process is a three-step process as identified below followed by a description of each.

1. identify LFUCG modeling needs,
2. evaluate the candidate software packages, and
3. recommend a software package.

4.2 Identify LFUCG Modeling Needs

The first step leading to the selection of an appropriate hydrologic/hydraulic modeling software package is to identify the needs of LFUCG. Identifying LFUCG's modeling needs occurred through a series of discussions on the topic in meetings with LFUCG staff, through gaining an understanding of LFUCG's Sanitary Sewer System, and through an understanding of the Consent Decree and its requirements. The following is a description of the items considered in clearly identifying the modeling needs of LFUCG.

4.2.1 Model Uses

The primary reasons why LFUCG is investing in the development of an H&H computer model are documented in Section 2. The H&H computer model of the wastewater collection system needs to be capable of being applied to meet these goals.

4.2.2 Modeling Software Capabilities

The following capabilities were identified as considerations in the appropriate modeling software package. A qualitative assessment was made as to the importance of each consideration.

<u>Simulate surcharge, backwater conditions</u> - Surcharging and backwater conditions exist in the LFUCG wastewater collection system. A modeling software package that is fully dynamic is necessary. A modeling package that offers anything less than a solution technique that can model gradually varied, unsteady flow conditions in a closed pipe system will not meet LFUCG's modeling goals.

<u>Model can simulate inflow/infiltration (I/I)</u> – The LFUCG collection system is a separate sanitary sewer system with no combined sewer system. The modeling software must have the capability to simulate I/I.

<u>Customization capable</u> – The ability to customize the software to LFUCG's needs is an important consideration. At the onset of the model development, no immediate customization

is identified. Some customization capability is desired to meet potential needs that may arise through its either short- or long-term application.

Scenario management – The capability to manage multiple modeling scenarios is an important consideration. This is particularly important when evaluating remedial measures and capacity assurance alternatives. Scenario management is considered a valuable capability.

Supports continuous simulation – The capability to simulate flow rates and water depths over a long period of time (e.g., for a one-year period or multiple years as opposed to single rainfall events) is an important consideration. This capability is considered important as it may be applied during the evaluation of the remedial measures and capacity assurance alternatives.

Real-Time Control (RTC) support – The capability to dynamically model changing settings in the collection system is a consideration. In-system and offline storage may be considered as remedial alternatives.

Support WWTP linkage (hydraulics, not water quality or process) – The capability to simulate the hydraulics of a wastewater treatment plant, effectively moving the boundary conditions of the computer model from the headworks of the WWTP to its effluent discharge point, is a consideration. This could be helpful for evaluating alternatives at the plants. This capability is considered necessary.

Pump stations – The capability to explicitly (i.e., pumping curves, wet-wells, operational strategy, etc.) model pumping stations is an important consideration for LFUCG since there are numerous pump stations across their collection system. This capability is necessary for LFUCG.

Force mains – The capability to model force mains is an important software consideration. Force mains are a part of the LFUCG Sanitary Sewer System. It may not be necessary to explicitly model each force main, but at least the flows from the pump stations will be simulated and discharged to a manhole along a gravity sewer line. The modeling software should have the capability to model force mains using a pressure equation.

GIS compatibility/sophistication – The capability of the software to use GIS technology and be compatible with LFUCG's in-house GIS is important to LFUCG.

Data interchange capabilities – The capability to import data primarily from LFUCG's GIS and export data as well to usable formats is considered valuable.

Data management capabilities – The ability to manage the modeling related data is an important consideration in the selection of an appropriate modeling software package. The ability to create sub-models, use metadata, customize the model database, track changes, and skeletonize the system are capabilities to be considered. The capability to be compatible with LFUCG's asset management plan is also important. The ability to query data and efficiently store the model attribute data is important to LFUCG.

History of proven performance – Has the model been used previously to support similar types of studies?

Model acceptance to regulators– Has the model been accepted by the US EPA previously?

Model performance – The reliability of the model engine to be numerically stable and the overall software performance reliability are important considerations when selecting the modeling software. In addition to model reliability is the model simulation speed. Software that is relatively fast in performing the model simulations is preferred. This will enable more efficient modeling.

Model user interface – The user interface must be suitable to the identified users/caretakers.

Model output – Does the model provide the results in a clear and usable format?

Vendor support – The reliability and competence of the software support is an important consideration.

Sustainability – The ability to maintain and sustain an up-to-date model over the long-term is important. Is the software flexible to accommodate future needs to expand, change, upgrade, etc.? Will outside users be able to use the model to support other agency objectives?

Model Results Viewer Software – This is a piece of software than can only be used to view model results and not change or edit the model. This can be valuable in sharing modeling results and enabling different stakeholders to view profiles of any portion of the modeled Sanitary Sewer System as well as dynamic model results. The availability of this option at a relatively easy and affordable manner is considered a valuable option.

4.3 Evaluate Candidate Modeling Software Packages

The more commonly used hydrologic/hydraulic modeling software packages that are available today and used for sanitary sewer wastewater collection system modeling are identified below as candidate software packages. The company or organization that provides the software is provided in parentheses. A brief discussion is provided of the advantages and disadvantages of each relative to each other, based on experience with the modeling software packages, vendor demonstrations, and basic research of the software as needed to understand capabilities available in the most recent versions of the software at the time of the evaluation.

4.3.1 InfoWorks (Wallingford Software) - good for medium to very large projects, good comprehensive capabilities including database management, not SWMM-based

4.3.2 PC-SWMM (Computational Hydraulics International) - good for small to medium projects, adequate GIS compatibility, SWMM5-based, database management not as strong as others

4.3.3 MIKE URBAN (Danish Hydraulic Institute) - good for medium to large projects, good GIS capability and compatibility, SWMM5-based, good database capability

4.3.4 XP-SWMM (XP Software) - good for small to medium size projects, SWMM-based, GIS capabilities not as strong as others, simulation speed not as strong as others

4.3.5 InfoSWMM (MWHSoft) - good for small to medium sized projects, good GIS compatibility, data management capability not as strong as others

4.3.6 EPA SWMM5 (U.S. EPA) - good for a range of project sizes, this is the EPA developed and approved SWMM5 software, not strong GIS capability, not strong on database management

4.4 Model Recommendation

Based on the described understanding of LFUCG's modeling needs and the capabilities of the candidate software packages, the MIKE URBAN hydraulic modeling software is the selected software that best meets LFUCG's short-term and long-term hydraulic modeling needs. The following is a brief description of the reasons for selecting the MIKE URBAN software.

1. is fully dynamic model
2. offers the capability to model the size and complexity of LFUCG's collection system, including pump stations and force mains,
3. simulation run times are reasonable; this is a notable advantage over XP-SWMM,
4. has scenario management capability,
5. has good GIS compatibility with LFUCG's existing GIS (ArcGIS),
6. is SWMM5-based, representing the recently EPA created and endorsed software
7. has good database management capability; searchable
8. offers technical support from a company (DHI) that has been around for a long-time and has a viable long-term strength
9. has a free model results viewer software that enables the opportunity to share results with a variety of stakeholders with minimal training and no cost.

Section 5 - Flow Monitoring and Rainfall Data Programs

A temporary flow monitoring program and accompanying rainfall monitoring program have been established to collect the necessary data to support the calibration and verification of LFUCG's H&H computer model. This section describes how the flow and rainfall data will be used to support the H&H model development, particularly model calibration and verification. It also provides basic documentation of the flow and rainfall monitoring programs.

5.1 Flow Monitoring Objectives

The primary objective for the flow monitoring program is to measure flow rates and water depths in the sanitary sewers in response to a range of storm events, which will provide an accurate basis for calibrating and verifying the hydraulic model. The flow and rain data will also be utilized to document areas experiencing high levels of rainfall-dependent inflow and infiltration (RDII) that will be used as part of the Sanitary Sewer Assessment work in identifying focus areas.

5.2 Flow Monitoring Procedures and Documentation

Procedures have been established to develop a flow monitoring program that will be sufficient to provide reliable data to support the objectives of the development, calibration, and verification of the H&H computer model for all seven Sewersheds.

5.2.1 Monitoring Periods

The monitoring periods of the drainage sewersheds are arranged to meet the CD deadline requirements. Each sewershed group will be monitored for a minimum of four months: Group I Sewersheds are being monitored from April 2008 through the end of July 2008; Group II Sewersheds will be monitored in the spring of 2009, while it is desirable that the Group III Sewersheds also be monitored at the same time with the Group II Sewersheds. Because of the necessity to understand the functioning of the entire sewer network, all monitors in a given phase must be operational by the beginning of that phase. If within the 4-month monitoring period for either group, the storm events monitored do not provide sufficient data for the calibration requirements as originally intended, an assessment will be made regarding extending the monitoring periods to meet the project objectives.

5.2.2 Preliminary Flow Monitor Locations

The entire LFUCG service area was divided into three major groups and seven drainage sewersheds. A thorough review of the sewer system maps for each major drainage sewershed further delineated contributing sub-sewersheds, with each representing a significant portion of the flow in that drainage basin.

The preliminary location of the flow monitors focuses on isolating the flow at each Recurring SSO location and in each sub-sewershed. Recurring SSOs that are the result of maintenance issues instead of hydraulic capacity deficiencies are generally excluded. See Section 6.2.2 for a detailed description of these SSOs. The meters will be strategically located to provide detailed monitoring of the inflows from other sub-sewersheds and the outflows to the trunk sewers and outflow through manhole, basement, and pump station SSOs. Each flow monitor is equipped with level and velocity sensors to measure the water depth and velocity in the sewer pipes at 5-minute intervals. Flow rates are then calculated from the depth and velocity values.

The elements essential for the determination of the preliminary locations include:

1. ***Thorough understanding of the system layout***—Certain system features have flow characteristics, which define system performance. The understanding of these features is critical to properly represent the system with a hydraulic model, and often, therefore, require flow monitoring. These features include Recurring SSOs, pump stations, treatment plants, and outfalls.

2. ***Determination of sub-sewershed discharge points to the trunk sewers***—The confluence of major tributary sub-sewersheds with trunk sewers provides the primary locations for the flow monitors.

3. ***Upstream of key SSOs***—Monitors are located upstream of Recurring SSOs tributary to major sanitary sub-sewersheds. Some Recurring SSOs have tributary areas sufficiently small to have no significant impact on the sewer system hydraulics; these require no monitors.

4. ***Pump Stations***—Pump stations where SSOs are identified will have flow monitors installed on the influent side. Pump stations with SSOs that are determined to be maintenance related may be excluded. This is important in order to help accurately quantify the flows arriving at the pump station. Select pump stations will be monitored if the pump station records are not available or are available, but not in a usable format. Flow monitors will also be considered at the discharge points from the pump station force mains into the gravity sewer lines.

5. ***Trunk sewer***—Flow meters will be located at critical points along the trunk sewer, including points of major confluence and upstream of crossover points between parallel trunk sewers. Trunk sewers are the "Major Gravity Lines" as defined in the Consent Decree, which are gravity sewer lines that are 12 inches in diameter or larger.

6. ***Treatment plants***—Locate flow monitors on all gravity influent lines to the treatment plants near the WWTP. Some force mains discharge directly to the headworks of a WWTP.

The project team, using the criteria above, will identify locations for flow monitoring covering all the major drainage sewersheds.

5.2.3 Final Flow Monitor Locations

Prior to field investigations, the detailed sewer maps showing the proposed flow monitor locations will be reviewed with LFUCG staff. In the proximity of each preliminary location, several candidate manholes will be identified. From these candidates a primary manhole will be selected. Detailed field investigation of the primary manhole and the other candidates will yield a single site for each preliminary location. These investigations will include verification of existing flow boundaries, physical inspection of manholes including manhole access, pump station operation, health and safety, and any other pertinent items that influence the selection of a specific flow monitoring site.

In some cases, the primary monitoring manhole may not meet the requirements of the selection criteria; consequently, the investigations will continue to check upstream and downstream manholes. The manhole inspection process will be documented in a standard site inspection report. Once the suitable location for each monitoring site is identified, a final site report will be generated that includes the location of the manhole, pipe sizes, flow direction, hydraulic conditions, depth of sediment, traffic conditions, and special notes on the access to the manhole, etc. For some flow monitoring locations that do not meet all the selection criteria and have no substitute manholes, a special monitoring plan will be prepared that includes best access to the manhole, special equipment required to open the manhole for data collection, best time for data collection, whether the manhole is in a busy street, and special safety equipment required.

5.3 QA/QC

The purpose of the QA/QC efforts is to identify problems or potential problems with the flow and rain data being collected and to submit findings to the flow monitoring crew quickly so that any concerns can be addressed promptly. This will help maximize the value of the project flow monitoring effort. To ensure the data quality, two levels of QA/QC will be implemented throughout the flow monitoring task.

First, the flow monitoring crew performs an initial QA/QC of the data once the data is downloaded from the designated flow site. QA/QC measures are taken at the flow monitor site and additional steps are taken to QA/QC the flow data once back in the office. After collection of the first round of data, depth versus velocity scatter plots are developed. Based upon a review of the data, it will be determined whether the site has hydraulic characteristics conducive to meeting the objectives of the study. If appropriate, a recommendation will be made to change the monitoring configuration, equipment, or location.

The second step is for the modeling team to review the monitoring data to identify any obvious questions which are relayed promptly back to the monitoring crew so that they can quickly address any issues. The flow monitoring crew makes the flow and rain data available via their website each week and emails the modeling team to advise when the flow and rain data has been posted. The efforts are intended to further strengthen the QA/QC effort in order to minimize the collection of unreliable or un-useful data and serves to help better prepare the team to utilize the data appropriately and understand the system hydraulic behavior. A simple spreadsheet has been created to track and document the QA/QC of the flow monitoring data and rainfall data. Key potential problems to look for include:

- Missing data
- Sensor drift (depth or velocity)
- Data shifts - sudden changes in flow response may be indicative of a problem

- Dramatic change from previous observations in the pattern of the flow response to rainfall

- Any other unusual response or changes from previous observations

In this step, the data obtained weekly will be promptly reviewed and documented in the QA/QC spreadsheet. The scattergraph of the data obtained since the last download will be plotted and overlaid on the scattergraph of the previous data. Data problems associated with sensor fouling or drift will be identified and the field maintenance crew alerted for appropriate action. Upon any changes in system hydraulics indicating a need for pipeline maintenance, LFUCG will be alerted. The QA/QC measure will verify that the system-wide flow monitoring uptime of 90% has been achieved per the Consent Decree requirement.

5.4 Rainfall Data Analysis

Rainfall data provide the basic time-variable input to the model, and therefore the precision, accuracy, and resolution of these data are of critical importance to the project. Inadequate or erroneous rainfall data introduce calibration errors, or misrepresent model input, which in turn reduce model accuracy and reliability for simulation of the sewer system.

Rainfall data will be collected through a temporary rain gage network that will be implemented at the Sewershed level at the same time of the flow monitoring program for the respective Sewersheds. The rainfall data will be collected in 5-minute time intervals for the duration of the flow monitoring program. The rainfall data collected from the temporary ground rain gage network will be used to develop input hyetographs to the H&H model and to correlate wet-weather flow response in the Sanitary Sewer System to rainfall. The rainfall data collected at these locations provide good measurement of rainfall at the point of collection.

A total of approximately thirty rain gages will be installed across the seven Sewersheds which should provide an adequate characterization of the spatial variability of rainfall. The installation of the rain gages will seek locations that avoid rain shade where obstacles may interfere with an accurate collection of rainfall data. These locations are generally on the roofs of accessible buildings away from tall trees and other buildings. Preliminary locations are identified based on an appropriate spatial distribution of the rain gages and initial potential buildings that may accommodate them. The final locations are determined in large on the ability to obtain permission to access the property and building rooftops. Public buildings are initially considered. The rainfall data will be collected on a regular basis and the quality checked to assure that reliable data are being collected.

Section 6 – Model Development Procedures

This section of the Hydraulic Model Report defines the procedures to develop the model, including mapping, data management, determination of flow inputs, and model calibration procedures. Critical data needs (sewer data, rainfall data, and flow, etc.) for model development are identified and described.

The model development process will apply the SWMM5 modeling capability with the MIKE URBAN software package (See Section 4) as the modeling environment in which the sewer network and sewershed catchment data will be formulated, maintained and calibrated.

6.1 Model Organization and Linkage

The LFUCG's Sanitary Sewer System is organized at five different levels. They are listed below in order from the level representing the largest area to the smallest area.

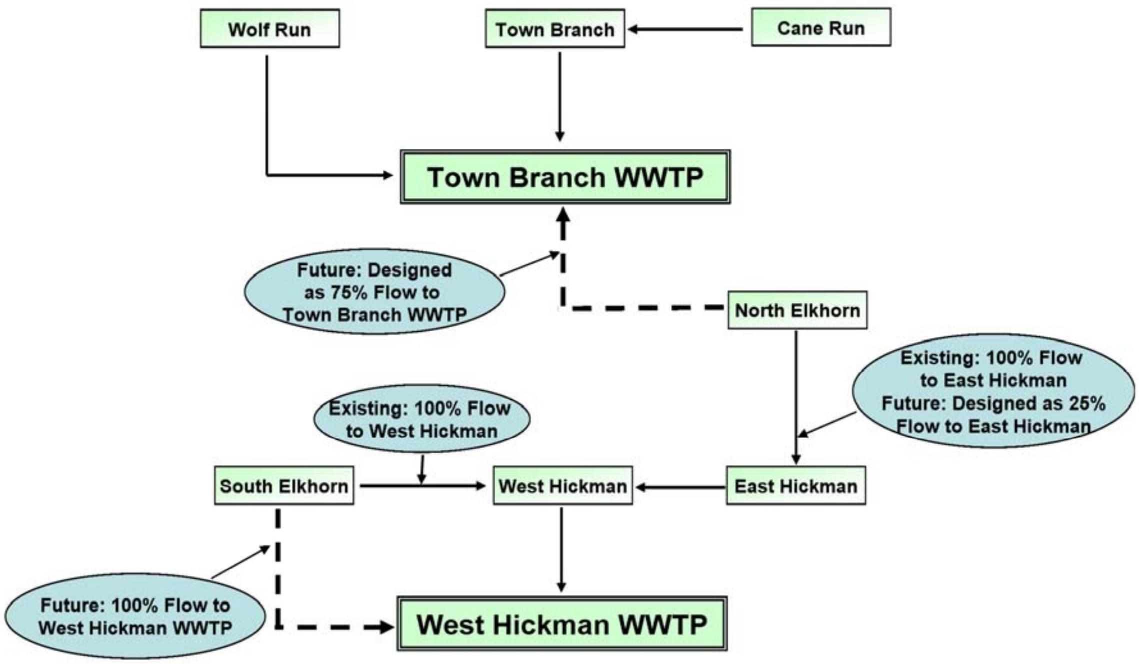
1. WWTP service area
2. Groups
3. Sewersheds
4. Sub-Sewersheds, and
5. Catchments

These delineations will be used to organize and manage the model datasets and execute the project. The various sewersheds delineations, and their significance to the modeling effort, are discussed individually below.

6.1.1 WWTP Service Area

The WWTP service area represents the area that contributes its wastewater flow to one of the two LFUCG wastewater treatment plants; the West Hickman WWTP or the Town Branch WWTP. This is important to understand in order to organize the model datasets and perform the planning evaluations. Two configurations will be used for the planning evaluations; a current (2008) configuration as well as a new configuration that will exist in the near future that involves re-directing some flow from the North Elkhorn Sewershed from the West Hickman WWTP to the Town Branch WWTP. **Figure 6-1** illustrates these two WWTP Service Area configurations.

Figure 6-1 Existing and Future WWTP Service Area Configurations



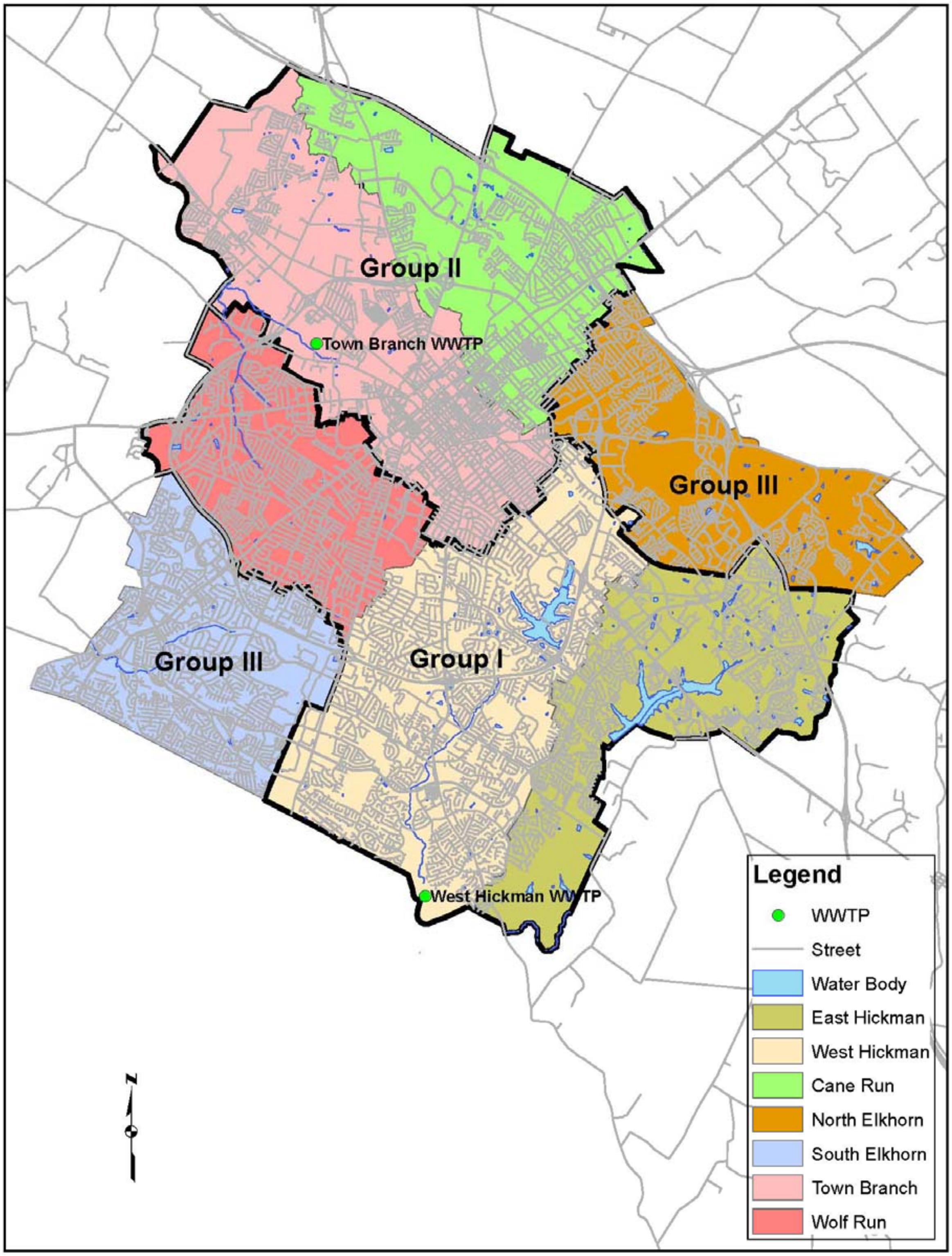
6.1.2 Drainage Sewersheds and Groups

The LFUCG service area is divided into seven drainage Sewersheds as illustrated in **Figure 6-2**. Sewershed is defined in the Consent Decree as "a section of LFUCG's WCTS that is a distinct drainage or wastewater collection area and designated as such by LFUCG." These seven sewersheds are grouped into three Groups in the Consent Decree. The three Groups of Sewersheds are listed below.

- Group One: West Hickman, East Hickman, and Wolf Run Sewersheds
- Group Two: Cane Run, and Town Branch Sewersheds
- Group Three: North Elkhorn and South Elkhorn Sewersheds

These sewersheds follow watershed boundaries, and thus more closely reflect the topology of the sewer system. This delineation is directly relevant to the modeled network organization, as this delineation represents the seven distinct model networks that have been developed. Modeling team assignments will be organized at the sewershed level.

Figure 6-2 Seven LFUCG Drainage Sewersheds and Groups



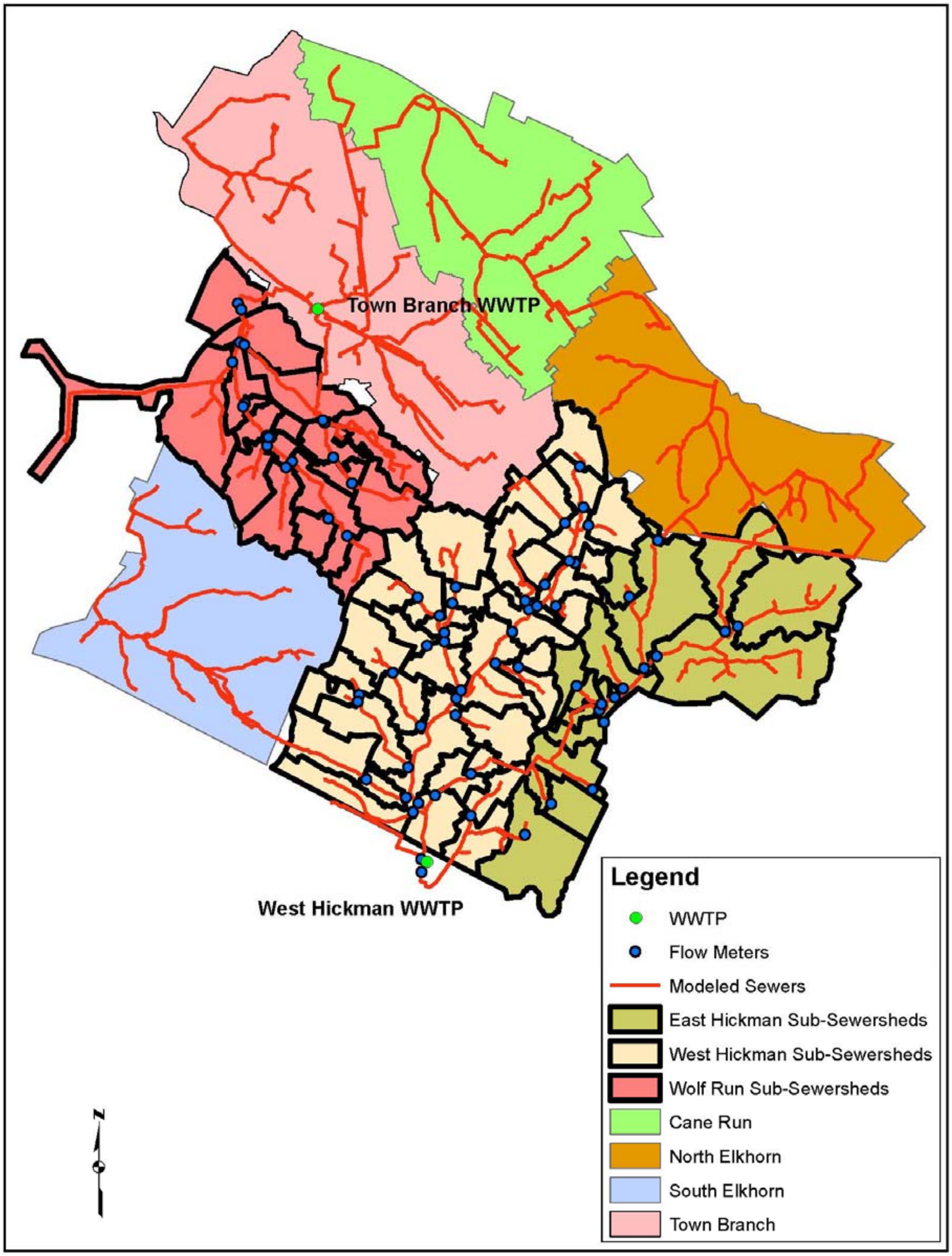
6.1.3 Drainage Sub-Sewersheds

A finer level of sewershed delineation is at the sub-sewershed level. The seven drainage sewersheds have been subdivided into sub-sewershed areas to provide a finer level of detail in supporting project execution. The locations of the flow monitors that are part of the temporary flow monitoring program (See Section 5.1) primarily determine how the sub-sewersheds are defined. Modeling work will also be organized at this level, especially during the calibration stage of the project. **Figure 6-3** identifies the individual sub-sewersheds that have been delineated for the Group I Sewersheds.

6.1.4 Catchment Areas

The finest level of basin delineation is at the catchment level. This level of delineation is the level at which individual model basin areas (i.e., RUNOFF catchments) will be delineated. These basins will be delineated during model development to represent the drainage area associated with each flow loading point on the modeled sewer network. The sewershed characteristics (i.e., I/I parameters for sewersheds) will be determined at the catchment level and used as model input.

Figure 6-3 LFUCG Sub-Sewersheds – Group I



6.2 Model Extents

The LFUCG's models will include all Major Gravity Lines, Pumping Stations, locations with Recurring SSOs, and Force Mains. Modeled features, including the sewer network, SSOs, pump stations and force mains, are discussed below.

6.2.1 Modeled Sewer Network

All Major Gravity Lines will be included in the model network. Major Gravity Lines are defined as any of the following: all gravity sewer lines that are twelve inches in diameter or larger; all eight-inch gravity sewer lines that are necessary to accurately represent flow attributable to a service area in each of the sewersheds; all gravity sewer lines that convey wastewater from one pumping station service area to another pumping station service area; and all gravity sewer lines that substantially contribute, or that LFUCG knows will likely substantially contribute to Recurring SSOs. The modeled sewer network is shown in **Figure 6-4**.

6.2.2 Modeled SSOs

The model will be configured to represent all Recurring SSO locations as defined in the Consent Decree. Recurring SSOs include manhole SSOs, pump station SSOs as well as building backups. A total of 111 Recurring SSO and un-permitted discharge locations are identified in Appendix A of the Consent Decree and will be included in the model, except for a relatively small group of SSOs where historical maintenance data is available that support that they are caused by a correctable condition via maintenance and operations management measures. These listed Recurring SSOs show no history of being related to hydraulic capacity deficiencies in the Sanitary Sewer System and are referred to as Correctable/Corrected Recurring SSOs. These Correctable/Corrected Recurring SSOs are listed in **Table 6-1** along with a brief history of their activation conditions. The modeled Recurring SSOs are presented in Figure 6-4.

Figure 6-4 Modeled Sewer Network, SSOs, and Pump Stations

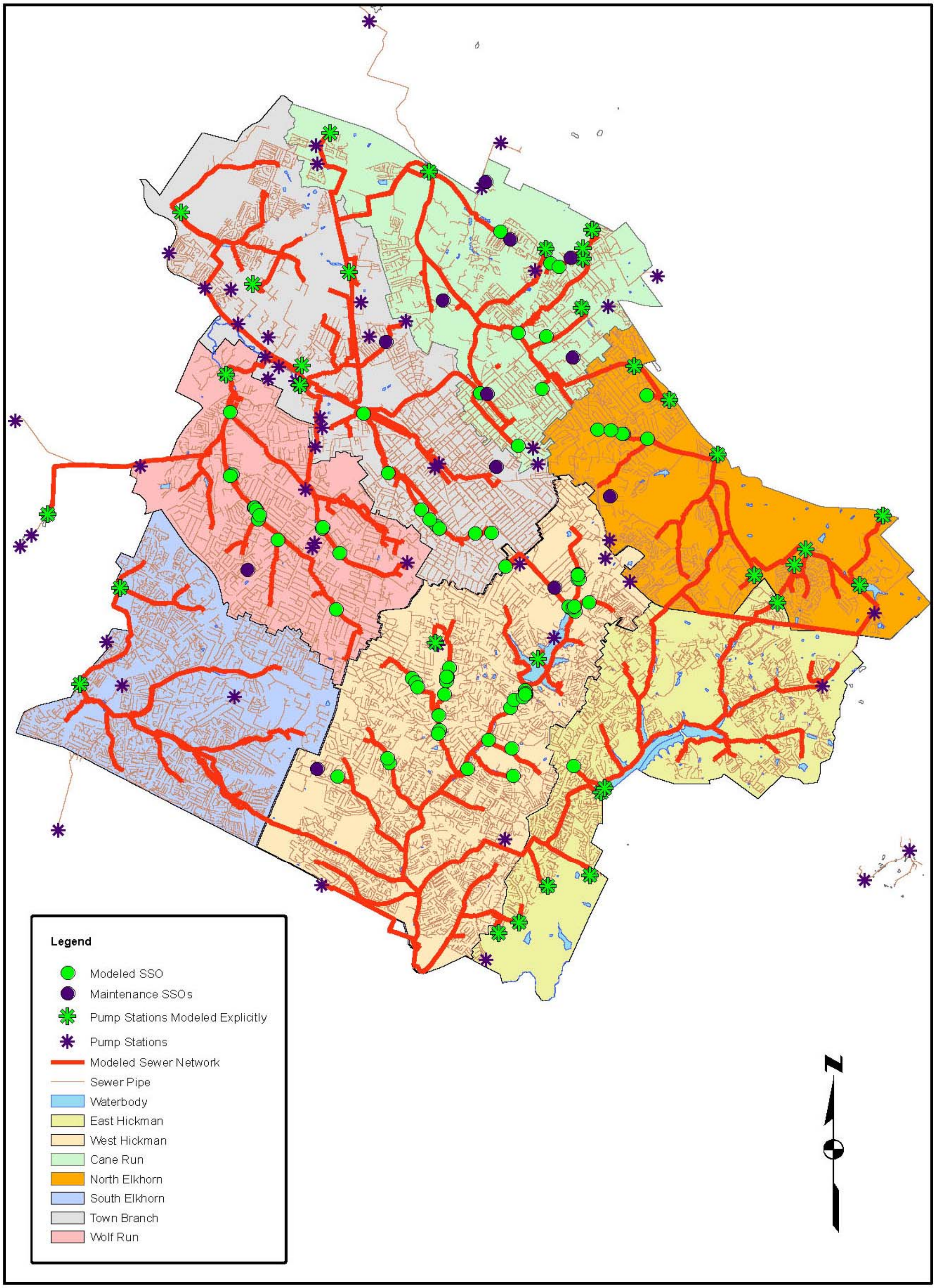


Table 6-1 List of Correctable/Corrected Recurring SSOs

No.	Consent Decree Recurring SSO ID Number	LFUCG ID Number	Geographic Location	2001-2006 SSO History
1	30	basement	245 Radcliffe	Records associated with this location indicate backup problems are attributed to either 1) privately owned lateral problems or 2) "hard" rains. LFUCG has previously identified this area for a priority stormwater management project. Design of the SW project is complete and LFUCG has purchased two homes across the street from this location for the construction of SW detention basin. Sanitary sewers in this location are also being relocated.
2	31	basement	209 Radcliffe	**No SSOs** reported since the two events that occurred within one-week period in 2002.
3	78	MH CR6_130A	7th & Jackson	**5/5/02 SSO** -grease- 0" of precipitation in 3 days prior to event, 0.42" precipitation over 3 day previous to that. No other recorded SSO events in 2001-2006 timeframe. SSO location pre-dates 2000 SSOP update.
4	79	MH CR6_132A	Shelby St.	Manhole removed from system per Consent Decree Appendix A.
5	91	Hamburg Pump Station		Four Separate SSO events in 2003 due to force main repairs, one SSO event due to electrical breaker problem. Zero SSO events otherwise in 2001-2006 timeframe.
6	93	basement	265 Vanderbilt Dr.	**7/15/03 SSO** - grease and **7/17/03 SSO** - grease-1.27" precipitation on July 15 but zero precipitation on July 17.
7	94	MH WH10_400	Nichloasville Rd.	**1/7/02 SSO** - grease -0.32' of precipitation on 1/6/02/0.2' precipitation of 1/7/02. 1.14" of precipitation on 1/23 and 1/24, no SSO. **12/16/02 SSO** - grease-0.16' of precipitation 2 days before event, no precipitation day before or day of event.
8	96	MH WR3_103A	Poppy Ln.	**12/16/02 SSO** - grease-0.16' of precipitation 2 days before event, no precipitation day before or day of event. **4/11/03 SSO** - grease-0.03" of precipitation on 4/10/03 and 0.09" of precipitation on 4/11/03.

No.	Consent Decree Recurring SSO ID Number	LFUCG ID Number	Geographic Location	2001-2006 SSO History
9	97	MH NE2_154	1454 Jingle Bell Ln.	**1/2/03 SSO** - grease-0.17' precipitation on 1/2/03/0.05" precipitation on 1/3/03. **6/18/03** SSO-grease-0.03" on 6/17/03/ 0" precipitation on 6/18/03.
10	102	MH CR7_134	1943 Stanton Way	**7/1/03 SSO** - grease -0.17" precipitation over previous 13 days. **10/16/03 SSO** - grease -0.58" precipitation over previous 11 days
11	105	MH CR3_18C	115 W. Loudon Ave.	**2003 - 2SSO events 2004-3 SSO events 2006-1 SSO event**, Some with measured precipitation, others with zero precipitation. All maintenance records say "grease".

6.2.3 Modeled Pump Stations

The model will include the critical pump stations and force mains owned or operated by LFCUG within the collection system. The only exception is pump stations that serve a single structure or building and for the pump station serving Southland Christian Church in Jessamine County. The pump stations will be represented in the model by one of the two methods:

1. Pump stations with Recurring SSOs and pump stations that deliver large quantity of flows will be modeled explicitly. Pump curves defining discharge head-flow rate relationship will be determined either from on-site pump testing or from "manufacturers" records. Detailed understanding of the physical structure of the pump station wet well, as well as the number of pumps and the control philosophy that is in operation at the station, will also be investigated.

2. Small pump stations with relatively insignificant impact on system flows will be modeled as a flow loading point. These pump stations are generally used to deliver sewer flows from a few homes or a small subdivision.

Table 6-2 lists the pump stations where Recurring SSOs are located. These pump stations will be modeled using method#1 described above.

Table 6-2 LFUCG Pump Stations with Recurring SSOs

Pump Station Name	Pump Station Address
Armstrong Mill Road	2755 Armstrong Mill Rd
Bluegrass Field	1031 Air Freight Dr
Deep Springs	469 Anniston Dr
Dixie	1459 Huntsville Dr
East Hickman	3316 Buckhorn Dr
Eastlake	1326 Fenwick Rd
Greenbriar 1	3770 Katay Dr
Greenbriar 2	3592 Winchester Rd
Hartland 1	3630 Timberwood Ln
Hartland 2	2140 Leafland Pl
Hartland 3	4904 Hartland Pkwy
Lower Cane Run	1760 Mcgrathiana Pkwy
Man O War	2079 Bryant Rd
Mint Lane	1510 Man O War
North Elkhorn	2201 Elkhorn Rd
Shadeland	857 Glendover
Shandon Park 2	765 Kingston Dr

Pump Station Name	Pump Station Address
Sharon Village	1985 Haggard Ct
South Elkhorn	2500 Bowman Mill Rd
Thoroughbred Acres	619 Parkside Dr
Town Branch	335 Jimmie Dr
Winburn	1985 Russell Cave Rd
Wolf Run	755 Enterprise Dr

6.3 Network Data Development

6.3.1 Data Transfer

LFUCG developed and maintained seven sewer system models (one for each sewershed) in XPSWMM format. MIKE URBAN software has been selected to develop the new hydraulic models. Modeled sewer network data will be derived from the existing models as the primary data source. The existing models will be directly imported into the new model interface.

LFUCG also developed GIS data to define the network elements (individual database records with unique identifiers), spatial data (topology, x-y grid coordinates, invert elevations, etc. for each record) and attribute data (pipe diameters, plan lengths, pipe material, etc. for each record). The GIS data will be used to perform QA/QC check on the existing models.

6.3.2 Dataset Development Procedure

Currently, LFUCG maintains seven separate models, one for each Sewershed. In the future, there may be needs to merge some of the models into one. The modeling team intends to keep the current pipe IDs for easy reference. If multiple Sewershed models are merged into one model, no duplicate manhole IDs should exist since each manhole in the LFUCG Sanitary Sewer System has a unique ID. Therefore, no additional naming convention is anticipated to be needed.

Once the existing models are converted into MIKE URBAN format, the modeler will review the plan view of the model to determine any connectivity data gaps. Similarly, the modeler will review the profiles to identify any questionable sewer system attribute data or data gaps. When such data problems are found, the modeler will first review the GIS sewer system attribute data and attempt to resolve any data discrepancies. If the discrepancies cannot be explained by referencing GIS, the project team will then use the procedures outlined in Section 7 including using paper records search or through field investigations.

6.3.3 Network Data Verification Procedure

Once the data problems have been resolved by the paper records search or through field investigations, the model files will be revised. If appropriate, an electronic file containing the corrections will be submitted to LFUCG staff responsible for GIS data maintenance to update the GIS database.

6.4 Sewershed/Sub-Sewershed Data Development

Two key aspects of sewer system behavior are defined by the sewershed and sub-sewershed areas that are hydraulically connected to the system: (1) base, or dry-weather, flow conditions; and (2) wet-weather flow conditions. Each aspect is discussed individually below.

6.4.1 Base Flow Development

There are two components of base flow: (1) the sanitary wastewater component (or base wastewater flow, BWF); and (2) the groundwater infiltration (GWI) component. Each component is addressed below.

6.4.1.1 Sanitary Wastewater Component

The sanitary wastewater component of base flow (BWF) has historically been developed from several sources, often used together to define both sanitary and groundwater flows. The typical approach involves the use of population data, oftentimes derived from land use data (or census data), together with an assumed unit wastewater flow rate (gallons per day per capita) to define BWF. Flow monitoring data within the system, as well as flow data collected at the WWTP, are then used to define the composite base flow (BWF plus GWI). Finally, the difference between the observed flow and the computed BWF is attributed to GWI.

6.4.1.2 Groundwater Infiltration Component

The LFUCG model will incorporate groundwater infiltration (GWI) estimates based on two sources of data.

1. Inferred measurement of GWI - the dense network of flow monitors used for model calibration (see Section 5 of this Hydraulic Model Report) will provide data that can be used to estimate GWI throughout the system. This will be accomplished in the smaller basin areas where diurnal low flows can be attributed primarily to GWI. The specific procedure is described below (see Section 6.4.2) in greater detail.

2. WWTP flow-based estimates - at the WWTP service area level, GWI is attributed to the difference between observed flows and the estimated BWF for the service area.

Taken together, the above sources of data will enable accurate GWI estimates to be made at the modeled-basin level of precision.

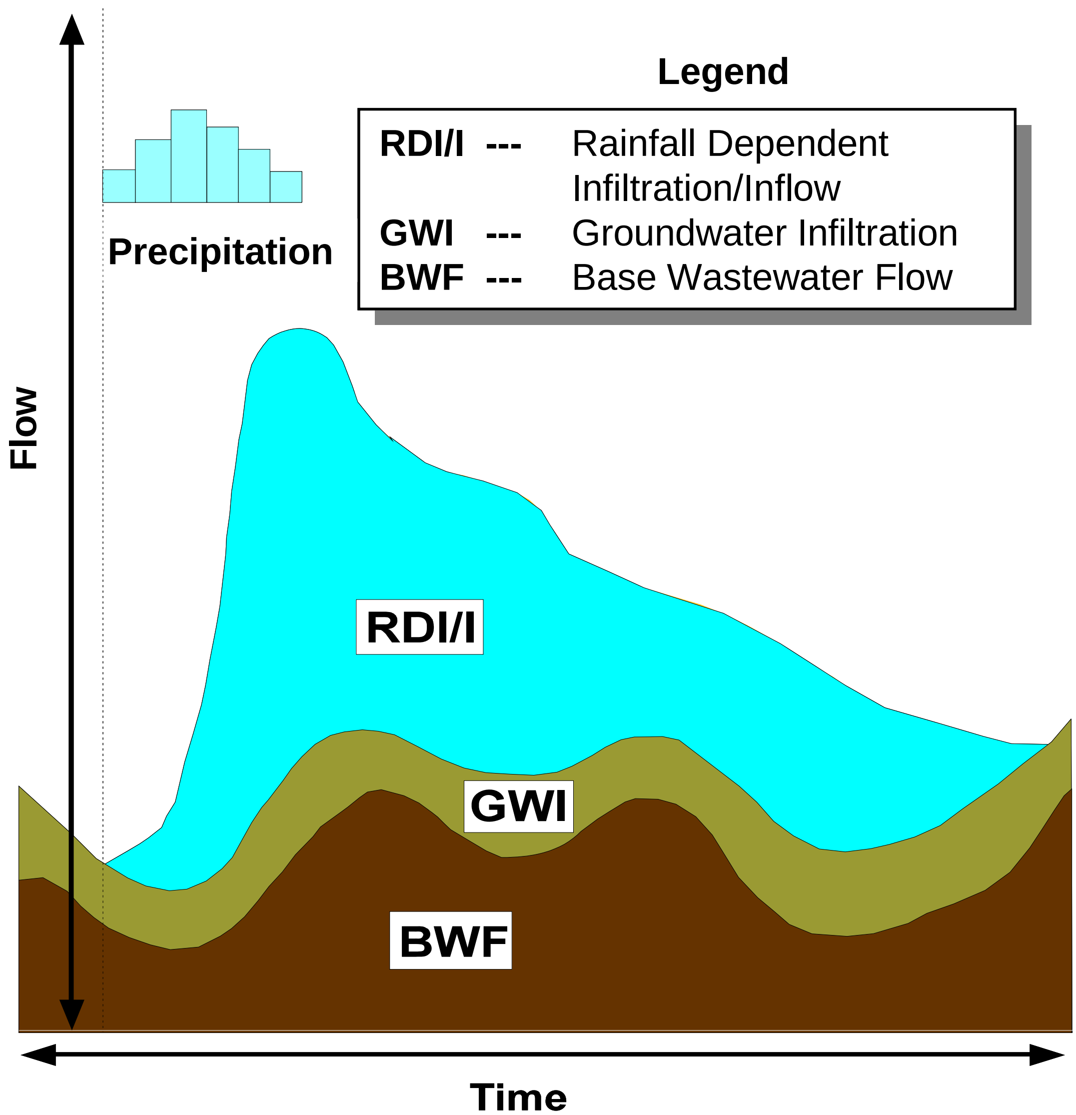
6.4.2 Hydrologic Response to Wet Weather Conditions

The hydrologic processes that contribute wet-weather flow in a sanitary sewer system are not understood well enough to deterministically model the physical processes with typically available data. As a result, empirical data are used to estimate the hydrologic response in the sanitary sewer system. The approach is described below.

The rainfall and flow monitoring data will be analyzed to develop an understanding of the system RDI/I characteristics using a computer program designed for this purpose known as SHAPE. SHAPE consists of a set of computer utility programs to evaluate the complete record of flow and rainfall data, isolate typical dry- and wet-weather periods, define characteristic sanitary flows, determine seasonal dry-weather infiltration rates; and develop unit hydrographs representative of I/I.

The project team using the SHAPE computer program will divide the measured flow data into characteristic flow components appropriate for flow forecasting. As illustrated in **Figure 6-5,** these components are dry-weather flow (DWF), and rainfall dependent infiltration and inflow (RDI/I) in response to wet-weather conditions. DWF consists of base wastewater flow (BWF) from residential, commercial, and industrial users, and groundwater infiltration (GWI) that enters the collection system through defective pipes, pipe joints, and leaking manhole walls. Decomposition of the flow data into each of the major wastewater components is essential to understanding the sources of flow in the system, the relative quantities of I/I into the system, and whether I/I is excessive in the system.

Figure 6-5 Components of Wet-Weather Wastewater Flow



Dry-Weather Flow Characterization

The characteristic flows for each catchment will be determined in the following manner:

1. Identify periods where flows are clearly not influenced by rainfall.

2. Identify the minimum flow each day (this usually occurs about 4:00 a.m.). Different methods are available to estimate the groundwater infiltration (GWI) component which is subtracted from the minimum flow to yield an estimate of the base wastewater flow (BWF) which can be developed as an average value or a hydrograph.

3. Divide the BWF hydrographs into weekdays and weekends. Statistically evaluate the weekday and weekend hydrographs for the period of record to determine characteristic hydrographs for the meter.

4. Allocate the meter's BWF hydrographs to each tributary catchment.

5. Statistically evaluate the GWI for the period of record to determine average GWI and seasonal minimum and maximum GWI.

6. Allocate the meter's average, minimum, and maximum GWI to each tributary catchment.

7. Verify the level of groundwater monitoring data collected during the Sanitary Sewer Assessment or monitoring program.

Rainfall-Dependent Infiltration/Inflow (RDI/I) Characterization

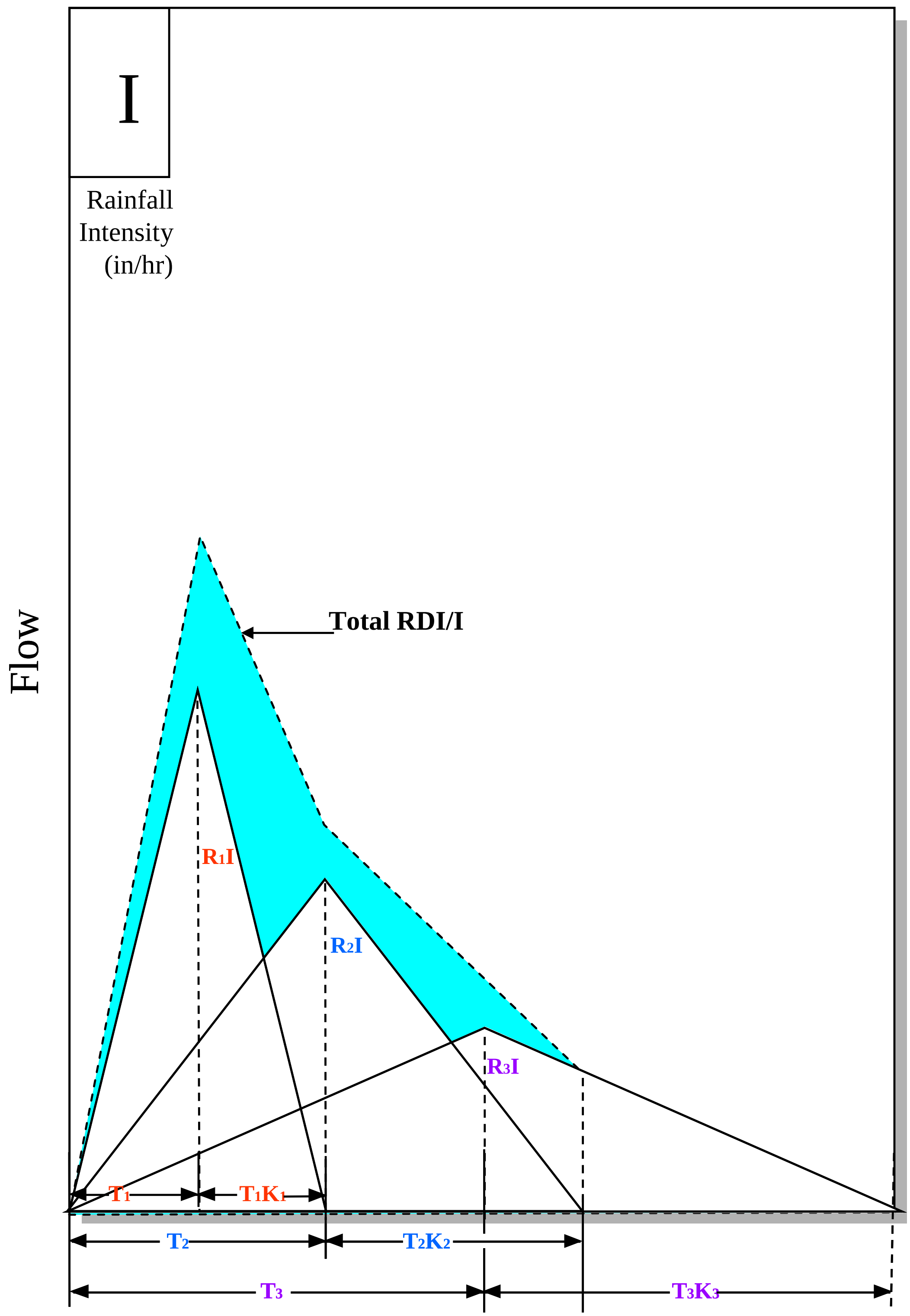
The project team will use a unit hydrograph approach to determine a characteristic relationship between rainfall and RDI/I for each meter. **Figure 6-6** illustrates how the RDI/I from a single hour of rainfall with an intensity of "I" is characterized under this approach. Experience indicates that it often requires up to three unit hydrographs to adequately represent the various ways that rainfall becomes RDI/I. Each unit hydrograph is characterized by the following three parameters:

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

- T: The time to peak in hours

- K: The ratio of time to recession to the time to peak

Figure 6-6 Triangular Unit Hydrograph Approach to Decomposition of the Wet-Weather Sanitary Sewer Hydrograph



This approach allows estimating unit flow parameters appropriate for forecasting design flows. This method of hydrograph decomposition considers a range of parameters including rainfall depths, sewered area, antecedent moisture conditions (AMC), and groundwater elevations to better quantify individual wastewater flow components in the system. Unit hydrograph parameters are developed through a systematic analysis of measured flow and rainfall. Once developed, these unit hydrograph parameters and design rainfall hyetographs can be used to define RDI/I inflow hydrographs for collection system modeling/evaluation. The approach to developing RDI/I unit hydrograph parameters follows:

1. First, the project team will define RDI/I events by subtracting the characteristic dry-weather flows (BWF and GWI) from the measured flow record, as illustrated in Figure 6-5. For each event, the total R will be calculated for the event by dividing the RDI/I volume by the rainfall volume.

2. Then, the project team will identify events where most RDI/I is due to direct inflow and/or very rapid infiltration. Typically, these are intense, short-duration thunderstorms preceded by relatively dry antecedent conditions. These events are used to determine R1, T1, and K1, characterizing the first unit hydrograph.

3. Next, the project team will identify events where infiltration is maximized. These are typically long duration, low intensity events preceded by wet antecedent conditions. These events are used to determine R2, T2, and K2, characterizing the second unit hydrograph. If these events have very long recession limbs, it will be necessary to develop R3, T3, and K3, for the third unit hydrograph.

4. R, T, and K parameters for the three unit hydrographs characterizing RDI/I at the meter are assigned to all catchments tributary to the meter.

5. Finally, the project team will verify the R, T, and K parameters by using them along with catchment areas to develop inflow hydrographs for a more complex rainfall event. These hydrographs are then routed through the collection system with the model developed and compared with measured hydrographs for this event.

Using the above procedure, the project team will determine the appropriate R, T, and K values of the above-mentioned hydrographs for model input. This allows the model to easily accommodate monitored system hydrographs, and facilitates the calibration of the model, as well as evaluating rehabilitation alternatives.

6.5 WWTP Flow Rates and Hydraulics

The WWTP hydraulics will be modeled as a boundary condition for the sewer system model. Data will be collected from the available WWTP effluent flow records for the purpose of building boundary conditions at each of the downstream (WWTP) individual model boundaries. The project team has investigated the available data in a series of meetings with LFUCG WWTP staff and is currently working with LFUCG staff to define specific data acquisition requirements, which will vary from plant to plant based on the specific data collection processes and equipment used at each plant. Initially, effluent flow rates and water surface elevation at the plant headworks are the data of interest, as these data will be used to define boundary conditions. The specific representation of each boundary condition will be established after detailed review of the data and after reviewing plant headworks operating practices with each plant manager.

6.6 Model Calibration Procedures - Separate Sewers

Model calibration involves collection of flow monitoring data (rainfall and sewer flow rates/elevations) and development of an initial model input dataset, followed by successive applications of the model by adjusting calibration parameters until the model results are in agreement with the observed data. Note that the model calibration is a critical step in ensuring the model will properly simulate the prototype system over a range of storm events. Model calibration is accomplished by adjusting initial estimates of the selected variables, within a specified range, to obtain a satisfactory correlation between simulated and observed values.

The variables selected to adjust or calibrate are the parameters that cannot be observed precisely (e.g., percent impervious, soil infiltration parameters, etc.), and which have the greatest effect on the accuracy of the results. The calibration parameters are prioritized according to their influence on the model results, which can vary from one drainage system to other. The calibration parameters are prioritized based on knowledge of modeling case studies of similar sewer systems.

This section presents the model calibration procedures to correlate the simulated hydraulic grade line (HGL) and flow rates with the observed values at the flow monitoring sites during the calibration storm events.

6.6.1 Dry-Weather Flow Calibration

The dry-weather flow input for the model will be developed based on the available flow monitoring data for the project area. Using the DWF analysis of the measured flow data, the diurnal flow patterns will be established. These patterns are then applied to the average DWF from each catchment that are estimated based on the available flow monitoring data. The estimated DWF with appropriate diurnal patterns will be used as flow inputs to the model and then calibrated using the measured flow monitoring data during dry periods. In addition, land use and population data may be used to support the dry-weather calibrations.

6.6.2 Wet-Weather Flow Calibration

The project team will use field data collected from the flow monitors to perform the wet-weather calibration. At least two (2) storms from the flow monitoring data will be selected for the model calibration and verification in each sub-model. Additional events will be used for further verification if required for specific sub-models. Note that the storm events selected for wet-weather calibration of the sewer-system model shall produce a sewer-system response to a range of antecedent moisture conditions.

The model calibration and verification will be performed using estimates of R, T and K during selected storm events, which are derived based on the flow monitoring data. The model calibration efforts will be performed to obtain the best correlation of the simulated and observed flow data for the two events. These efforts include adjusting base flow rates to calibrate antecedent flow conditions and adjusting the R, T and K parameters to produce the sewer system response similar to the measured values for the calibration and verification events. Through the calibration and verification effort, the representation of the sewer system hydraulic characteristics and I/I response will be confirmed.

6.6.3 Sensitivity Analysis

To maximize the calibration, a sensitivity analysis will be conducted to examine and confirm the model response to changes in various input parameters within acceptable ranges. Either existing analyses for the Model or separate sensitivity analyses will be performed in order to maximize the effectiveness of the calibration.

Section 7 - Field Investigations

This section describes the requirements and protocol for field investigations that will be necessary in the course of the model development. The primary objective of the field investigation protocol is to develop a focused approach that will result in optimal effort and expenditure in conducting the field investigations. In addition, this protocol will enable LFUCG to systematically identify and correct the deficiencies in existing GIS data, and eventually update the GIS sewer system database.

7.1 Field Investigation Requirements

The field investigations will primarily include verification of the sewer attribute data that are in question and filling missing values. In general, the requirements include verification of manhole invert and rim elevations, sewer sizes, pipe material, and attributes of special structures (drop manholes, flow diversion chambers, flow control gates, etc.). Other activities are expected to include verification of sewershed delineations, confirmation of land use data, and other miscellaneous data that affect estimation of the model input parameters.

7.2 Field Investigation Protocol

The modeling team will initially generate the model sewer networks and profiles in MIKE URBAN from existing XPSWMM models. After a thorough review of plan and profile views and referencing GIS data, the modeling team will assess the completeness and reliability of the sewer system data. Subsequently, the modeling team will prepare a list of sewer system data deficiencies and discrepancies that require verification. As a next step, the modeling team will review the paper based sewer maps and recent sewer system studies obtained during data collection task to resolve the data issues. In addition, the modeling team will coordinate with LFUCG staff to review their records to address data problems. Finally, if the data verification cannot be achieved by review of the paper maps and sewer system studies, the modeling team will prepare a Request for Field Investigation (RFI) for each data discrepancy and or data gap. Issues to trigger RFI include pipe size difference, connectivity ambiguity, and invert elevation discrepancy, etc.

The modeling team will document in a spreadsheet the process to determine the need for field investigation. This spreadsheet will include, at minimum, the following fields:

		Step 1		Step 2		Step 3		
Item No.	Description of GIS Data Problem	Paper Maps/ Records Review (yes or no)	Problem Resolved? (yes or no)	LFUCG Review (yes or no)	Problem Resolved (yes or no)	Need Field Investigation (yes or no)	RFI No.	Comments

Each RFI will be assigned a unique tracking number and include detailed information such as manhole and/or pipe ID, a map indicating the location of the manhole/pipe that need to be investigated, and a list of sewer attribute data to be verified or recorded. The modeling team will also indicate any specific directions for field crew for observing and measuring special features during field investigation (e.g., sewer connections in a drop manhole, flow regulator configuration in a SSO diversion structure). A blank RFI is depicted in **Figure 7-1**.

The modeling team will provide the RFI to the field investigation team on as needed basis during the model development. The field investigation team will then schedule the work and perform the field investigations according to the RFI. The field investigation team consists of experienced staff who will document the results in a Field Investigation Report (FIR). This team will sometimes be accompanied by the modeling team that initiated the request, as required (e.g., especially critical, unusual, or otherwise key features of the system).

A unique tracking number (with reference to RFI) will be assigned to each FIR. **Figure 7-2** includes a blank FIR to show the key results that will be recorded. The field team, as an attachment to the FIR, will prepare a detailed sketch that depict the location of the subject manholes and pipes and specific locations where the field measurements are obtained. In addition, digital photographs will be obtained and attached to the FIR. Note that Figures 7-1 and 7-2, if necessary, will be finalized during the initial stage of model development, prior to commencing any field investigations.

In addition to verifying sewer attribute data, the field investigations during model development may require confirmation of the sewershed delineations, land use data, and other miscellaneous data that affect estimation of the model input parameters. The modeling team will include a detailed description of the request in the RFI and necessary maps to enable the field team to perform the investigations. The field observations will be documented in the FIR.

The field investigation team will comply with Occupational Safety and Health Administration (OSHA) requirements for confined space entry and other safety procedures during entering/investigating manholes and similar structures. In addition, the field team will coordinate the investigations with LFUCG staff. The coordination involves advance notification of the field activities, scheduling the field work to avoid conflict with other LFUCG operations, and requesting the presence of LFUCG staff to perform investigations, if required.

The modeling team will use the field investigation results to supplement the GIS data to develop sewer networks and forward that information to LFUCG if the GIS data require an update.

Figure 7.1 Request for Field Investigation (RFI) Form

Request for Field Investigation (RFI)

H&H Model

Lexington-Fayette Urban County Government

Tracking number: ____________ Requested by: ____________ Date requested: ____________

Drainage Basin: ____________ Neighborhood: ____________

Pipe ID: ____________ Upstream MH ID: ____________ Downstream MH ID: ____________

Pipe Length: ____________ U/S MH Coordinate: ____________ D/S MH Coordinate: ____________

Street Location Description: ____________

Map Attached: Y ☐ N ☐ Interceptor (High Flow): ☐ Combined Trunk (Low Flow): ☐ Sanitary Trunk (Moderate Flow): ☐

Problem Description: ____________

Specific Instructions: Please complete a Field Investigation Results (FIR) Form for the information checked below. Please include a field sketch and a disk with digital photo(s) labeled with the RFI tracking number.

- ☐ Pipe Diameter
- ☐ Manhole Rim Elevation
- ☐ Manhole Depth
- ☐ Manhole Invert Elevation
- ☐ Pipe Material
- ☐ Sediment Depth
- ☐ Drop Manhole
  - ☐ Incoming Pipe Diameter
  - ☐ Incoming Pipe Invert

For Flow Diversion Manholes:

- ☐ Weir Length
- ☐ Weir Height
- ☐ Outfall Pipe Diameter
- ☐ Outfall Pipe Offset from MH Invert

Other Instructions: ____________

Figure 7.2 Field Investigation Results (FIR) Form

Field Investigation Results (FIR)
H&H Model
Lexington-Fayette Urban County Government

Tracking number(from RFI): ________ Investigated by: ________ Date Investigated: ________

Pipe Diameter: ________ (inches) Manhole Invert Elevation: ________ (ft) Drop Manhole: Y ☐ N ☐
Manhole Rim Elevation: ________ (ft) Pipe Material: ________ Incoming Pipe Diameter: ________ (inches)
Manhole Depth: ________ (ft) Sediment Depth: ________ (inches) Incoming Pipe Invert: ________ (ft)

For Flow Diversion Manholes:
Weir Length (ft) Outfall Pipe Offset from MH Invert (ft)
Weir Height ________ (ft)
Outfall Pipe Diameter: ________ (ft)

Field sketches attached?: Y ☐ N ☐ On Back?: Y ☐ N ☐
Digital photograph(s) included?: Y* ☐ N ☐ *(Disk attached with digital photos labeled with the RFFI tracking number.)

Comments/Sketch

Additional comments attached?: Y* ☐ N ☐ *(Additional sheets attached and labeled with the RFFI tracking number.)