City of Cleveland Heights Partial Consent Decree

Capacity Assessment Report

Final

Prepared For

Final - October 2022

Previous Submittals: March 2020, February 2021, September 2021

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APPENDICES

Attachments

ACRONYMS

AGOL	ArcGIS Online
BBU	Basement Backup
BOD	Basis of Design
CCTV	Closed-circuit (Sewer) Televising
CD	Consent Decree
cfs	cubic feet per second
CMOM	Capacity, Management, Operations and Maintenance
CT	Common Trench
DCIA	Directly Connected Impervious Area
DEM	Digital Elevation Model
DVI	Doan Valley Interceptor
DW	Dividing Wall
DWF	Dry Weather Flow
DWO	Dry Weather Outlet
EWWTP	Easterly Wastewater Treatment Plant
FMP	Flow Monitoring Program
ft	feet or foot
GARR	Gauge Adjusted Radar Rainfall
GIS	Geographic Information System
GPAD	Gallons per Acre per Day
GPDIM	Gallons per Day per Inch Diameter Mile
HHI	Heights Hilltop Interceptor
HHI-LSSES	Heights Hilltop Interceptor Local Sanitary Sewer Evaluation Study
HHI-OEP	Heights Hilltop Interceptor Operational Evaluation Project
HGL	Hydraulic Grade Line
ICM	Integrated Catchment Modeling
IOCMP	Integrated Overflow Control Master Plan
I/I	Infiltration/Inflow (to sanitary sewers)
LF	Linear Feet
LIDAR	Light Detection and Ranging
LOS	Level of Service
MACP	Manhole Assessment and Certification Program (NASSCO)
MCIP	Member Community Infrastructure Program
MG	Million Gallons

MGD	Million Gallons per Day
MS4	Municipal Separate Storm Sewer System
NASSCO	National Association of Sewer Service Companies
NEORSD	Northeast Ohio Regional Sewer District
NPDES	National Pollutant Discharge Elimination System
OEP	Operational Evaluation Project
O&M	Operation and Maintenance
PACP	Pipeline Assessment and Certification Program (NASSCO)
PFL	Peak Flow Limitation
QMR	Quick Operation and Maintenance Rating
SSES	Sanitary Sewer Evaluation Survey
SSO	Sanitary Sewer Overflow
SWO	Stormwater Outlet
TY	Typical Year
USEPA	U.S. Environmental Protection Agency
WWF	Wet Weather Flow

1.0 OVERVIEW

In 2017, the City of Cleveland Heights entered into a Partial Consent Decree (CD) with the U.S. Environmental Protection Agency (USEPA) and the U.S. Department of Justice (DOJ). The CD required Cleveland Heights to complete a Capacity Assessment Report as described in the CD Main Text Section V.E. Paragraph 28. This capacity assessment report provides information needed to develop improvement alternatives and an integrated plan to control potential sanitary sewer overflows and provide adequate capacity in potential problem areas. A web meeting was held with USEPA to discuss the draft report on Friday, October 16, 2020. This report version includes updates in response to review comments from USEPA received on December 22, 2020, and on August 9, 2021. The USEPA written comments and related responses are included with this report as **Attachment 1** and **Attachment 2**.

This report documents the following:

- System model used, including the model software and its capabilities
- Modeling process, calibration, and verification
- Flow and rainfall monitoring program
- Sanitary sewer system elements that are projected to experience surcharge or overflow during the modeled wet weather events
- Deviations from the planned model development established in the USEPA Approved System Characterization Monitoring Plan Approved April 20, 2018 (Appendix 1) and Approved System Modeling Plan Dated November 2018 (Appendix 2)
- Additional requirements provided in the CD

1.1 MODEL BACKGROUND AND UPDATE FOR CAPACITY ASSESSMENT

A model representing the Cleveland Heights sanitary sewer collection system was developed for the Northeast Ohio Regional Sewer District's (District) Heights Hilltop Interceptor-Local Sewer System Evaluation Study (HHI-LSSES) conducted from 2016 to 2019. The HHI-LSSES model was created by combining the Existing Conditions Model from the Heights Hilltop Interceptor-Operational Evaluation Project (HHI-OEP, May 2009) with a portion of the District's Easterly Baseline Master Model. The resulting HHI-LSSES model was updated and expanded by modifying the hydrologic and hydraulic representations to support model calibration.

The CD model was developed by extracting the Cleveland Heights portion of the final HHI-LSSES model. This model was expanded and recalibrated per the CD and was used to support development of the Cleveland Heights Integrated Overflow Control Master Plan (IOCMP). The model was expanded, and subcatchments were refined to reduce areas to approximately 10 acres or less. Upstream subcatchments were reduced to 5 acres or less and the hydraulic model was extended to reach the refined subcatchments. These reduced subcatchments allowed for more accurate simulation of flows and hydraulic conditions in the local sewers. The additional sewers allowed for the model to account for attenuation and capacities in the upstream sewers and therefore resulted in a better match to the observed data and a better understanding of system response. This improves resolution and accuracy of the model to estimate potential wet weather overflows and basement backups in the local sewer system. Both the HHI-LSSES and the current capacity assessment effort under the CD conducted extensive flow and rainfall monitoring in the Cleveland Heights sewer system. This report documents the model refinement, updates, and calibration with a summary of the flow monitoring program.

1.2 SYSTEM OVERVIEW

1.2.1 Common Trench Sewers

Cleveland Heights is served by a separate sanitary sewer system comprising traditional separate trench and common trench sewer configurations, with a total length of approximately 129 miles. Common trench systems were primarily constructed prior to 1960 with the sanitary and storm sewers in the same trench to reduce construction cost and disruption, particularly in areas where the top of rock is shallow.

The aging common trench systems are often found to produce high sanitary sewer infiltration and inflow (I/I) rates. The prevalence of common trench sewers, and especially over-under sewers, appears to be unique to Northeast Ohio. Common trench sewers collect flow from private property where a high percentage of storm flow enters the sanitary lateral before it reaches the public system. This is likely because the aging private property sanitary and stormwater service laterals are also typically constructed in a common trench in these areas. Common trench sewers are classified in three types: common trench standard manhole, dividing wall, and over/under (invert plate) systems.

Common trench standard manhole systems have separate manholes for the sanitary and storm sewers that share the common trench. The dividing wall systems share a common manhole for the storm and sanitary sewers that are separated hydraulically by a weir or dividing wall. Over/under invert plate systems share a common manhole for the storm and sanitary sewers with an access opening, covered by a metal plate, on the invert of the storm sewer to the sanitary sewer below. Over/under, piped access systems share a common manhole with full access to the storm sewer and a vertical pipe positioned in the storm sewer manhole bench that allows for access to the sanitary sewer under the storm sewer. **Figures 1-1** through **1-3** show the common standard, dividing wall, and over/under manhole configurations. **Figure 1-4** shows locations of the various trench types in the Cleveland Heights System.

The SSES confirmed trench types system wide. As of this report, the sewer system is composed of 21% separate trench and 79% common trench sewers. The common trench sewer systems are composed of 33% over/under, 4% dividing wall, and 63% common standard. The modeled sewers range in size from 6 to 36 inches in diameter for local sewers and up to 120 inches for the District interceptors. The Cleveland Heights Phase 1 SSES report provides additional detail regarding the Cleveland Heights sewer systems.

Figure 1-1. Common Standard Manhole Configuration

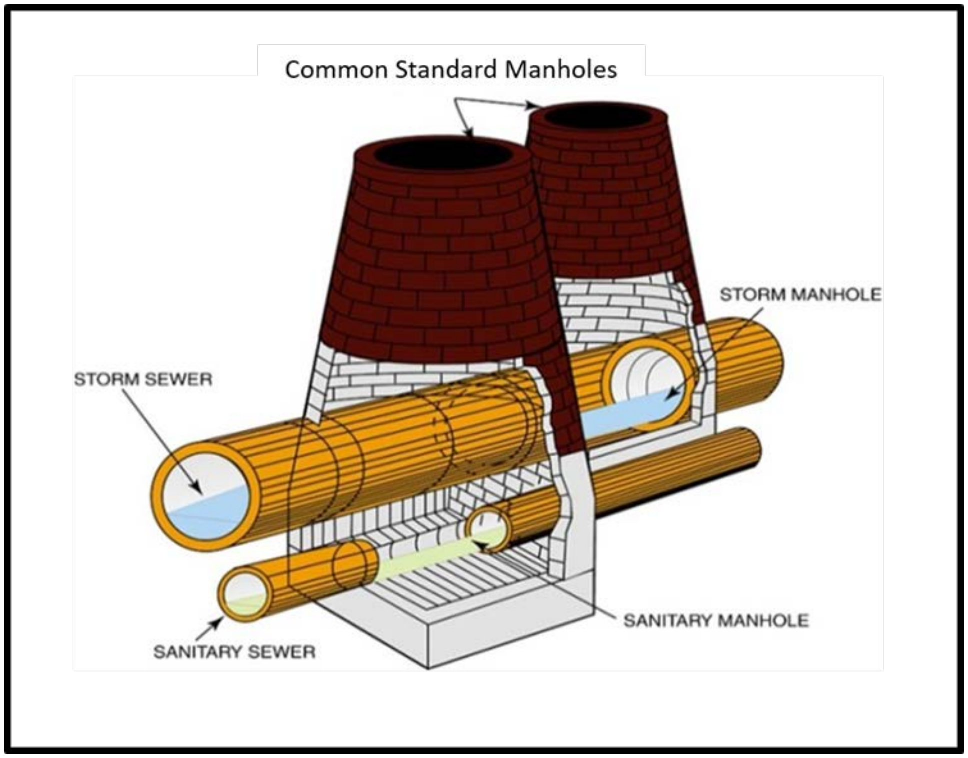


Figure 1-2. Dividing Wall Manhole Configuration

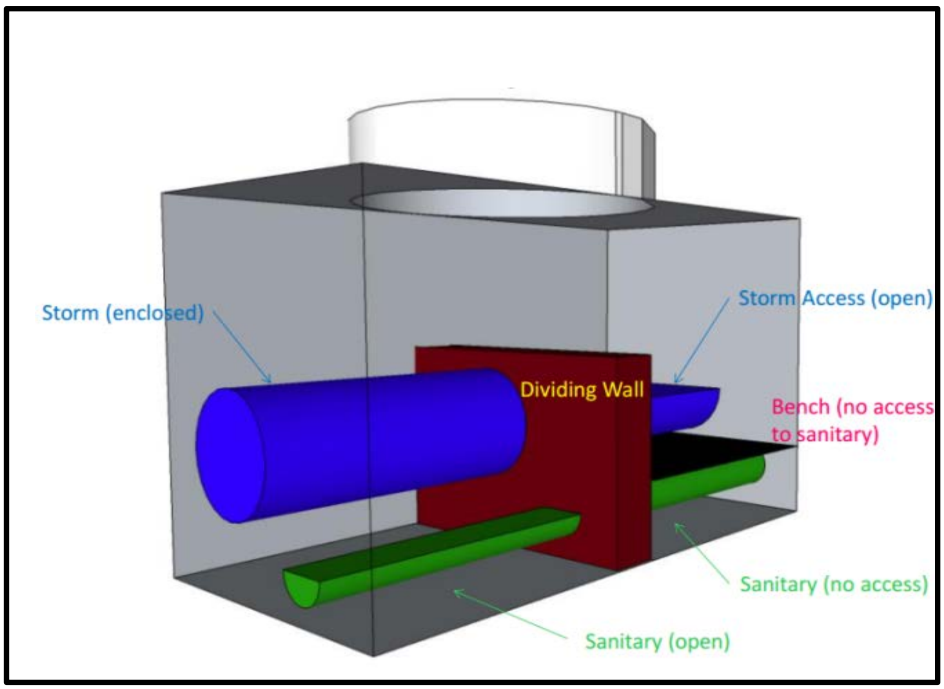
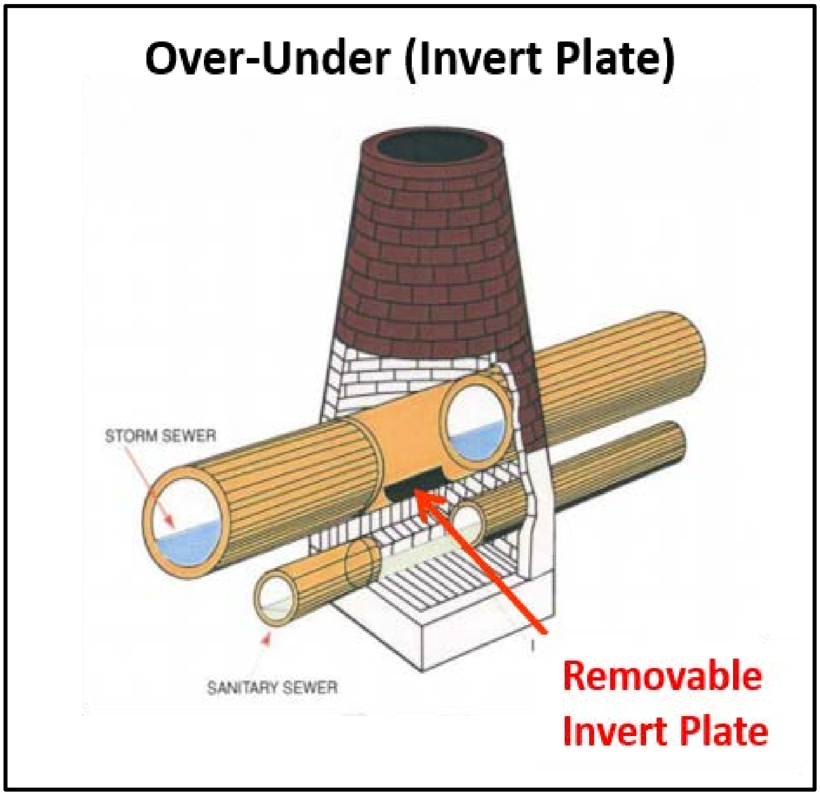


Figure 1-3. Over/Under Manhole Configurations



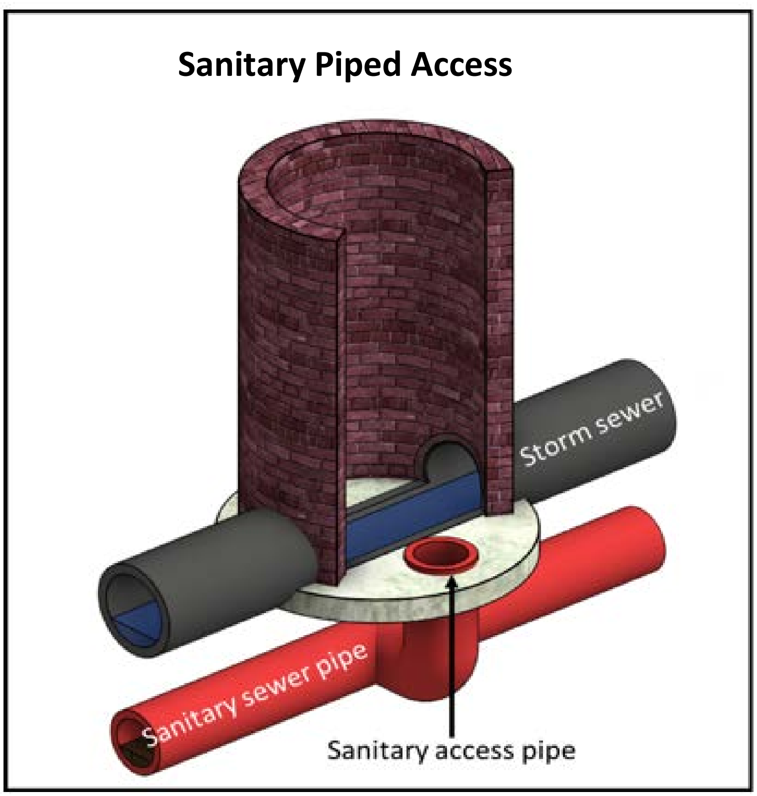
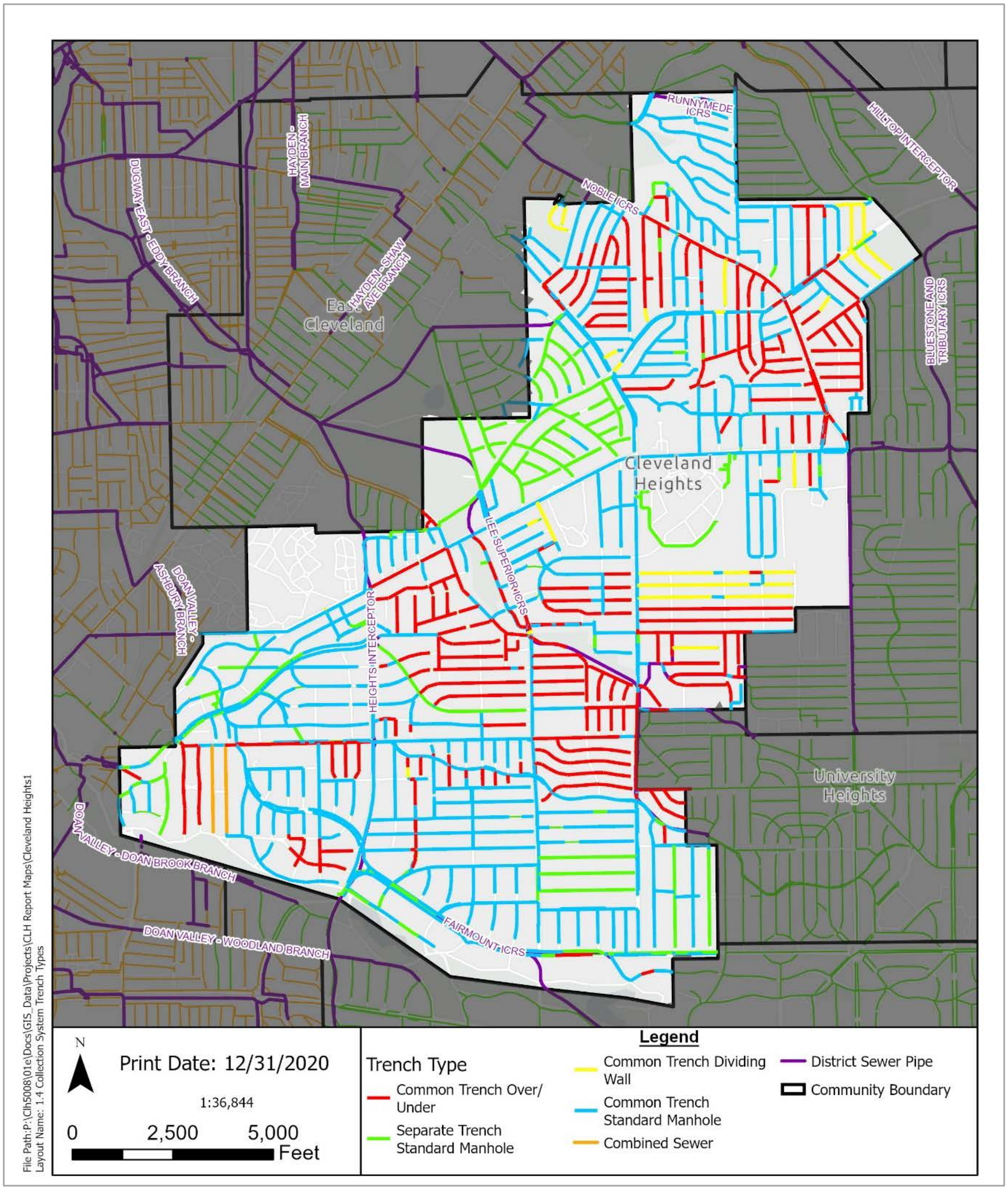


Figure 1-4. Collection System Trench Type Map



1.2.2 Sewer System Dyed Water Testing

Field investigations were conducted to support understanding of the Cleveland Heights sewer system, and the highly variable wet weather flow responses observed. Investigations included physical inspection, smoke testing, and dyed water testing.

The investigations have shown that common trench sewers tend to exhibit higher I/I rates than separate trench systems. This is likely due to the proximity of sanitary and storm sewer pipes in the common trench, system age/leaky pipe joints, and unseated or missing invert plates. Cleveland Heights has been replacing damaged and missing invert plates as they are identified. Detailed field investigation results can be found in the *Phase 1 Sewer System Evaluation Survey Report*, Dated February 2020.

Mainline dyed water testing of common trench storm sewers and accompanying sanitary sewer CCTV inspection has observed significant leaking between the storm and sanitary sewers via both the invert plates and pipes, as well as leaky service connections. **Figure 1-5** shows an example of infiltration observed at sanitary sewer joints during testing. Dyed water testing was conducted by flooding common trench storm sewer reaches with dyed water and with CCTV equipment positioned in the sanitary sewer. The storm drain was plugged to simulate surcharged conditions where feasible. **Figure 1-6** and **Table 1-1** summarize three locations where plugging of the storm drain was not conducted due to field conditions. **Figure 1-7** shows a schematic of the dyed water flood testing. Sewer system investigations conducted in Cleveland Heights are described in more detail in both the Phase 1 SSES report and in HHI-LSSES reporting.

Figure 1-5. Sewer Joints Leaking During Dyed Water Testing

Figure 1-6. Field Investigation Map – Locations where Storm Drain Plugging was not Feasible

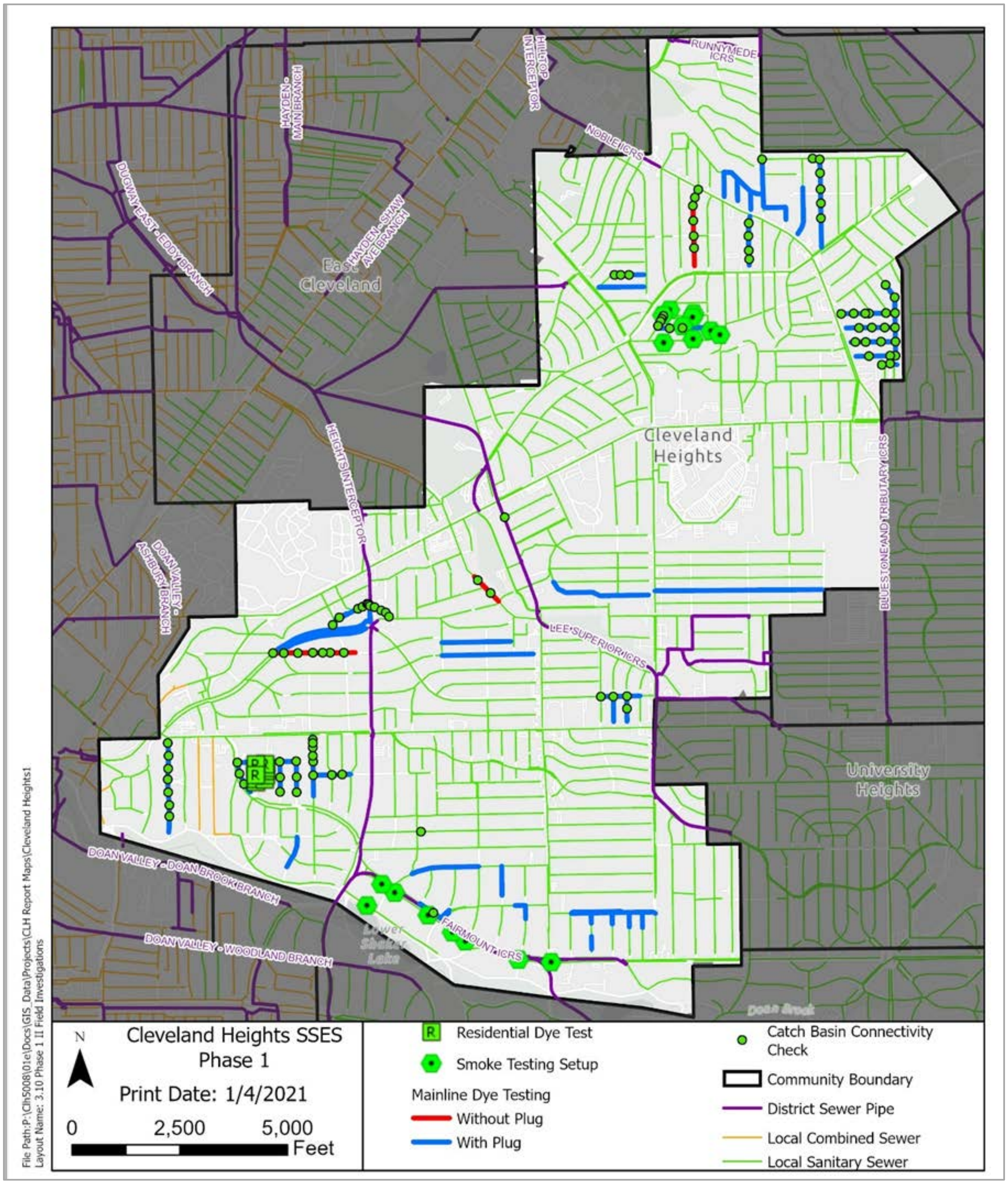
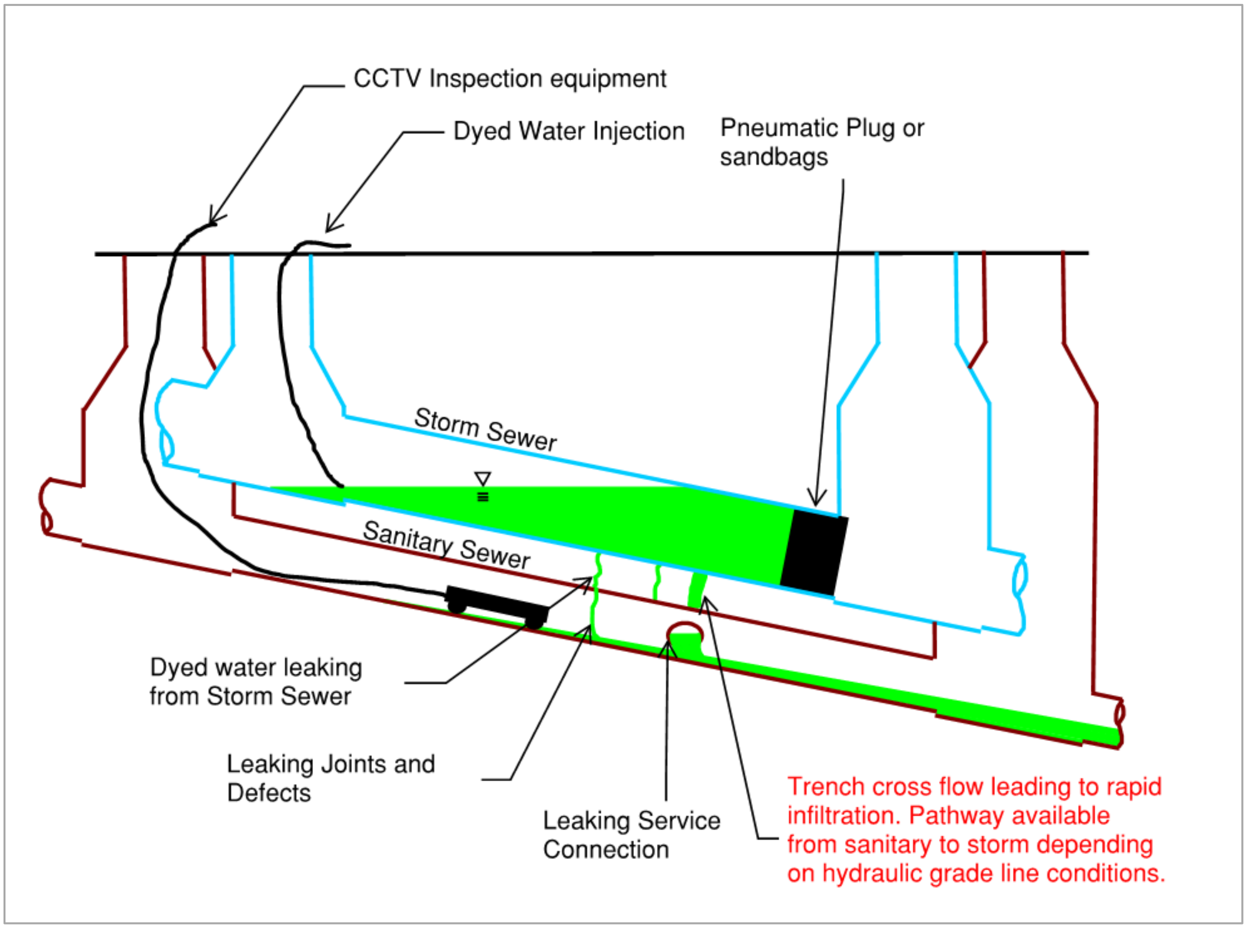


Table 1-1. Locations and Conditions - Storm Drain Plugging Not Conducted			
Street Name	Upstream Manhole	Downstream Manhole	Field Conditions for not Plugging Storm Drain
Edgehill Rd	SA16AECK0	SA16AECD0	Storm sewer size range from 36 to 60 inches, too large for plug.
Pembroke Rd	SA16APSH0	SA16APOK0	Storm sewer size range from 18 to 24 inches, crew mentioned water pressure too high for plug.
Superior Ave	SA16AHVN0	SA16AHVK0	Busy street, did not plug storm sewer to speed up work; very leaky over/under area.

Figure 1-7. Typical Dyed Water Flood Testing Schematic



1.2.3 Reported Problems and Recent/Ongoing Improvements

Cleveland Heights receives relatively few sanitary sewer basement backup complaints. Many of the complaints have been associated with temporary sewer system obstructions such as roots or other debris found in the mainline public sewer, or in the private property service laterals. At the beginning of the District's HHI-LSSES project in the fall of 2015, the District met with community representatives for Cleveland Heights to discuss existing information and known problem areas. This discussion identified four problem areas as summarized in **Table 1-2**.

Table 1-2. Community Reported Problem Areas

Problem Area ID	Location	Reported Problem
1	Coleridge Road between Coventry Road and Stratford Road	Basement backups
2	Fairfax Road between Marlboro Road and Stratford Road	Basement backups
3	Euclid Heights Boulevard between Berkeley Road and Superior Road	Basement backups
4	Fairmount Boulevard between Ardleigh Drive and Coventry Road; Delamere, south of Nottinghill Lane	Basement backups

The City received basement backup complaints in the Delamere neighborhood, and in the Randolph Road area, north of Noble Road, but not in other areas. As a result of the complaints, the City completed a sewer system rehabilitation project in the Randolph Road area, and the Delamere problem area was addressed via a sanitary and storm sewer system improvement project, partially funded by the District, to replace selected sewers and provide inline storage for wet weather flows.

The City has also benefitted from the recent Fairmount Boulevard Sanitary Relief Sewer (FBSRS) project completed by the District in Cleveland Heights. This project constructed a new sanitary sewer and inline storage in Fairmount Boulevard, from Shelburne Road to an existing District interceptor system drop shaft located west of Lee Road. This project controlled three previously active sanitary sewer overflows (SSOs), eliminated two previously unknown SSOs, and reduced the risk of basement backups in the local tributary areas. The FBSRS is shown as the solid green line on the north side of Fairmount Boulevard in **Figure 1-8**.

Figure 1-8. Fairmount Boulevard Sanitary Relief Sewer Location Map

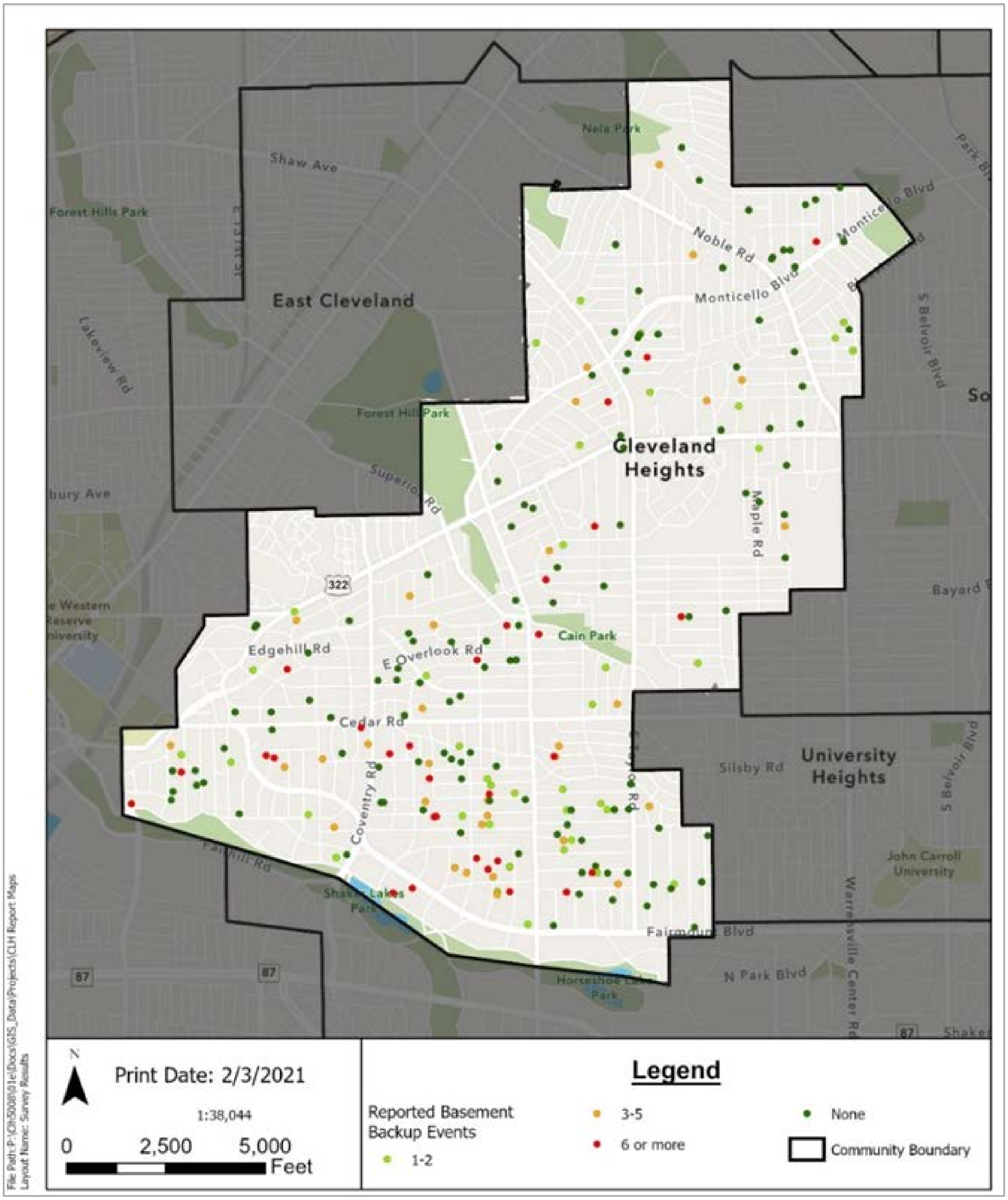
Basement Backup Survey

The HHI-LSSES project has found, particularly in common trench areas, that actual performance is often better than projected using the system model. This is believed to result from both the storm sewer system capacity and the storage volume available in the sewer trench for flows that exceed sanitary and storm sewer system capacities. Cleveland Heights has conducted a preliminary public survey that was available to residents and is considering conducting a more detailed survey that may be sent/emailed to all residents. The survey requested occurrences of basement backups and other flooding issues in the past 10 years. There is also preliminary planning by the District to potentially deploy a common complaint questionnaire and AGOL tracking system for member communities that would help make the information collected more uniform and would display via ArcGIS online (AGOL).

Figure 1-9 shows results to date from the recent Cleveland Heights survey. Annual reporting can include updates as additional surveys and tracking are implemented. Future survey information will help check the validity of model projected problem areas and could potentially be used to update prioritization of any proposed system improvements.

In projected basement backup areas where there are no flooding reports or survey information returned to substantiate projected problems, the City will likely propose to closely monitor performance to help confirm level of service. Periodic temporary flow or level monitoring of sufficient duration will be used to assess performance in problem areas that may arise based on survey and/or complaint information. The resulting information could be used to guide O&M efforts, update model calibration and prioritization, and support preliminary design efforts as appropriate. Project definition investigations are also proposed, particularly in common trench improvement areas, to help identify the I/I sources in more detail and better define the proposed planning level improvements prior to preliminary design.

Figure 1-9. Reported Basement Backup Events last 10 Years



Common Trench Sewer System Performance

Common trench sewer system level-of-service (LOS) performance may be better than projected by the model due to the sewer trench providing storage volume for peak flows during wet weather. Because the systems are leaky, the sewage and stormwater flows may also mix during wet weather. In the common trench configuration, because the sanitary sewer is in the bottom of the common trench, beneath the storm sewer, when the water surface elevation in the trench is below the storm sewer, the water is conveyed primarily in the sanitary sewer to the downstream WWTP. This is also observed for small rainfalls where storm sewers tend to drain into the common trench and then as infiltration to the sanitary sewer system. Ultimately, more stormwater is sent to the WWTP for treatment.

Limited testing indicates that common trench system stormwater may contain more E. coli than separate trench stormwater, but this is expected to be highly variable depending on the specific system, the service area, and the rainfall. It is also unknown if the annual bacterial loading to surface waters is higher or lower, however, due to the offsetting effect of treating stormwater during smaller rainfalls that infiltrate into the common trench sanitary sewers, as most of the annual rainfall total volume is from smaller rainfalls.

A very long-term objective would be to effectively separate the stormwater and sewage flows in common trench systems, either through system rehab or reconstruction. This is extremely costly and would need to be integrated with other infrastructure renewal work over many decades.

2.0 MODEL UPDATE

A model representing the Cleveland Heights sanitary sewer collection system was developed for the District's Heights Hilltop Interceptor-Local Sewer System Evaluation Study (HHI-LSSES) conducted from 2016 to 2020. The HHI-LSSES model was created by combining the Existing Conditions Model from the Heights Hilltop Interceptor-Operational Evaluation Project (HHI-OEP, May 2009) with a portion of the District's Easterly Baseline Master Model. The portion of the Cleveland Heights sewer system tributary to the Heights Hilltop Interceptor system originated as the HHI-OEP model. The area in Cleveland Heights west of Coventry Road and tributary to the Doan Valley Interceptor (DVI) was added from the Easterly Baseline Master Model (ESBL201405DVT-20141009_20150928).

The CD model was developed by extracting the Cleveland Heights portion of the final HHI-LSSES model. This model was expanded and recalibrated per the CD and was used to support development of the Cleveland Heights Integrated Overflow Control Master Plan (IOCMP). The model was expanded, and subcatchments were refined to reduce areas to approximately 10 acres or less. Upstream subcatchments were reduced to 5 acres or less and the hydraulic model was extended to reach the refined subcatchments.

The sewer system is modeled using the Innovyze InfoWorks ICM 9.5 model (Version 9.5.1.19011 Unicode December 2018) and follows the District's modeling standards and protocols. The District modeling standards have been used by the District and local consultants for all separate and combined sewer modeling of systems tributary to District facilities. **Appendix 3** contains the District's current modeling standards and protocols.

2.1 PROJECT MODEL UPDATE AND EXTENSION

Before calibration, the model was expanded and subcatchments refined to better simulate flows and hydraulic conditions in the local sewer pipes. Most subcatchments were refined to 10 acres or less, while the upstream most subcatchments were refined to 5 acres or less. A 10-acre subcatchment contains up to approximately 50 structures.

The Cleveland Heights portion of the HHI-LSSES model includes 268 subcatchments and 1,239 conduits totaling 281,519 linear feet (LF), with 1,297 nodes/manhole structures. The Cleveland Heights model refinement resulted in a total of 936 subcatchments. The Cleveland Heights model extension added 1,428 conduits totaling 333,503 LF, and 1,749 nodes/manhole structures, for a new total of 2,667 conduits with a total length of 615,022 LF, and 3,046 total nodes/manhole structures. This model expansion more than doubled the size and complexity of the previous HHI-LSSES model. Model refinement efforts are described in the following sections.

2.1.1 Subcatchment Delineation

Subcatchments were delineated along parcel lines considering flow splits, diversions, SSOs, and flow meter locations. Subcatchment loadings were assigned to the nearest manhole at approximately 1/3 distance from the downstream boundary. **Figure 2-1** shows the original and new subcatchment delineation of the entire model. **Figure 2-2** illustrates distribution of subcatchment areas for the new Cleveland Heights model in blue and for the entire HHI-LSSES model in orange. The graph shows that 50% of subcatchments are less than 5 acres (versus 12% in HHI-LSSES) and 96% of subcatchments are now less than 10 acres (versus 30% in HHI-LSSES). Only 4% of subcatchments are from 10 to 30 acres which are primarily located in commercial areas.

Figure 2-1. Subcatchments Re-Delineation Overview

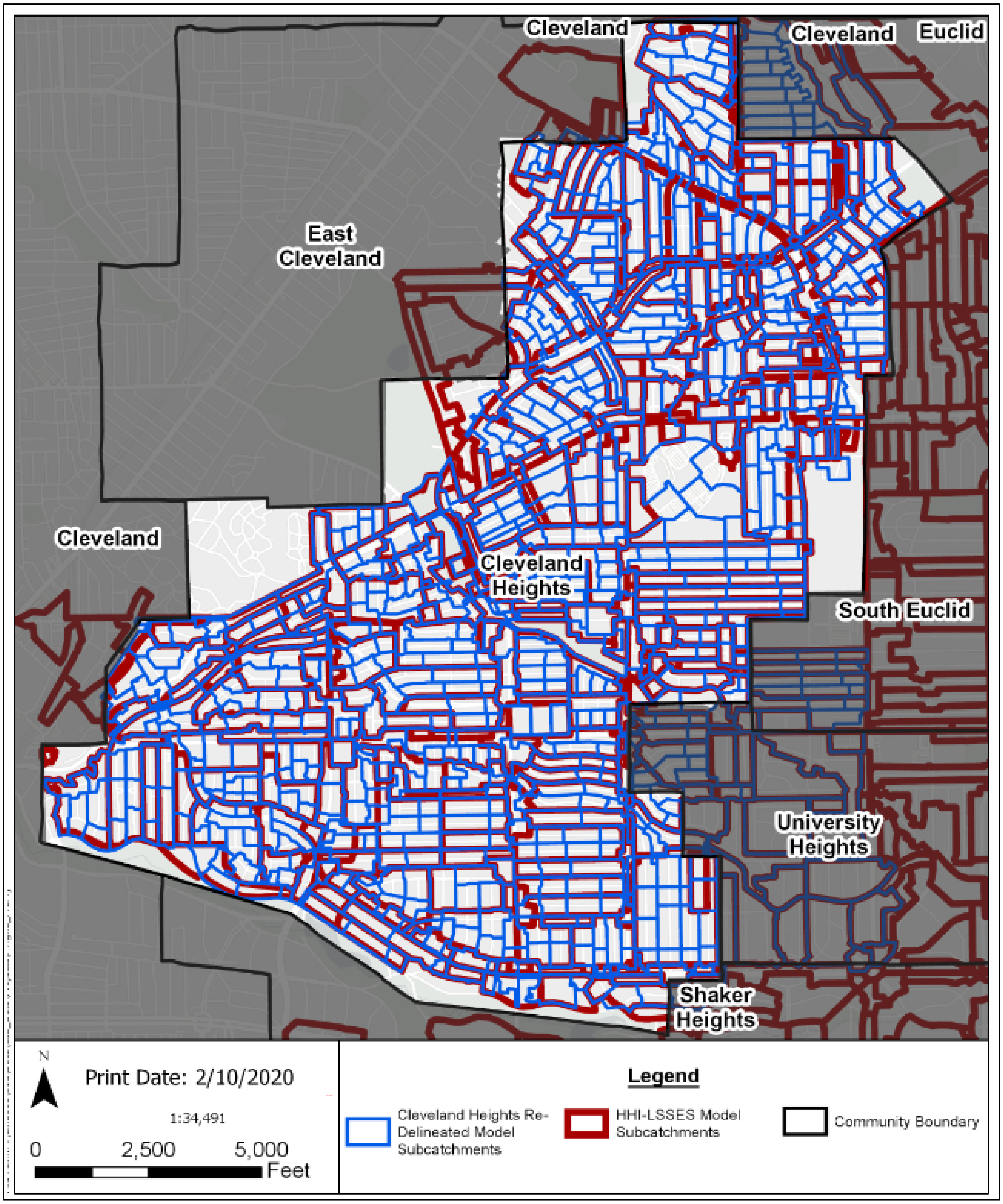
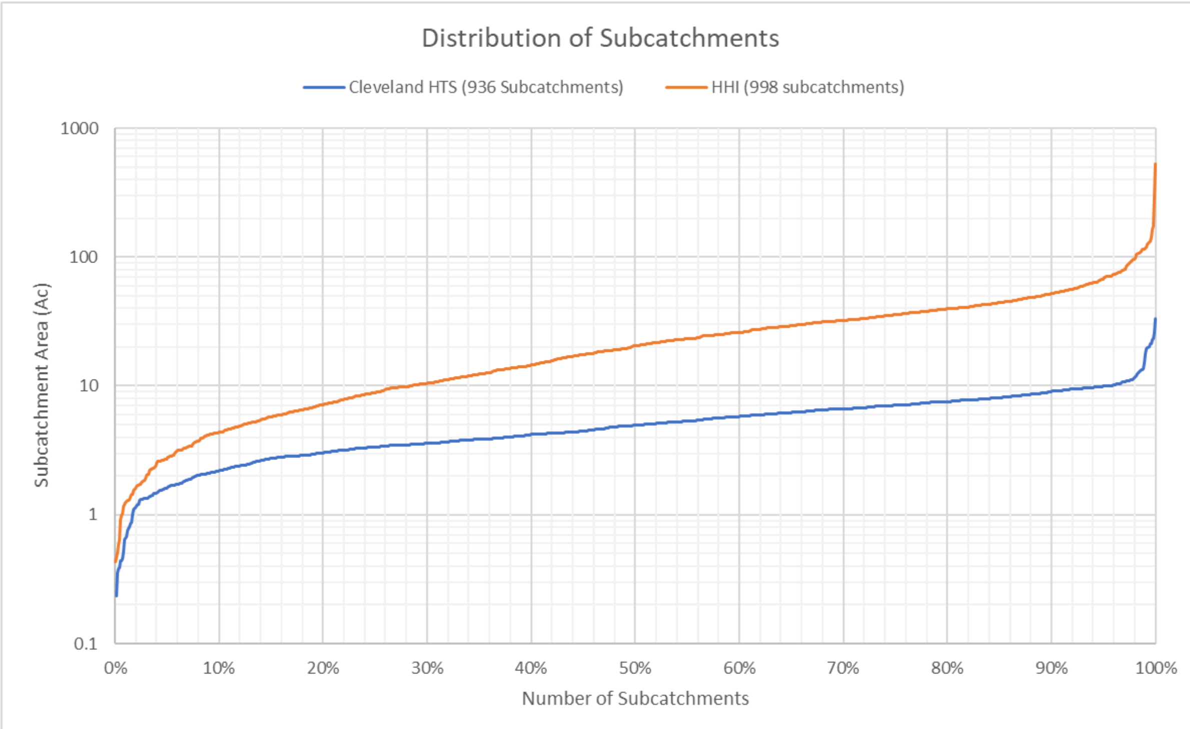


Figure 2-2. Subcatchment Area Distibution



The new Cleveland Heights model catchment area distribution is shown in blue. The previous entire HHI-LSSES model is shown in orange.

Approach

The refined subcatchments replaced the original subcatchments. The updated modeling parameters are based on the new, more detailed subcatchments. For subcatchments tributary to a flow meter, the model calibration parameters were assigned based on the metershed. The parameters were refined in the standard process to support calibration. For subcatchments not tributary to a nearby flow meter, the parameters were assigned based on the subcatchment the majority of the smaller subcatchment falls within.

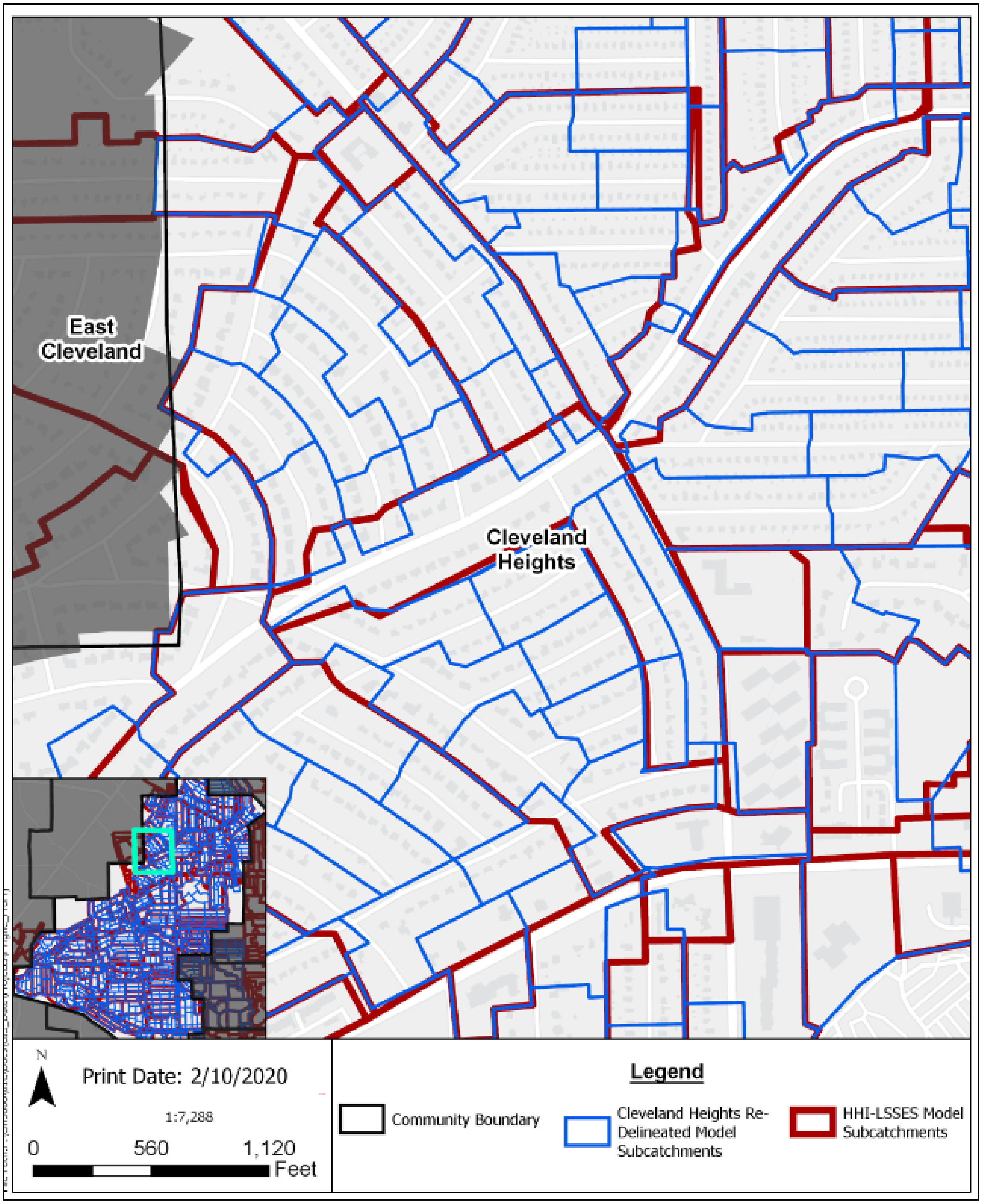
Current model subcatchment parameters were initially assigned based on the HHI-LSSES parameters. The original subcatchment borders did not always match the new smaller subcatchments. **Figure 2-3** provides an example of subcatchment borders before and after refinement and re-delineation. The original HHI subcatchments were split into new subcatchments to match with additional pipes extended upstream and the new subcatchment boundaries were refined to match the more detailed Cleveland Heights model. Because the areas tributary to previous calibration meters were large, the total area to a calibrated point did not change significantly.

For Dry Weather Flow (DWF) parameters, the population and baseflow from an original subcatchment was distributed among the new subcatchments based on area. The wastewater profile from the original subcatchment was assigned to the new subcatchments. For Wet Weather Flow (WWF) parameters, the same parameters from the original subcatchment were assigned to the new subcatchments. The WWF parameters are based on percentages of area, not an absolute value, and therefore were not split among the new subcatchments.

The refined model was validated with both the HHI-LSSES flow monitoring data and new Cleveland Heights flow monitoring data. As a result the wet weather hydrologic parameters for all model subcatchments were reviewed and further refined where appropriate during calibration, as detailed **Section 4.2 Wet Weather Flow Calibration**.

As additional detailed field data is collected or rehabilitation projects are performed, the model can be updated and run with the updated conditions to project current system performance.

Figure 2-3. Example of Updated Subcatchment Delineation



2.1.2 Local Sewer System Model Extension

Sewers were added to the model to coincide with the updated/refined subcatchments. Sewer parameters were based on record drawings and data in the NEORSD ArcGIS Online (AGOL) database, when available. Record drawings were available for about 40% of the sewer system, field investigations were completed for 30%, and the remaining 30% comprising primarily upstream sewer segments, were estimated using interpolation. If record drawings were not available for short stretches of sewer, either GIS values were used or constant slope, diameter, and roughness were assumed. If record drawings were not available for large stretches of sewer, field data were collected for the reaches of sewer needed. Connectivity inconsistencies between the AGOL line work and record drawings were also investigated. Rim elevations were established based on digital elevation model (DEM) information from 2017 Light Detection and Ranging (LIDAR) data.

For sewers with less than 30 acres of tributary area, if record drawings were available, the most upstream pipe inverts were added based on record drawings while the inverts between were interpolated, see **Figure 2-4**. If no record drawings were available, the sewers were assumed to follow the slope of the ground, with the depth to invert assumed to be the same as the nearest downstream manhole with detailed information (see **Figure 2-5)**. GIS values were used for diameter, if available, or otherwise assumed. For roughness, a standard Manning *n* value of 0.0143 was used based on the model standards for unknown material, and the age and typical condition of the sewers. This also includes typical minor losses attributed to flow through manhole structures.

Per District standards, the following standard values were assigned for conduits and nodes:

- Conduit Head Loss Type – None
- Node Chamber Plan Area – 12.56 square feet
- Node Shaft Plan Area – 12.56 square feet
- Node Flood Type – Stored

Figure 2-6 shows the Cleveland Heights sewers included in the HHI-LSSES model in orange and the sewers added for the CD model extension in blue. District sewers are shown in purple.

Figure 2-4. Example of Interpolation Between Known Inverts

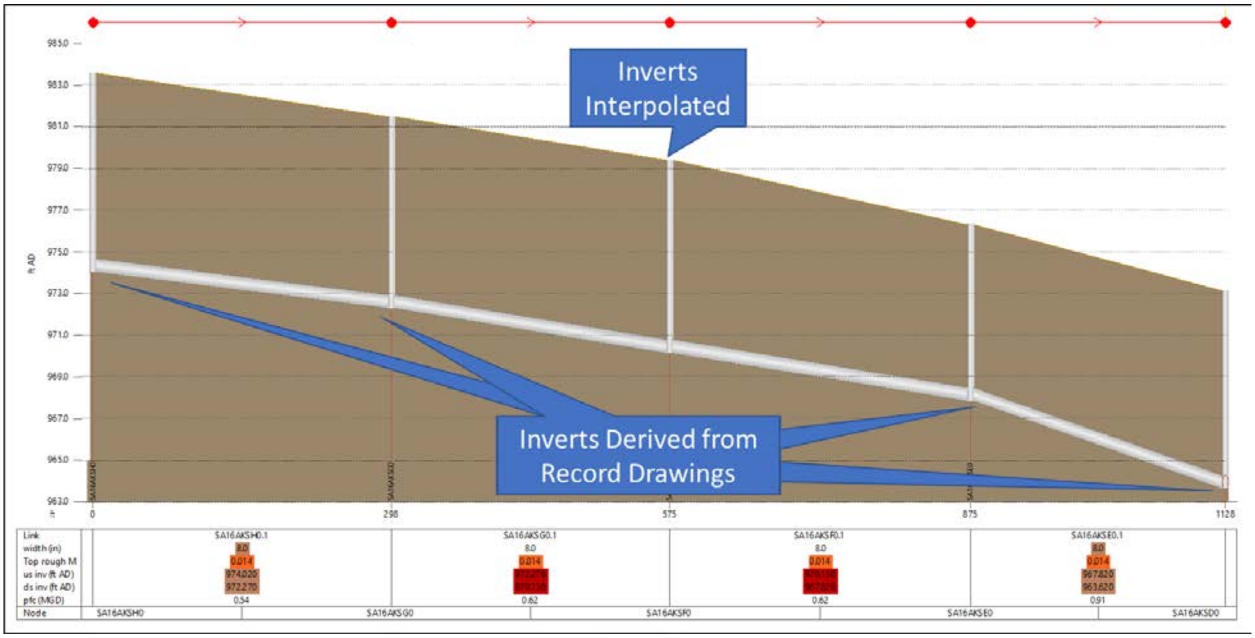


Figure 2-5. Example of Assumed Inverts Based on Ground Slope

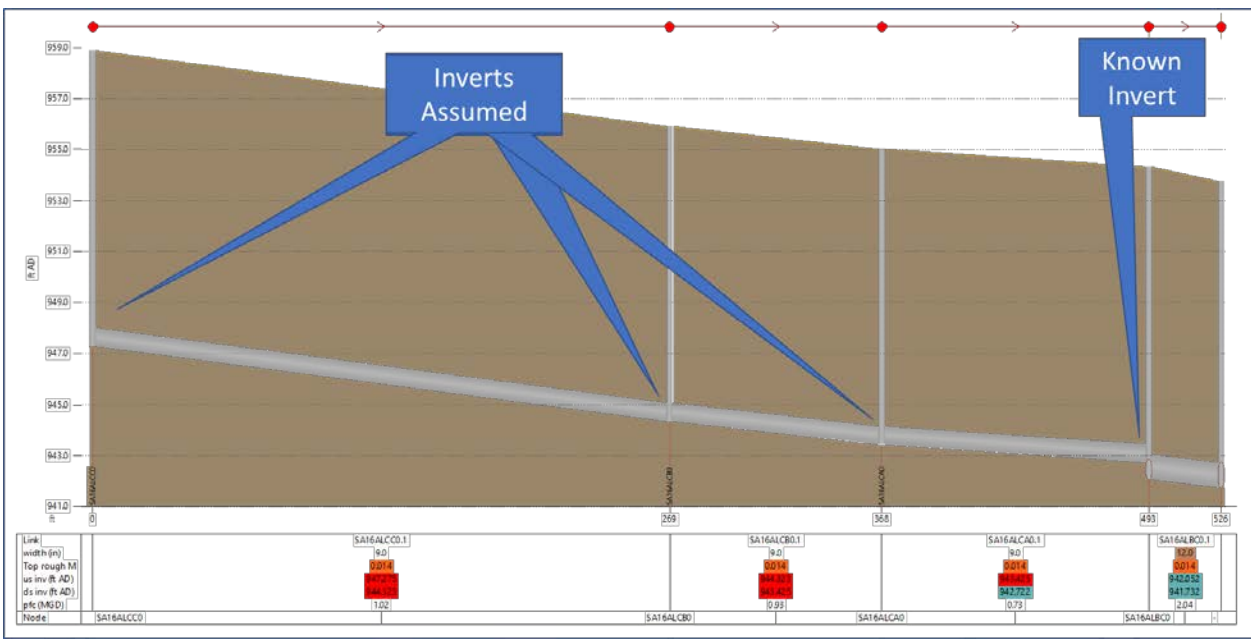
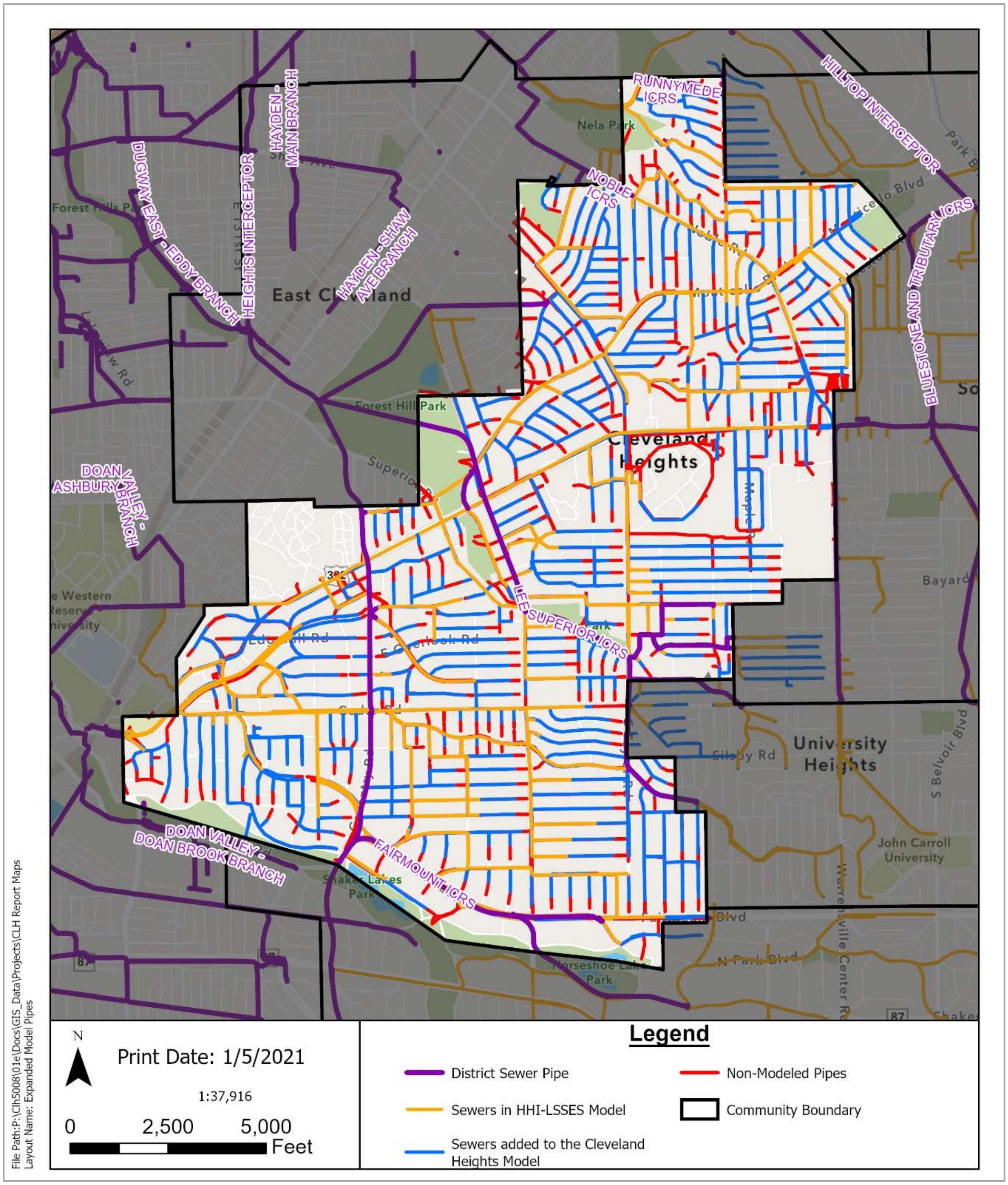


Figure 2-6. Cleveland Heights Modeled Sanitary Sewer System



2.2 COMMON TRENCH SEWER SYSTEM MODEL ELEMENTS

The common trench sewer systems present unusual modeling challenges. Because of the age, condition, and proximity of the two systems in the same trench in the public right of way (ROW) and on private property, the sanitary sewer wet weather flow response is typically higher in common trench systems. Dyed water testing has found that there are typically numerous points of storm sewer infiltration into the sanitary sewers. Groundwater inundation of the common trench sewers is not expected in the Cleveland Heights system, as perched and other local groundwater is uncommon in the area based on anecdotal information from local contractors.

During the HHI-LSSES project the modeling team attempted to model the storm and sanitary systems together as a pilot exercise in both a dividing wall system and an over/under (invert plate) system. This was called *coupled modeling*. This modeling concluded that developing an explicit model of the over/under system interaction between the storm and sanitary sewers is infeasible. This is largely because the invert plate conditions and numerous distributed public and private system defects and I/I contributions are not well known, and the I/I flows from both portions of the system are highly variable. Modeling of the dividing wall systems has proved more feasible, however, and has been completed for the current capacity assessment modeling. The associated storm sewer systems have been modeled in an approximate fashion using a GIS modeling approach. These concepts are introduced in the following sections and discussed in more detail in **Section 4. Model Calibration**.

Near Surface Soil and Geologic Conditions

Following is a description of near surface soils in the Cleveland Heights area. From the ground surface to the underlying bedrock, a generalized soil profile in Cleveland Heights may include a surficial layer of topsoil, commonly less than 1 foot thick, underlain by either naturally formed silty clays or imported fill materials of variable composition, such as silty sands or clays. These strata can range in thickness from 1 or 2 feet to several feet. Except for lenses of free draining, coarse-grained material, this strata commonly exhibits low permeability. Underlying these near-surface soils is shale bedrock. The shale is typically heavily weathered in the upper few feet until it transitions into intact material. Groundwater levels vary seasonally and spatially, depending on the amount of precipitation, runoff, evaporation, infiltration, and proximity to local waterways. The soil-rock interface typically limits groundwater migration vertically. Perched groundwater may be encountered in granular seams or lenses (natural or fill) situated above less permeable soils.

2.2.1 Storm Sewer System Modeling

Based on the coupled modeling pilot analysis outcomes, the Cleveland Heights storm sewer system was modeled in an approximate fashion using hydrology developed for previous District stormwater models in conjunction with the existing sewer system GIS. The District models do not typically extend piping into the local tributary storm sewer systems but were useful to approximate peak runoff rates for Cleveland Heights tributary areas. These peak rates were then expressed on a rate per area basis and compared with local storm sewer capacities determined based on storm sewer size and either existing slope, or a minimum flow velocity coupled with full pipe flow. This provided an estimate of the local storm sewer system level of service, e.g., capacity for 2-year, 5-year rainfalls, etc. which can be compared to existing sanitary sewer system performance for similar events, and the interaction considered qualitatively. **Sections 4** and **5** discuss this approach and results in more detail.

During implementation of improvements, local storm sewer systems may be modeled in more detail to determine the need for potential capacity increases if sewer replacement is needed. This would also consider other potential local stormwater management projects and green infrastructure approaches to reduce stormwater runoff.

2.2.2 Flow Limit Elements

The coupled modeling pilot exercise also resulted in a modified approach to model the existing system conditions in common trench areas using an approximate model element called a *flow limit*. Because the HHI sanitary sewer model does not explicitly include the storm sewer system and the innumerable interconnections, this interaction between the storm and sanitary sewer systems was approximated in some areas using “flow limit” model elements to achieve acceptable calibration to observed rainfalls.

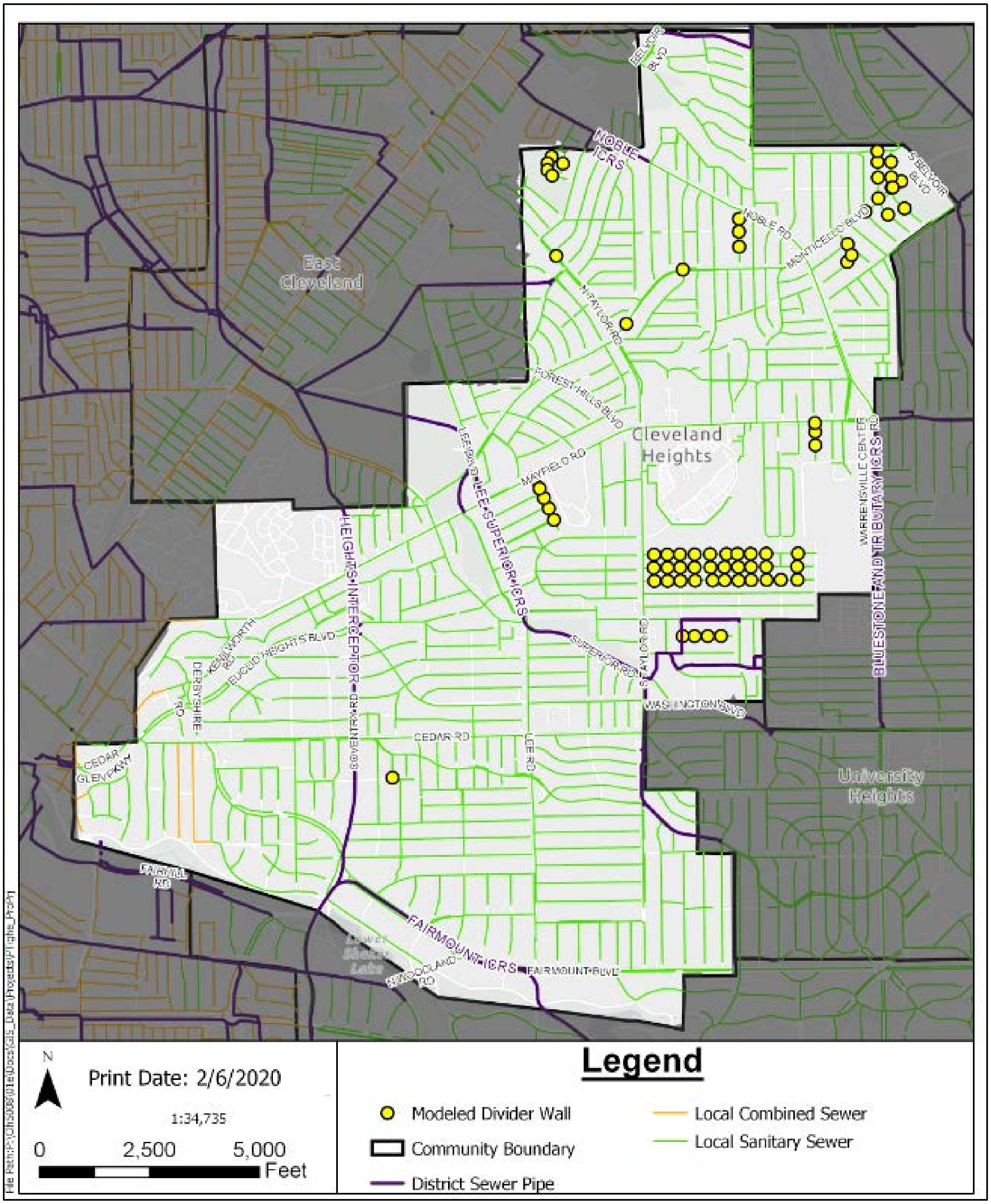
The flow limits consist of model weirs and orifices used at selected common trench locations to mimic the real system and achieve acceptable calibration compared to actual performance. The flow limits allow the high I/I tributary to the sanitary sewer to escape as the sanitary sewer becomes overwhelmed, thus approximating the real system’s operation. Higher flows are conveyed in the storm sewer system or stored temporarily in the common trench volume surrounding the sewers.

During analysis of improvement alternatives, flow limit elements are removed for projects that will reduce peak flows via system rehabilitation or new sewer construction.

2.2.3 Dividing Wall Manholes

All known dividing wall manholes were identified, physically inspected, and included in the sewer system model. A dividing wall was represented as a weir with appropriate width and elevation loaded to an outfall node. **Figure 2-7** shows the location of the modeled dividing walls.

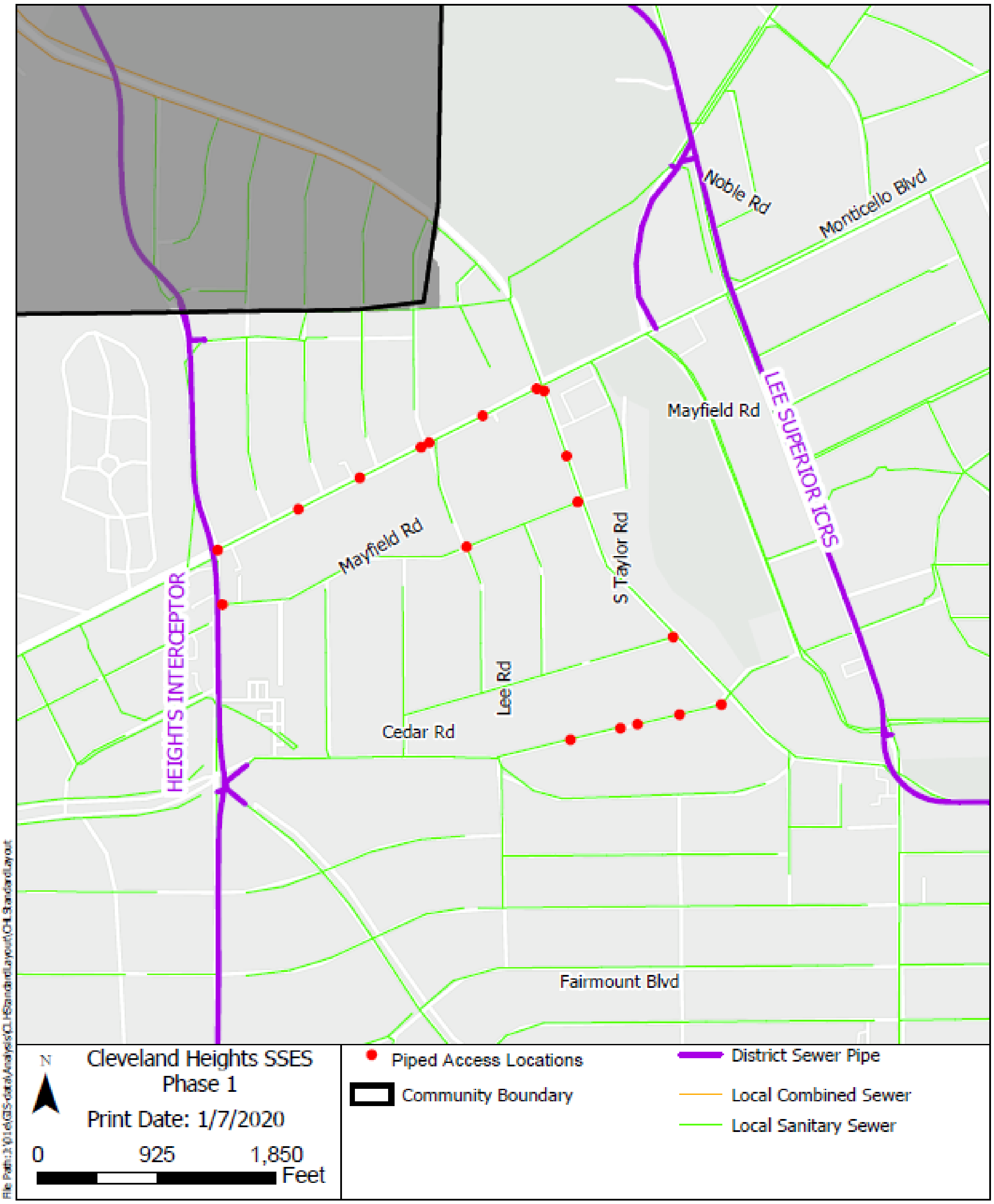
Figure 2-7. Modeled Dividing Walls



2.2.4 Piped Sanitary Access Manholes

Over/under piped sanitary access manholes identified during the SSES were included in the model. An access pipe was represented as a weir with appropriate width and elevation loaded to an outfall node. **Figure 2-8** shows the location of the modeled over/under piped sanitary access manholes.

Figure 2-8. Over/Under Piped Sanitary Access Manholes



2.3 ADDED/UPDATED SSOs

All known SSOs were verified and updated as appropriate. During the HHI-LSSES, all known SSOs were inspected to determine if they remain intact or have been eliminated. The Cleveland Heights SSES found 8 additional SSOs. The HHI-LSSES model included all intact SSOs. Previously modeled SSOs were modified as needed based on improved field information or flow monitoring data. **Figure 2-9** shows locations of the 37 Cleveland Heights SSOs represented in the HHI-LSSES model and 8 new SSOs discovered during the SSES. **Table 2-1** lists the SSO ID, modeled link ID, and location of all 45 SSOs in the Cleveland Heights model.

The *Phase 1 SSES Report, December 2020*, describes the SSO inspections in Section 3.5:

All known structural SSOs in the Cleveland Heights service area were inspected during the HHI-LSSES project. New SSOs found during the Phase 1 SSES were also inspected. Inspections were also performed for the SSOs that had previously been documented to be eliminated to confirm elimination.

All SSOs were inspected at MACP Level 2 using NASCCO's MACP Version 6.0.1. The inspections were completed using a Panaramo Optical Manhole Scanner in place of manhole entries. Excerpts of the scans are included with the MACP inspection reports, and the complete scan data is on file at Cleveland Heights. The MACP inspection reports can be found in Appendix 5. During inspection, if operations and maintenance issues were found, field crews performed follow-up cleaning and maintenance as necessary to optimize interim performance.

Figure 2-9. Modeled SSOs

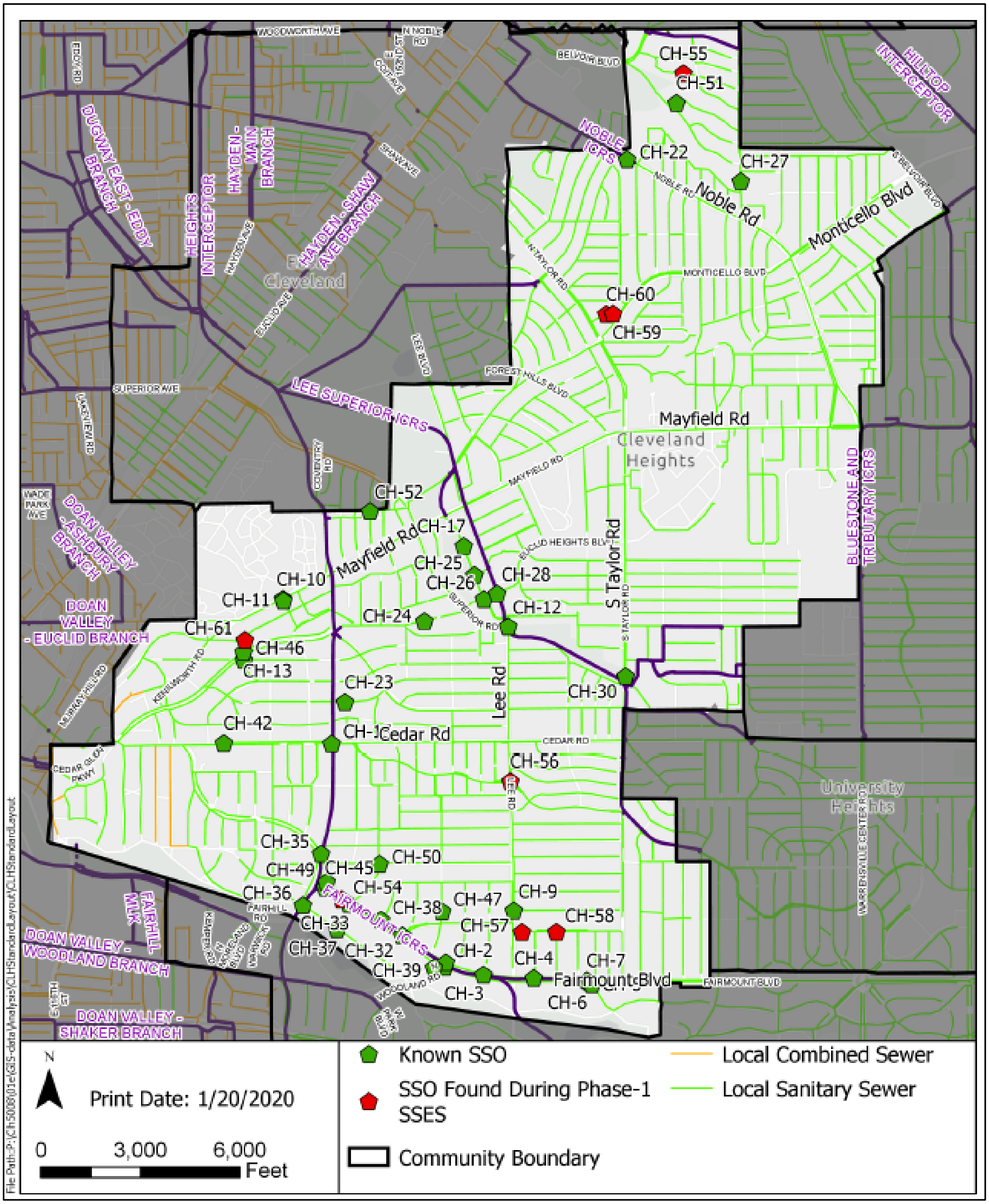


Table 2-1. Modeled SSOs

SSO ID	Model Link	Location
CH-1	CH-1.2	Fairmount at N. Woodland (3041)
CH-2	CH-2.2	Fairmount at N. Woodland (3026)
CH-3	CH-3.2	Fairmount at Wellington
CH-4	CH-4.2	Fairmount at Dartmoor
CH-5	CH-5.1	Fairmount at Shelburne
CH-6	CH-6.1	Fairmount at Shelburne
CH-7	CH-7.1	Fairmount at Shelburne
CH-9	CH-9.2	Bradford and Lee
CH-10	CH-10.2	Hampshire Lane at Mayfield (18")
CH-11	CH-11.1	Hampshire Lane at Mayfield (36")
CH-12	CH-12.2	Lee at Superior
CH-13	CH-13.2	Hampshire Lane at Euclid Hts Blvd
CH-15	CH-15.1	Coventry at Cedar
CH-17	CH-17.2	1685 Cumberland
CH-22	CH-22.2	2225 Noble Road
CH-23	CH-23.2	Berkshire east of Coventry
CH-24	CH-24.2	3003 Euclid Heights Blvd
CH-25	CH-25.2	Cumberland/Somerton
CH-26	CH-26.2	Euclid Heights Blvd/Cumberland
CH-27	CH-27.2	Quilliams, N. of Randolph
CH-28	CH-28.2	Euclid Heights Blvd and Lee
CH-30	CH-30.2	Taylor N of Superior
CH-32	CH-32.2	Fairmount at Arlington
CH-33	CH-33.2	Fairmount at Fairfax
CH-35	CH-35.2	2393 Coventry, w. of Fairmount
CH-36	CH-36.2	North Park and Coventry
CH-37	CH-37.2	Fairfax at North Park
CH-38	CH-38.2	Fairmount at Marlboro
CH-39	CH-39.2	3012 North Woodland
CH-42	CH-42.1	12537 Cedar Road
CH-45	CH-45.1	2764 Fairmount, in Island

Table 2-1. Modeled SSOs		
SSO ID	Model Link	Location
CH-46	CH-46.1	Edgehill at Euclid Heights Blvd
CH-47	CH-47.2	2528 Stratford, N. of Monmouth
CH-49	CH-49.2	2765 Fairmount, Just E. of Church
CH-50	CH-50.3	Scarborough at Lamberton
CH-51	CH-51.2	Langton at Atherstone
CH-52	CH-52.2	Eddington at Avondale
CH-54*	CH-54.2	2806 Fairmount Blvd
CH-55*	CH-55.2	3593 Fenley Road
CH-56*	CH-56.2	Lee at Meadowbrook
CH-57*	CH-57.2	E. Monmouth, W of Dartmoor
CH-58*	CH-58.2	E. Monmouth at Exeter
CH-59*	CH-59.2	3427 Thorne Rd
CH-60*	CH-60.2	3415 Thorne Rd
CH-61*	CH-61.2	2600 Hampshire Rd
*SSO discovered during the Cleveland Heights SSES		

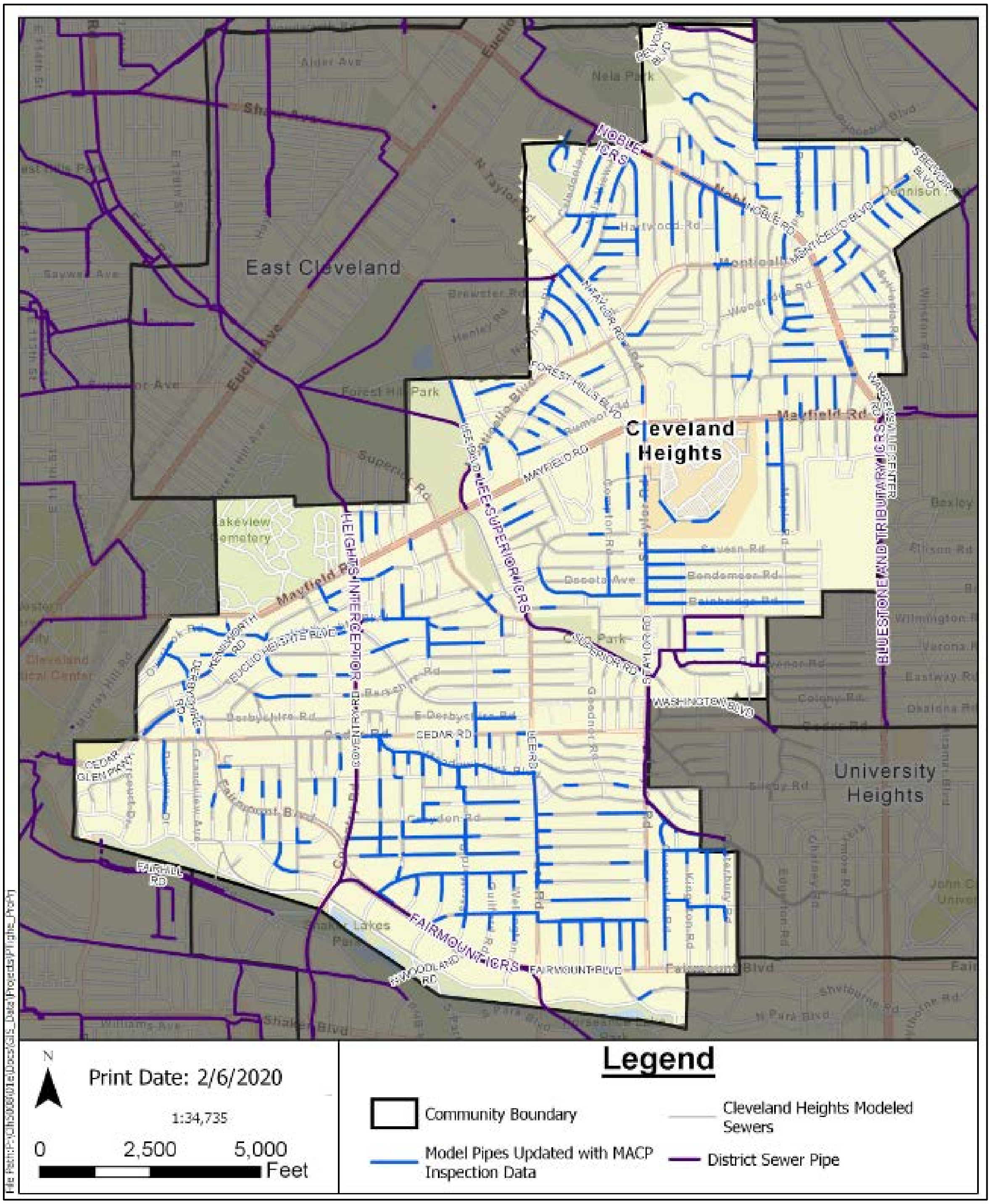
2.4 SEWER SYSTEM INVERTS

Section 2.1.2 summarizes how modeled sewer inverts were assigned. As part of the Cleveland Heights SSES, field personnel performed NASSCO Level 1 Manhole Assessment and Certification Program (MACP) inspections for the entire system. The Level 1 inspections were completed from the surface. At the time of model development and calibration, a portion of the MACP inspections were available and processed. The MACP inspection information was used verify sewer inverts, and confirm sewer connectivity, weir elevations, sewer defects, etc.

All MACP inspections included measurement verification of invert elevations. Approximately 30% of the modeled sewers have field verified inverts. The MACP inspection information was used to update the model hydraulics for selected sewers. The measurements of rim to invert were used with rim elevations from the DEM to establish the invert elevations. **Figure 2-10** shows the portions of the model that have field measured inverts incorporated. Each improvement project will conduct more detailed engineering surveys during preliminary design as determined by the proposed improvements. This information will be added to the model as it becomes available.

The analysis completed to date has performed invert checks where needed for the modeling and alternatives analysis. No further elevation survey or invert checks will be performed or used for development of the IOCMP proposed improvements. As IOCMP design projects are developed and implemented, MACP data and/or further elevation survey information will be used during detailed design of improvements as appropriate for each improvement project. Some projects such as sewer system rehabilitation or redirection of SSO flows may not require extensive engineering survey elevation information.

Figure 2-10. Measured Pipe Inverts Incorporated into the Model



2.5 DELAMERE DRIVE AREA STORM SEWERS

The Delamere Drive area has experienced frequent reported basement flooding. Because of the severity of the flooding, the area was considered a high priority and chosen for a more detailed modeling approach. The area was awarded a Member Community Infrastructure Program (MCIP) grant from the District to design and construct improvements. **Figure 2-11** shows the Delamere Drive area and neighboring sewers. The model extension in this area included the addition of the storm sewer system to better understand the potential interaction and to consider solutions for observed surface flooding. This area is served by a common standard system and the storm and sanitary sewer models are independent.

Figure 2-11. Delamere Drive and Neighboring Area Modeled System

3.0 FLOW AND RAINFALL MONITORING PROGRAM

Both the HHI-LSSES and the current capacity assessment effort under the CD conducted extensive flow and rainfall monitoring in the Cleveland Heights sewer system. The HHI-LSSES monitoring program in Cleveland Heights in the spring/summer of 2016 included 46 sanitary sewer model calibration meters, 4 storm sewer system meters, and 53 sanitary sewer micromonitoring locations to help target field investigations in areas of highest wet weather flow response.

For the current capacity assessment effort, calibration flow monitoring was conducted at 55 locations between July 14 and October 15, 2018. Most calibration flow meters collected data for the entire period. The only exceptions, CHS-36 and CHS-37 were installed on September 9 and September 5 respectively, to support the Delamere Drive analysis. Two temporary rain gauges were used in conjunction with the District's permanent rain gauges located in and around the Cleveland Heights service area. **Figure 3-1** shows the 2018 SSES flow meter and rain gauge locations.

Calibration flow monitoring was conducted to support expansion and upgrade of the model within the Cleveland Heights collection system. Micromonitoring used short duration flow meters to measure flows from small tributary areas (generally around 25 acres) to help screen and prioritize system field investigations, and to confirm performance of sewer system rehabilitation/separation projects. High flow and existing model-indicated problem areas were targeted with field investigations to identify sources of I/I and other potential problems such as SSOs and basement flooding.

3.1 FLOW MONITORING DATA

The calibration monitoring sites were selected to monitor the most active SSOs based on HHI-LSSES model volume and frequency and to better refine the model calibration by monitoring areas not covered in detail by the HHI-LSSES project. **Appendix 4** contains the detailed site installation sheets including the location and field observations.

Velocity, depth, and calculated flow rate were reviewed weekly during the flow monitoring period to evaluate data reliability. When necessary, the flow monitoring contractor adjusted flow data within the equipment's accuracy range to achieve balanced flows. Hydrographs were prepared and reviewed to identify data gaps and unusual system responses such as uncommon diurnal patterns, unexpected velocity/depth changes during dry weather, or peculiar wet weather responses. Velocity-depth scatter plots were also reviewed to evaluate meter performance and identify potential issues requiring attention during field visits. During the monitoring period, data edits to depth or velocity near a peak flow period (not just absolute peak but any moderate intensity rainfall) were not allowed. Edits made to the recession limbs and/or dry weather flows were acceptable in most cases. Data editing included the following:

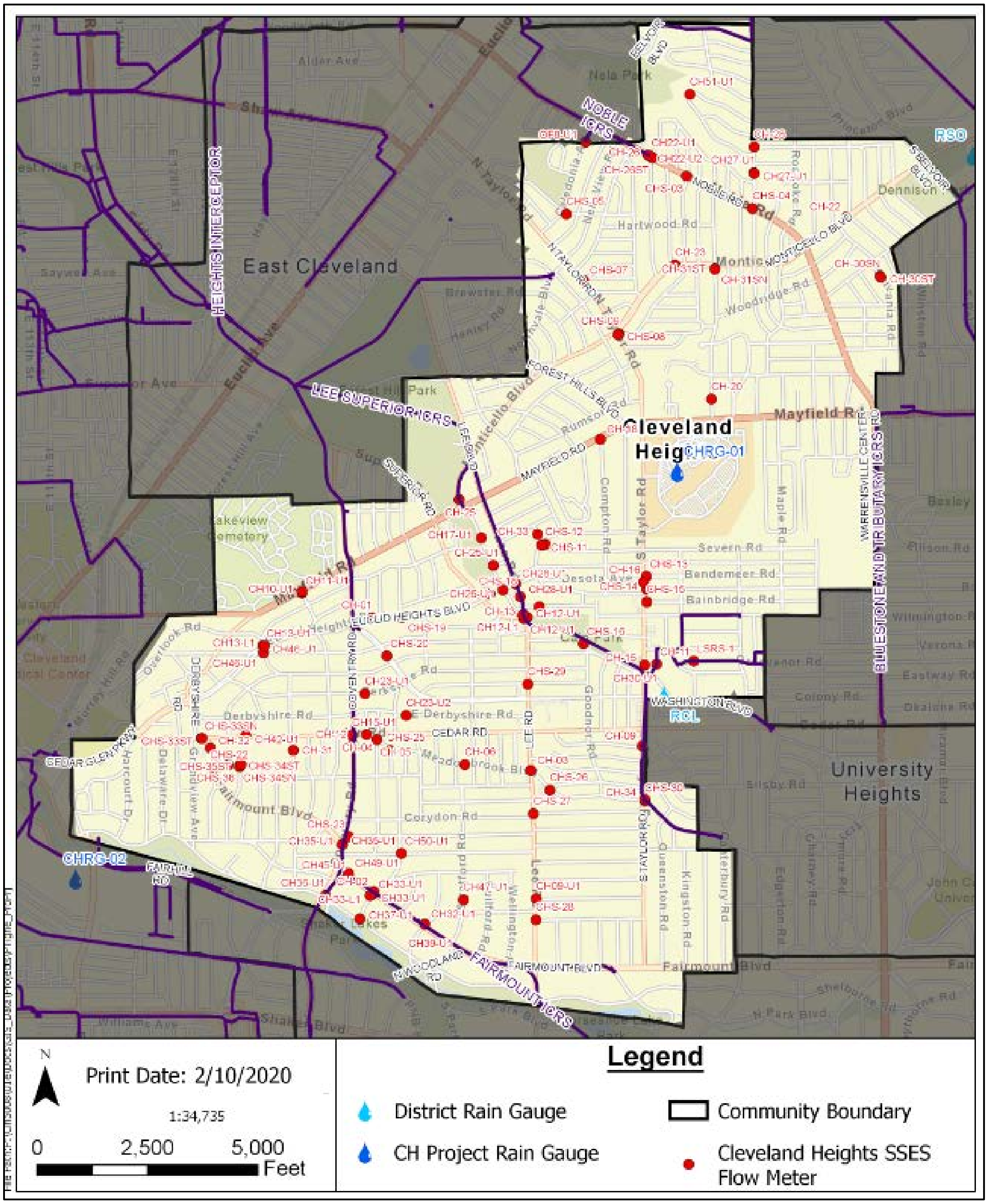
- Depth and/or velocity edits were made using scattergraph analysis to address data inconsistencies and missing data.

- Depth and/or velocity edits were made using data points before and after data inconsistencies and missing data.
- Depth and/or velocity adjustments were occasionally made due to debris on sensor.

Meter performance was summarized in tables showing each flow meter service history, data edits, missing data, questionable data, and unusual observations. If data issues were identified and meters were functioning properly, the data issues were flagged as “unusual observation”. If meter data appeared to be in question, the issues were flagged as “questionable data”. **Appendix 5** provides a summary matrix to document meter performance.

Overall, the meter data is considered reliable, with a few questionable sites exhibiting marginal hydraulic conditions and a few sites with missing data. The meters provided a total uptime performance of over 99% with 53 meters recording uptimes of 100%. The lowest uptime was 97.7% at CH33-U1. Occurrences of questionable or missing data did not significantly affect model calibration.

Figure 3-1. Calibration Flow Monitoring Locations



3.2 RAINFALL DATA

Radar-rainfall data was processed and made available through the District's subscription with Vieux & Associates. The Gauge Adjusted Radar Rainfall (GARR) was used to support the model assessment/calibration efforts and helped define the spatial distribution of rainfall in detail for the monitoring period. Rainfall data from the District's permanent gauges and the project's 2 temporary gauges located within or near the service area were used to ground truth the radar reflectivity. Locations of the rain gauges used are shown in **Figure 3-1**.

The radar rainfall grids are 1 kilometer square. Subcatchments with 66% or more area within a radar grid were assigned that radar data. For subcatchments with less than 66% area within a radar grid, an area weighted rainfall pattern was created from the radar rainfall data. For RTK areas, which tended to be larger, a metershed (and RTK unit hydrograph) was created by area weighting the radar rainfall data (even if more than 66% of the area was within one radar grid). **Figure 3-2** shows the radar rainfall grid, model subcatchments, hydrology method areas, and associated rain gauges. **Figure 3-3** shows other nearby District gauges included in the radar rainfall analysis for the HHI-LSSES and Cleveland Heights SSES analyses.

Rainfall data from the 2 temporary rain gauges were analyzed throughout the monitoring period to track the number and quality of events being recorded to support model calibration refinement. The rainfall statistics were averaged to identify potential calibration events. **Table 3-1** lists the average rainfall statistics (event start/end times, duration, total rainfall depth, and peak 1-hour intensity) for rainfalls of at least 0.2 inches recorded at the temporary rain gauges during the flow monitoring period using an inter-event period of 12 hours to define individual events. The minimum event criteria in the District's modeling standards (included in **Appendix 3**) for selecting suitable events for model calibration is a rainfall total of 0.2 inches and a peak rainfall intensity of 0.25 inches/hour. A total of 10 rainfall events met the criteria.

Figure 3-2. Radar Rainfall Grid with Model Subcatchments, Rain Gauges and Hydrology Method

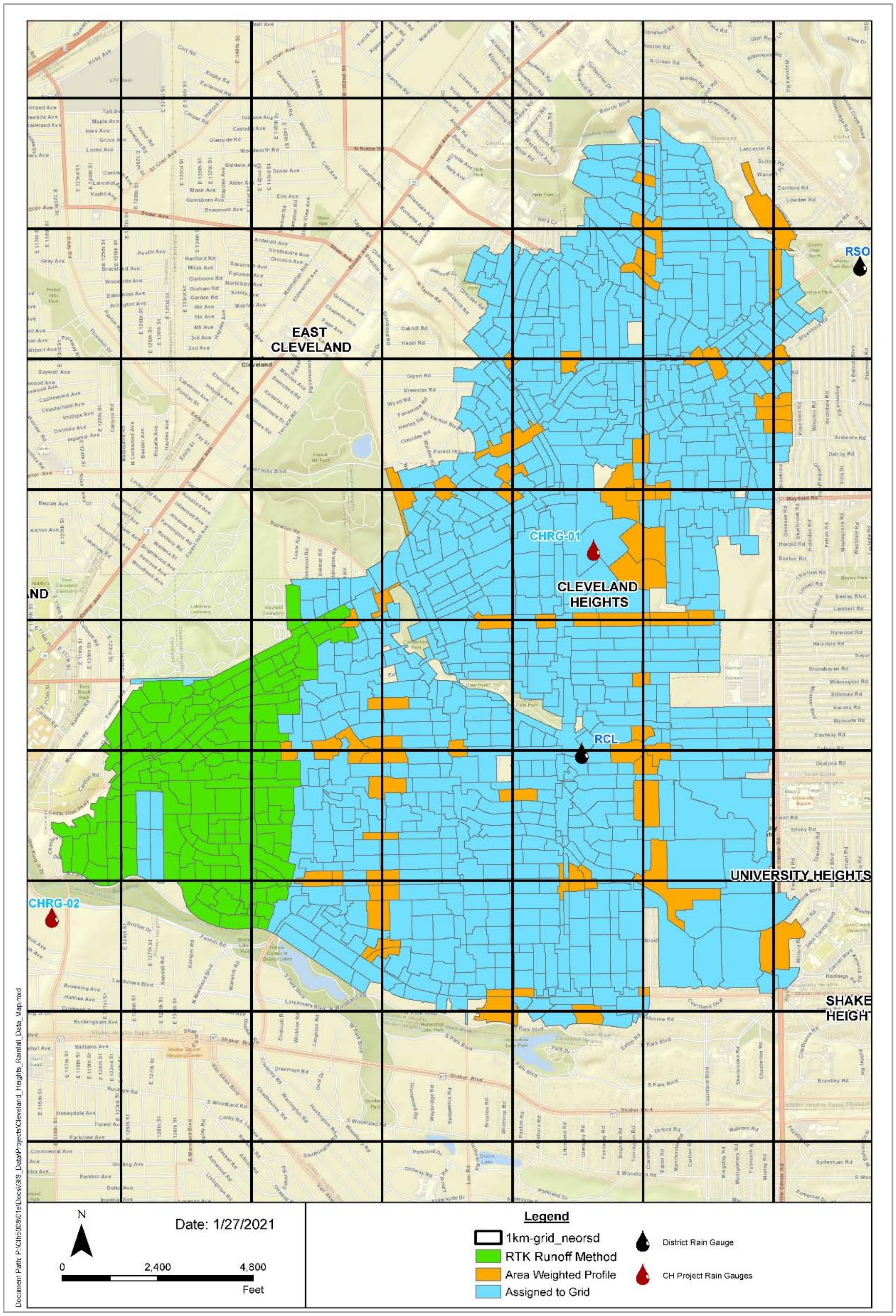


Figure 3-3. District Permanent and Cleveland Heights Temporary Rain Gauges

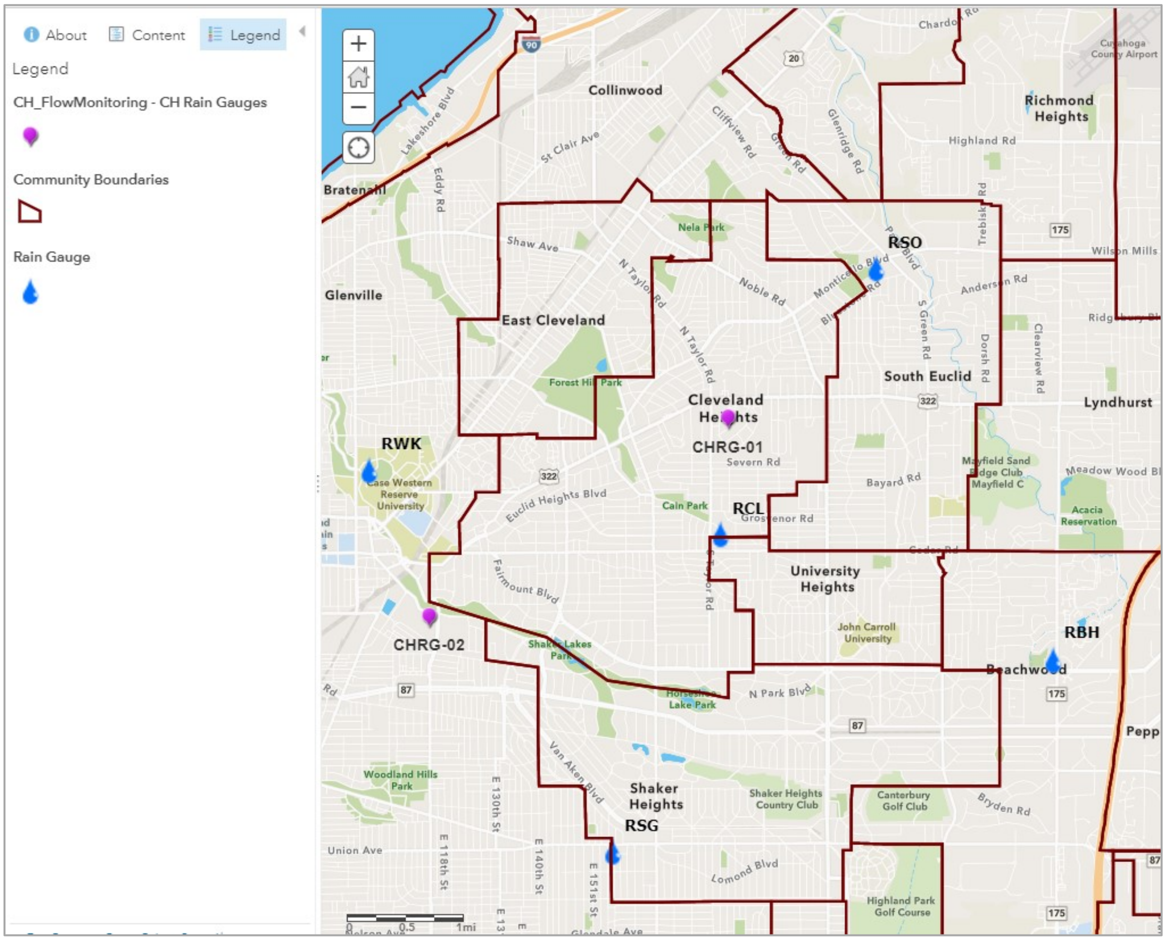


Table 3-1. Rainfall Event Summary

	Temporary Rain Gauge: CHRG-01						Temporary Rain Gauge: CHRG-02						District Rain Gauge: RSO					
Event ID	Start Date	End Date	Duration (hr)	Total Rain (in)	Peak 1-Hr Intensity (in/hr)	Peak 5-min Intensity (in/hr)	Start Date	End Date	Duration (hr)	Total Rain (in)	Peak 1-Hr Intensity (in/hr)	Peak 5-min Intensity (in/hr)	Start Date	End Date	Duration (hr)	Total Rain (in)	Peak 1-Hr Intensity (in/hr)	Peak 5-min Intensity (in/hr)
1	7/16/18 18:20	7/17/18 3:20	9.00	0.06	0.04	0.36	7/16/18 20:20	7/16/18 22:10	1.83	0.07	0.06	0.24	7/16/18 18:25	7/16/18 21:50	3.42	0.04	0.02	0.24
2	7/20/18 13:35	7/20/18 13:45	0.17	0.09	0.09	0.96	No Rainfall Recorded						No Rainfall Recorded					
3	7/22/18 22:20	7/22/18 22:25	0.08	0.02	0.02	0.24	No Rainfall Recorded						7/22/18 22:15	7/23/18 0:05	1.83	0.04	0.03	0.12
4	7/23/18 18:25	7/24/18 3:10	8.75	0.41	0.29	1.44	7/23/18 7:55	7/24/18 3:10	19.25	0.84	0.47	3.12	7/23/18 18:40	7/24/18 18:10	23.50	0.31	0.16	1.20
5	7/24/18 17:55	7/24/18 18:05	0.17	0.05	0.05	0.36	No Rainfall Recorded						No Rainfall Recorded					
6	7/26/18 18:05	7/26/18 21:00	2.92	0.91	0.60	1.56	7/26/18 18:15	7/26/18 20:45	2.50	0.85	0.74	1.44	7/26/18 18:00	7/26/18 23:15	5.25	1.28	0.60	1.80
7	7/28/18 0:15	7/28/18 1:20	1.08	0.31	0.31	0.84	7/27/18 23:10	7/28/18 0:50	1.67	0.58	0.52	1.80	7/27/18 23:15	7/28/18 1:20	2.08	0.21	0.20	0.60
8	7/31/18 12:55	7/31/18 14:10	1.25	0.07	0.06	0.12	7/31/18 12:45	7/31/18 14:00	1.25	0.08	0.07	0.12	7/31/18 12:50	7/31/18 14:15	1.42	0.08	0.06	0.12
9	No Rainfall Recorded						8/5/18 13:35	8/5/18 13:40	0.08	0.01	0.01	0.12	8/3/18 23:00	8/3/18 23:10	0.17	0.02	0.02	0.12
10	8/6/18 16:00	8/8/18 13:40	45.67	1.82	0.88	4.80	8/6/18 13:30	8/8/18 9:25	43.92	1.68	0.87	3.00	8/6/18 16:05	8/7/18 6:30	14.42	1.88	0.89	6.36
11	No Rainfall Recorded						No Rainfall Recorded						8/7/18 19:45	8/8/18 4:00	8.25	0.02	0.01	0.12
12	8/9/18 2:40	8/9/18 2:50	0.17	0.02	0.02	0.12	8/9/18 2:45	8/9/18 4:20	1.58	0.13	0.12	0.96	8/9/18 2:35	8/9/18 3:40	1.08	0.05	0.05	0.36
13	8/14/18 4:40	8/14/18 5:50	1.17	0.09	0.08	0.24	8/14/18 4:35	8/14/18 5:30	0.92	0.06	0.06	0.12	8/14/18 4:25	8/14/18 5:10	0.75	0.06	0.06	0.12
14	No Rainfall Recorded						8/16/18 7:20	8/16/18 7:25	0.08	0.02	0.02	0.24	No Rainfall Recorded					
15	8/17/18 7:55	8/18/18 6:20	22.42	0.07	0.02	0.12	8/17/18 7:45	8/18/18 6:50	23.08	0.13	0.04	0.24	8/17/18 15:05	8/18/18 7:45	16.67	0.07	0.03	0.12
16	8/21/18 2:05	8/21/18 17:10	15.08	1.05	0.42	3.24	8/21/18 2:00	8/21/18 17:00	15.00	1.08	0.54	3.60	8/21/18 2:05	8/21/18 23:50	21.75	1.17	0.40	2.76
17	8/22/18 12:50	8/22/18 14:15	1.42	0.06	0.04	0.24	8/22/18 13:25	8/22/18 14:20	0.92	0.07	0.07	0.24	8/22/18 13:35	8/22/18 15:20	1.75	0.07	0.05	0.12
18	8/29/18 15:25	8/29/18 21:05	5.67	1.22	1.20	3.48	8/29/18 15:25	8/29/18 16:35	1.17	0.85	0.84	2.28	8/29/18 15:25	8/29/18 16:45	1.33	1.30	1.28	2.88
19	9/3/18 21:20	9/3/18 21:30	0.17	0.06	0.06	0.48	9/3/18 21:15	9/3/18 21:40	0.42	0.11	0.11	1.20	9/3/18 21:25	9/4/18 6:10	8.75	0.02	0.01	0.12
20	9/5/18 19:05	9/6/18 9:45	14.67	0.43	0.38	2.16	9/5/18 19:00	9/5/18 20:05	1.08	0.10	0.10	0.24	9/5/18 18:55	9/6/18 9:55	15.00	0.55	0.49	3.24
21	No Rainfall Recorded						9/6/18 8:55	9/6/18 10:25	1.50	0.06	0.05	0.12	No Rainfall Recorded					
22	9/8/18 5:45	9/8/18 6:45	1.00	0.04	0.04	0.12	9/8/18 4:20	9/11/18 11:10	78.83	1.69	0.20	0.48	9/8/18 6:10	9/8/18 6:35	0.42	0.03	0.03	0.12
23	9/9/18 1:35	9/11/18 9:10	55.58	1.92	0.20	0.96	No Rainfall Recorded						9/9/18 1:55	9/11/18 10:50	56.92	2.22	0.24	0.72
24	9/19/18 3:40	9/19/18 3:50	0.17	0.02	0.02	0.12	9/19/18 3:40	9/19/18 4:10	0.50	0.02	0.02	0.12	9/19/18 3:40	9/19/18 4:15	0.58	0.02	0.02	0.12
25	9/21/18 16:30	9/21/18 16:40	0.17	0.08	0.08	0.60	9/21/18 16:25	9/21/18 16:35	0.17	0.04	0.04	0.36	9/21/18 16:25	9/22/18 1:45	9.33	0.15	0.14	1.08
26	9/24/18 17:10	9/25/18 5:00	11.83	0.81	0.25	0.72	9/24/18 16:55	9/25/18 4:55	12.00	0.65	0.22	0.72	9/24/18 17:05	9/25/18 5:15	12.17	0.98	0.29	1.08
27	9/25/18 21:15	9/26/18 11:30	14.25	1.10	0.53	1.20	9/25/18 21:10	9/26/18 7:15	10.08	1.08	0.51	1.44	9/25/18 21:15	9/26/18 11:45	14.50	1.19	0.58	1.08
28	10/2/18 15:20	10/2/18 15:25	0.08	0.01	0.01	0.12	10/2/18 15:10	10/2/18 16:10	1.00	0.14	0.14	0.96	10/2/18 15:00	10/2/18 15:10	0.17	0.02	0.02	0.12
29	10/5/18 14:10	10/5/18 16:20	2.17	0.02	0.01	0.12	10/5/18 14:10	10/5/18 15:50	1.67	0.02	0.01	0.12	10/5/18 14:10	10/5/18 14:50	0.67	0.02	0.02	0.12
30	10/6/18 6:25	10/7/18 6:00	23.58	1.00	0.66	2.28	10/6/18 6:30	10/7/18 6:05	23.58	1.32	1.03	2.40	10/6/18 6:20	10/7/18 7:50	25.50	0.97	0.54	2.28
31	10/12/18 9:05	10/12/18 9:10	0.08	0.01	0.01	0.12	No Rainfall Recorded						No Rainfall Recorded					
32	10/12/18 21:30	10/13/18 13:05	15.58	1.39	0.33	0.36	10/12/18 11:10	10/13/18 11:20	24.17	1.26	0.36	0.60	10/12/18 20:00	10/13/18 12:10	16.17	1.91	0.34	0.72
33	10/15/18 10:55	10/15/18 11:00	0.08	0.01	0.01	0.12	No Rainfall Recorded						10/15/18 6:50	10/15/18 6:55	0.08	0.01	0.01	0.12

*Event with Peak Hourly Rainfall Intensity Less than 0.25 in/hr

Figure 3-4 compares rainfall events recorded during the monitoring period to the 1-Hour and 6-Hour design events (4-Month, 6-Month, 1-Year, 2-Year, and 5-Year). Average rainfall events recorded during the flow monitoring period include rainfall events near the 1-Year, 1-Hour, and 6-Month, 6-Hour design events. **Figure 3-5** shows actual recorded rainfall compared to normal historic average rainfall for the entire flow monitoring period. Total rainfall was above average for the flow monitoring period.

Figure 3-4. Rainfall Comparison Chart

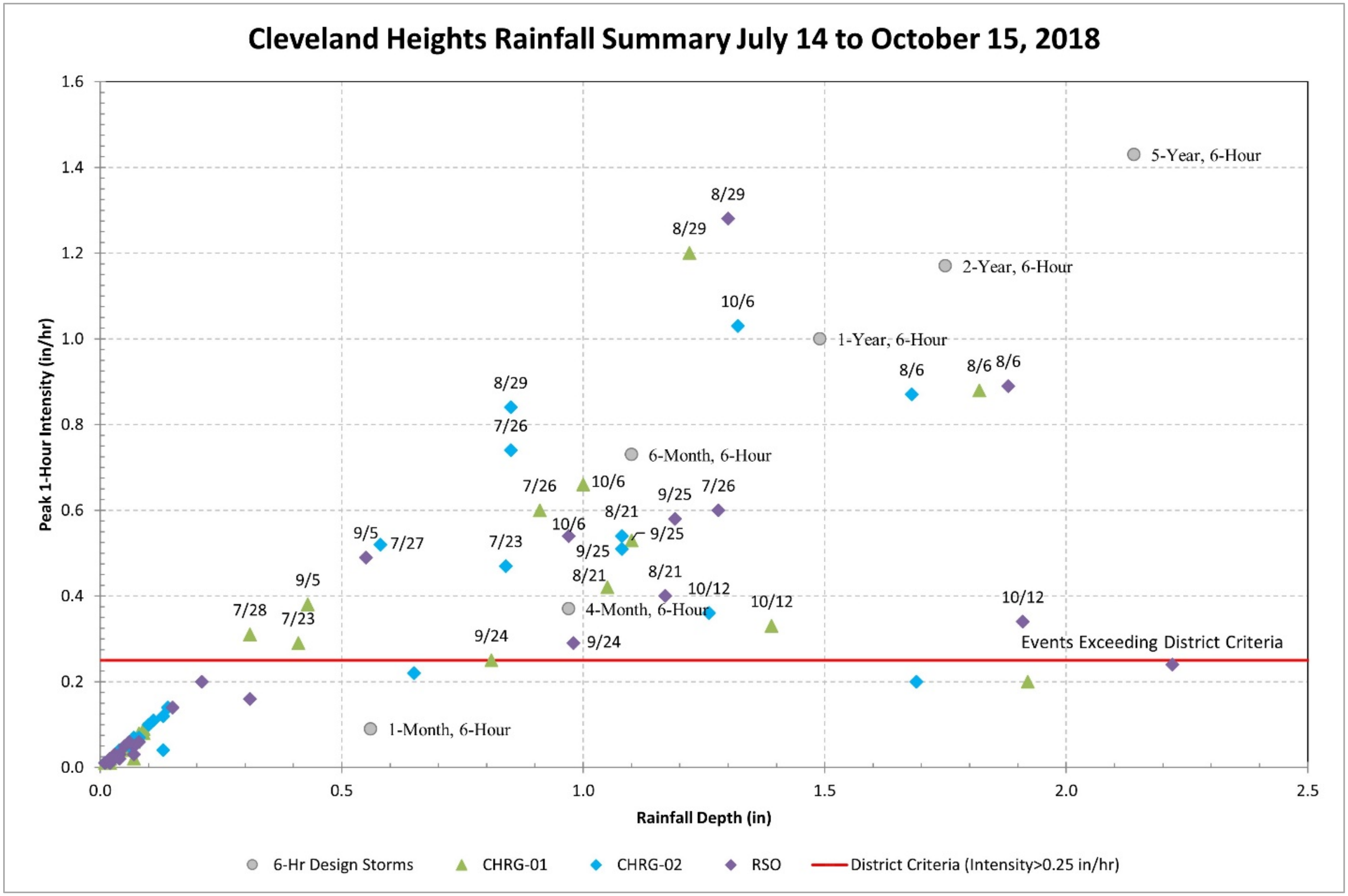
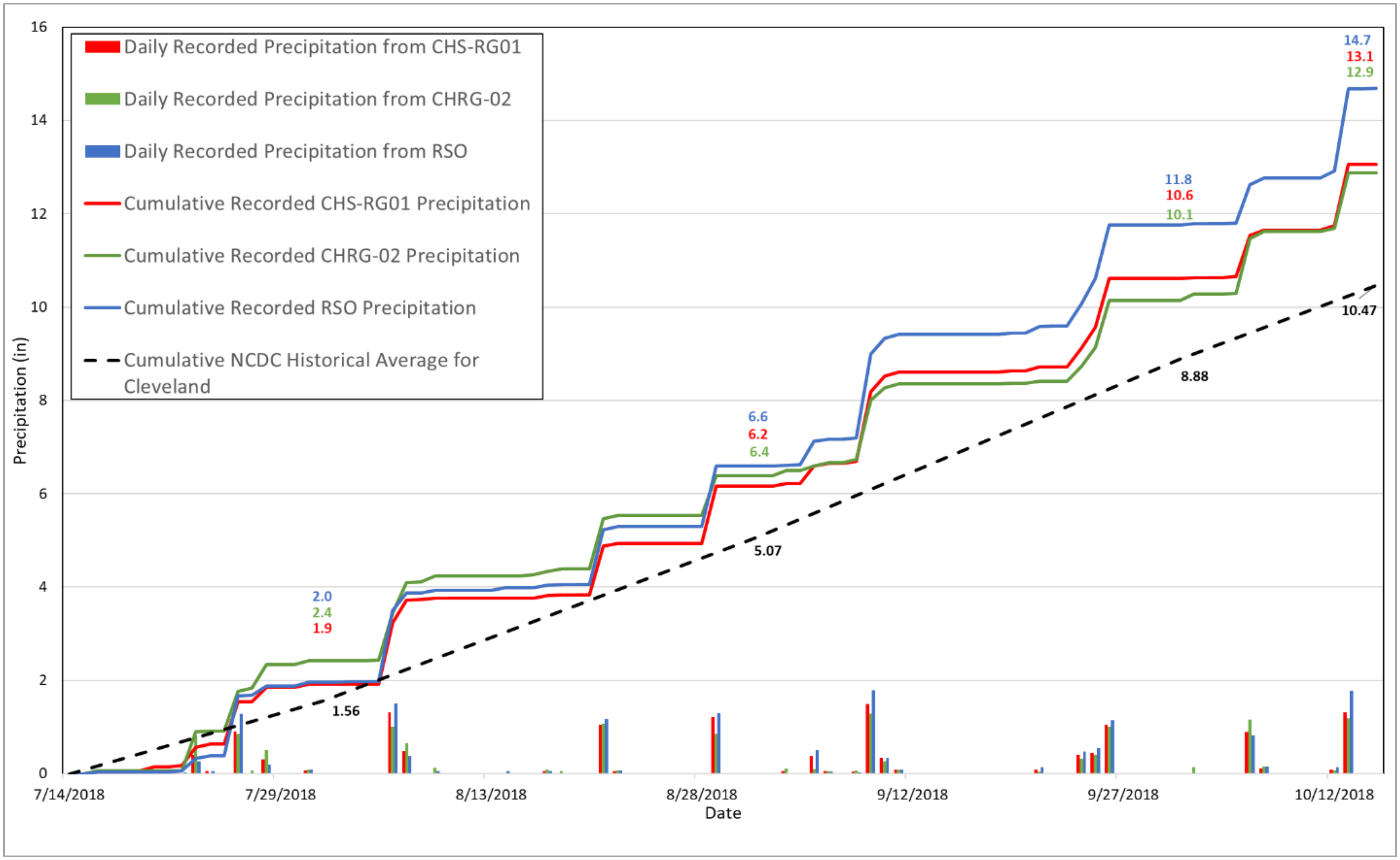


Figure 3-5. Comparison of Recorded Rainfall to Historical Average



4.0 MODEL CALIBRATION

Two flow monitoring data sets were available for model calibration. During the HHI-LSSES project, the Cleveland Heights area was monitored from May through August of 2016, with some monitoring locations continuing into November 2016. **Figure 4-1** shows the location of the 2016 meters and metersheds. The Cleveland Heights CD monitoring program was conducted to refine the HHI-LSSES areas and re-monitor critical locations. Because of the model extension, all HHI-LSSES meter sites were validated and calibration was refined, as necessary. **Appendix 6** contains a schematic of the connectivity of the flow meters between the two monitoring periods.

Model calibration focused on the periods May 1 through September 2016, and July 24 through October 15, 2018. The 2016 meters were installed for varying periods of time. Most 2018 meters were installed for the entire monitoring period. **Figure 4-2** illustrates the directly tributary metersheds for the combination of two monitoring programs. Both figures include small subcatchments in University Heights and Shaker Heights that are tributary to Cleveland Heights local sewers.

This section summarizes the model parameter adjustments performed to meet the targeted calibration guidelines in the District's modeling standards.

Figure 4-1. HHI-LSSES Metersheds

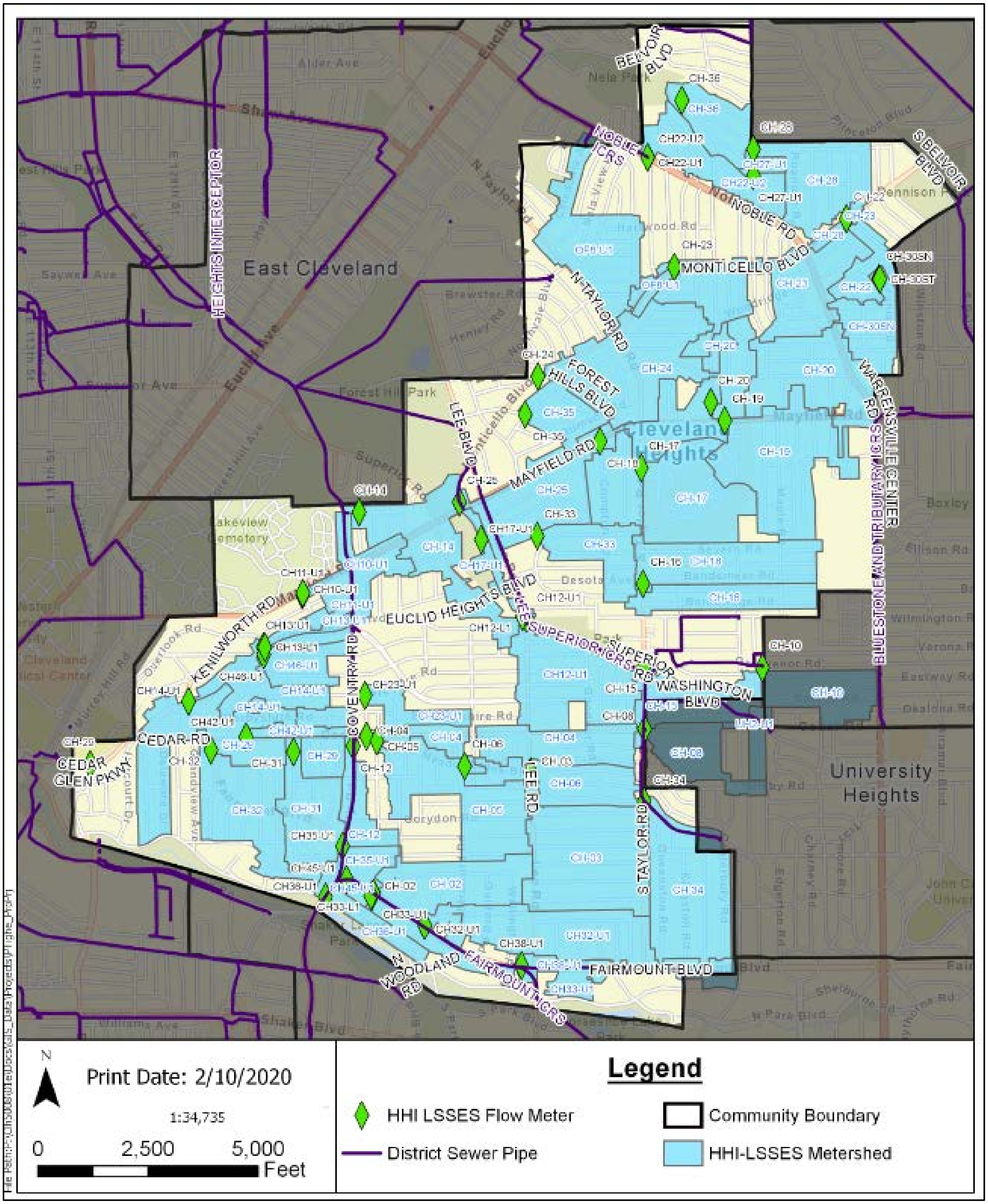
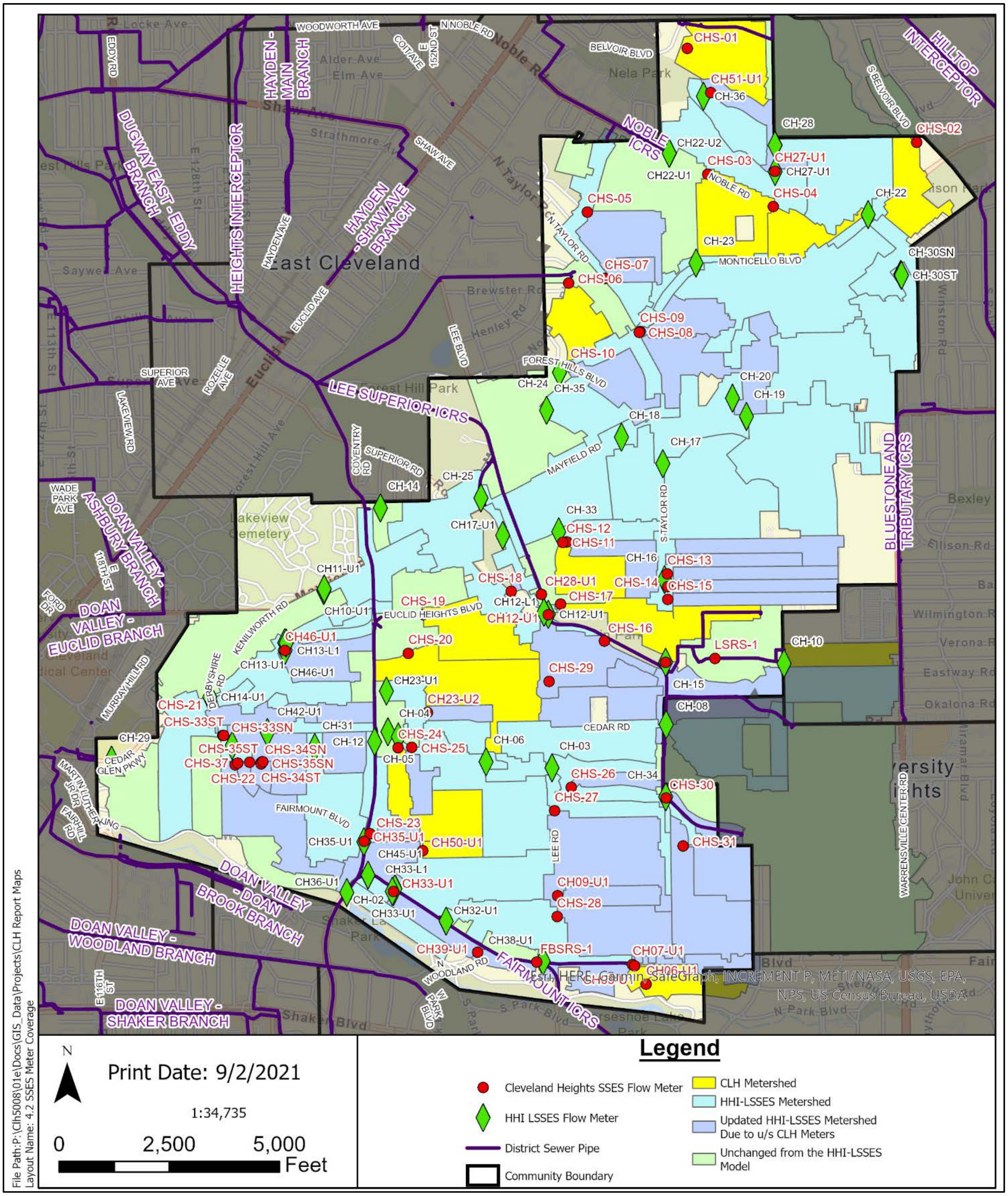


Figure 4-2. Combined HHI-LSSES and CD Calibration Metersheds



4.1 DRY WEATHER FLOW CALIBRATION

InfoWorks ICM dry weather flow (DWF) includes three components: sanitary wastewater flow, trade flow (industrial flow), and baseflow infiltration. Sanitary wastewater and trade flow typically have a daily diurnal pattern that varies from weekday to weekend. The baseflow infiltration may also vary monthly based on varying groundwater levels and antecedent soil moisture.

In the model, DWFs are estimated based on five components: population, wastewater generation rate, trade flow rate, baseflow infiltration rate, and diurnal peaking factors. Calibration of DWF is an iterative process of adjusting these parameters within acceptable ranges until model-estimated and monitored DWF responses agree for the targeted criteria. The following section describes the approach and results of DWF calibration.

4.1.1 Dry Weather Calibration Approach

The DWF calibration began with the upstream meters and proceeded downstream. The DWF calibration was performed to achieve reasonable volume, flow pattern, and depth comparisons with monitored responses. The DWF parameters and calibration approach are described as follows.

Wastewater Generation Rates

This parameter represents the average daily wastewater generation rates per capita. Initial wastewater generation rates from the HHI-LSSES model were used and adjusted, as necessary. Most of the initial rates were determined to be adequate and few adjustments were made as part of the calibration effort.

Diurnal Patterns

This parameter varies the average sanitary wastewater flows throughout the day. The distribution of these diurnal patterns to subcatchments was adjusted as needed during the calibration process to better match the monitored flow. When necessary, new diurnal patterns were created to better match monitored shapes.

Population

Population estimates for subcatchments were adjusted when necessary to generate more sanitary wastewater flows. The population was only adjusted if the wastewater generation rate and diurnal patterns could not be adjusted within reasonable values to match the monitored data. Most of the populations were determined to be adequate and few adjustments were made as part of the HHI-LSSES calibration effort.

Baseflow Infiltration Rate

Initial estimates obtained from the HHI-LSSES model were revised to match the observed monitored DWF values. The total meter baseflow was allocated to upstream tributary subcatchments based on an approximate area weighting.

Monthly or seasonal variations in DWF were not incorporated into the model as sufficient monitoring data was not available to support this level of analysis. This level of refinement to DWF representation was not necessary as this study is primarily focused on peak wet weather flows.

4.1.2 Dry Weather Calibration Periods

The following continuous 7-day periods produced no rainfall at most rain gauges and were used to calibrate the modeled DWF response. Dry weather periods were selected using gauge and radar rainfall data. Radar rainfall data was used for calibration to improve resolution and accuracy. District gauges surrounding Cleveland Heights were also used for the radar rainfall analysis. **Table 4-1** summarizes rainfall recorded during the dry weather flow periods

Table 4-1. Dry Weather Periods Rainfall Summary

	Dry Weather Period Rainfall Amounts, inches				
Rain Gauge	**RCL***	**RSG**	**RSO**	**CHRG-01****	**CHRG-02****
Community	Cle Hts	Shaker Hts	S Euclid	Cle Hts	SW Cle Hts
Dry Weather Fow Period					
2016					
5/22 - 5/28	0.01	0.00	0.00	NA	NA
6/9 - 6/15	0.01	0.01	0.00	NA	NA
8/31 - 9/6	0.00	0.00	0.01	NA	NA
10/5 - 10/11	0.02	0.00	0.07	NA	NA
2018					
7/14 - 7/21	0.06	0.62	0.04	0.02	0.01
8/10 - 8/16	0.06	0.07	0.06	0.00	0.00
9/12 - 9/19	0.00	0.00	0.02	0.00	0.00
9/27 - 10/5	0.35	0.12	0.04	0.00	0.01
*RCL moved slightly east into University Heights prior to 2018 monitoring					
**Gauges CHRG-01 and CHRG-02 were installed for the 2018 monitoring period only					

4.1.3 Dry Weather Calibration Criteria

The following criteria defined in the District's modeling standards were used as a guideline for model calibration:

- Observed versus predicted DWF calibration comparisons should closely follow each other both in shape and magnitude.
- Flow hydrographs should meet the following criteria:
- Timing of the peaks and troughs should be within 1 hour

- Volume of flow should be in the range of ±10%
- Peak flows should be in the range of ±10%
- Depth of flow should be in the range of ±0.33 feet

It was anticipated that many locations would not be able to meet all criteria for the two selected DWF periods based on the following:

- Meter data can be inaccurate during low flow conditions when the meter velocity sensor is not adequately covered by shallow dry weather flows associated with small tributary areas.
- Potential monthly/seasonal variation in baseflow is not currently represented in the model because the impact of this variation is generally not considered significant in this project for analysis of peak wet weather conditions. Subsequent analysis of larger rainfall events and improvement alternatives will consider the potential effects of seasonal variation and antecedent groundwater. Full understanding of these effects typically requires extended flow, rainfall, and groundwater monitoring, and continuous simulation of rainfall and flows, which is beyond the scope of this project. The common trench configuration and existing conditions may tend to make groundwater monitoring and modeling less valuable than in normal sanitary sewer systems because of the excessive water present from the storm sewer system.
- Temporary/infrequent activities (e.g., hydrant flushing, water main breaks, industrial process shutdown, etc.) contribute to unusual and unpredictable DWF responses.

Some of the small upstream subcatchments tended to have low flows which can make flow monitoring difficult, particularly for dry weather flow conditions. This has little impact on the overall project modeling, however, as peak wet weather flows are the focus of the project analysis. The flow monitoring program was extensive and extended into smaller areas than are typically monitored. As a result, the dry weather flows were low in some upstream locations, making that monitoring less reliable. In these cases, downstream flow meters were typically available to use for calibration of dry weather flows in the area.

4.1.4 Dry Weather Calibration Results

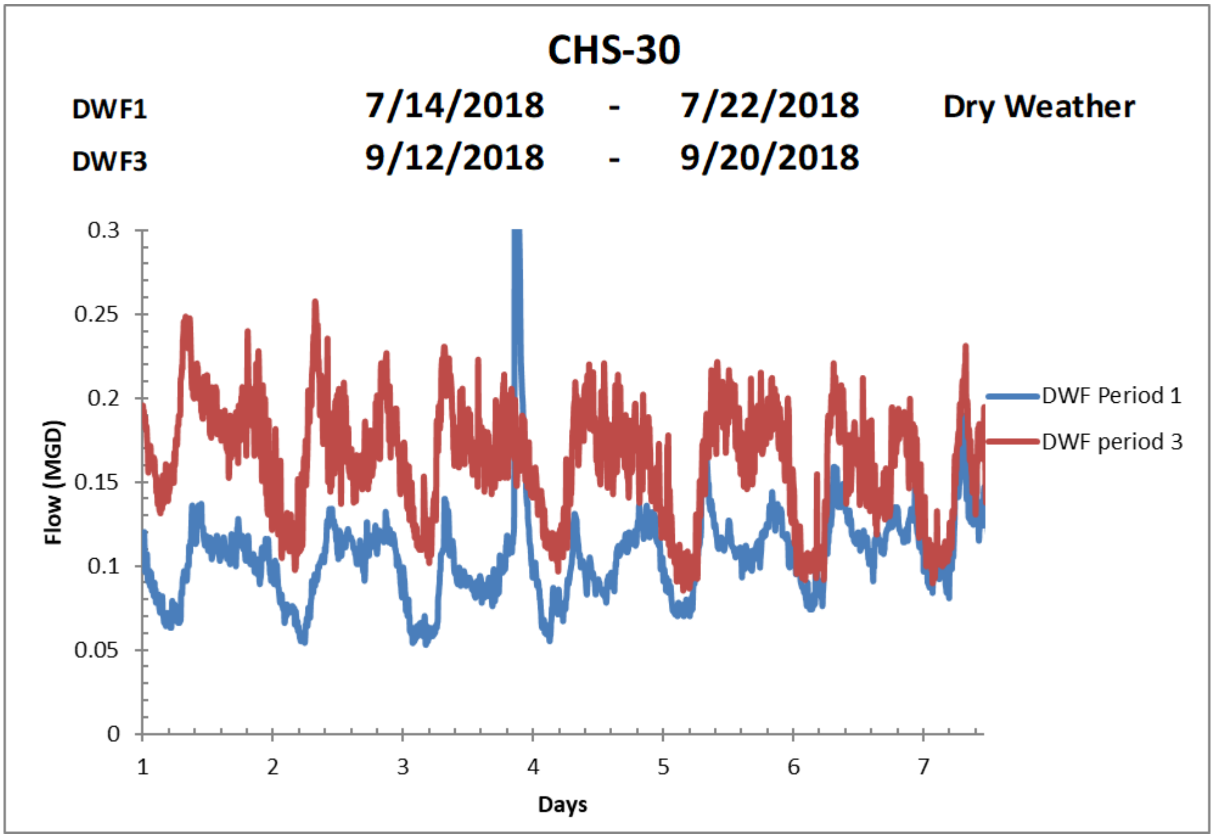
The DWF calibration results meet the objectives of the CD. **Appendix 7** includes meter versus model DWF statistics, plots, and discussion for each calibration flow meter.

Dry weather flow calibration criteria were not met for several meters due to common issues, including the following:

The DWF gradually changed between the monitoring periods as demonstrated in **Figure 4-3.** The increase is likely due to normal seasonal variation of the baseflow groundwater infiltration.

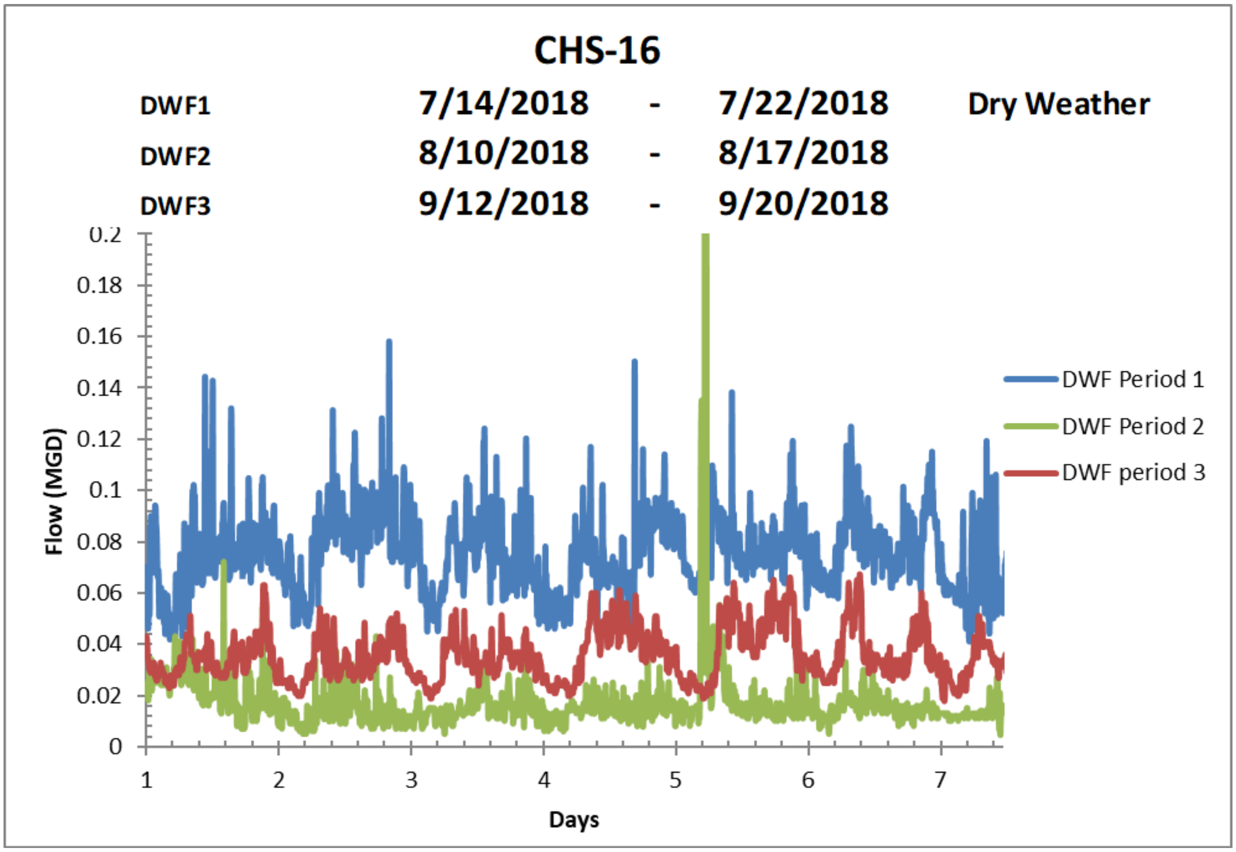
The comparison of volume shows the accuracy of the average DWF. When possible, the DWF was calibrated to match all DWF periods. However, when a balance could not be achieved while keeping both periods within the ±10% target, the model was calibrated to the highest DWF period.

Figure 4-3: Example Monthly DWF Difference



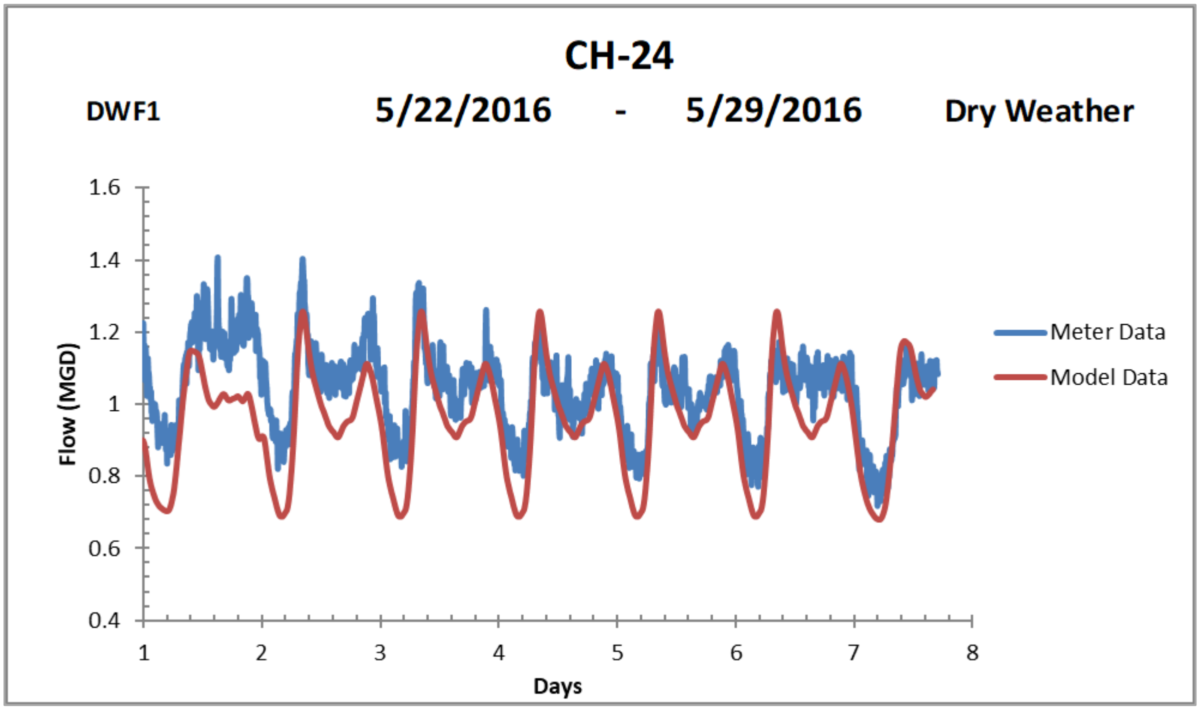
In many cases, the DWF varied month to month in an atypical manner. For example, in some cases the highest DWF was recorded in July. **Figure 4-4** shows an example of such a situation. The variation was likely due to low DWF rates and small tributary areas. Engineering judgement was used to determine which DWF periods were prioritized for calibration on a case-by-case basis.

Figure 4-4. DWF Atypical Variation Example



Long-term DWF recession was observed during some DWF periods as shown in **Figure 4-5**. The model was calibrated to the end of the period. As a result, the peak flows and volume were underestimated for some sites since the model typically did not focus on the long recession. The differences in flow are relatively small compared to the wet weather response.

Figure 4-5. DWF Period 1 Recession Example



During lower flows/depths, velocity readings commonly experience fluctuations and random spikes as shown in **Figures 4-6** and **4-7**. The model was calibrated to the middle of these fluctuations and the random spikes were ignored.

Figure 4-6. Random Spike During DWF Example

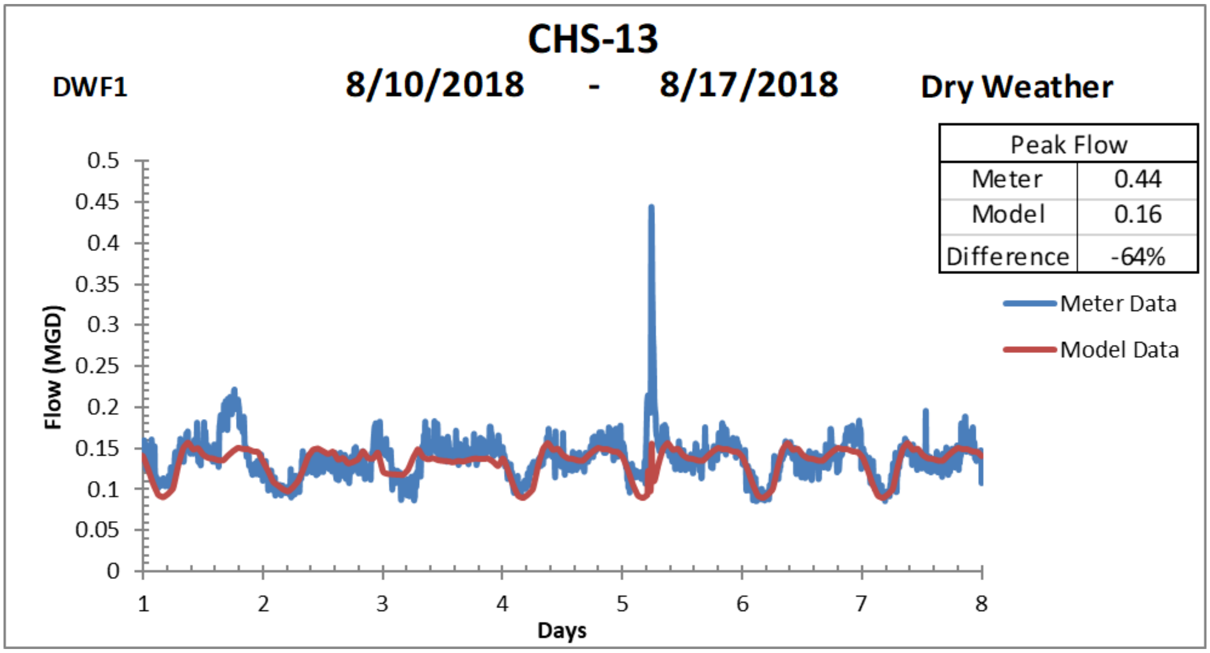
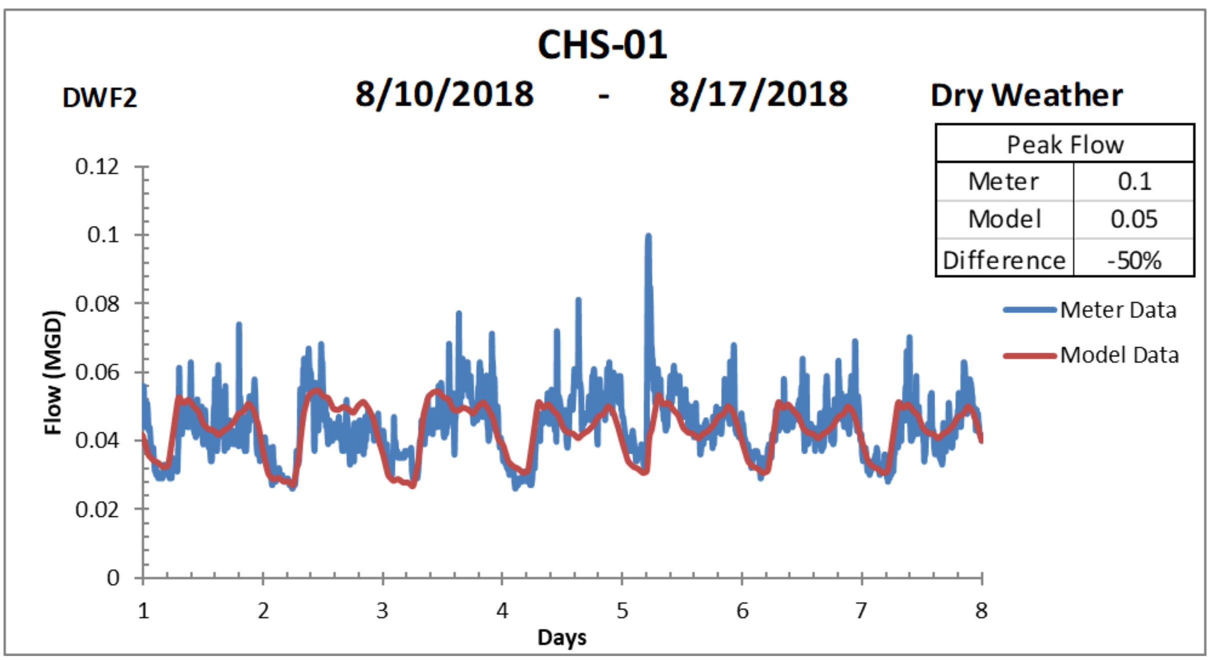


Figure 4-7. Regular Fluctuations During DWF Example



4.2 WET WEATHER FLOW CALIBRATION

Model calibration of wet weather flow (WWF) was performed using a continuous simulation which accounts for dry and wet antecedent soil moisture conditions instead of assuming one or the other with discreet event simulations. **Section 4.2.2** discusses the rainfall events selected for calibration. The goal was to sufficiently match peak flow rates, volumes, and peak depths for all events at each meter. This section summarizes the WWF calibration approach, criteria, and results.

4.2.1 Wet Weather Calibration Approach

Hydrologic and hydraulic parameters were adjusted in the project model to match monitored hydrograph shape and magnitude, including the peak flow rate, volume, and peak depth. Calibration results were compared with the targeted criteria provided in the District's modeling standards. The WWF calibration began with the upstream meters and proceeded downstream.

Runoff Methodology

The model includes areas from two different District models, the Easterly/Doan Valley Interceptor (DVI) and HHI-OEP models. The HHI portion of the model uses the Wallingford hydrology method because the original HHI-OEP model was developed using this approach. The Easterly model area west of Coventry Road uses the RTK method. The HHI-LSSES maintained these methods. Updating the model to use only one or the other method would have required significant effort with little added benefit. Therefore, these same methods were retained for the Cleveland Heights model. Additionally, by maintaining the hydrology methods, the Cleveland Heights updated CD model can be incorporated into the District master models.

The Delamere Drive area modeling included both the storm and sanitary sewers to develop improvement alternatives and design details. The Delamere area used a combination of RTK and directly connected impervious area (DCIA) methods (SWMM method). Duplicate subcatchments were made for each delineated area: a sanitary and a storm. The sanitary subcatchments were assigned the DWF values and used the RTK method to represent sanitary I/I flows. The stormwater subcatchments included runoff values only and used the DCIA (SWMM) method. Monitoring was completed in the Delamere storm and sanitary sewers to calibrate the models in these areas.

Figure 4-8 and **Table 4-2** summarize the portions of the model that use each method and the associated flow meter locations.

Figure 4-8. Hydrologic Methodology Map with Flow Meter Locations

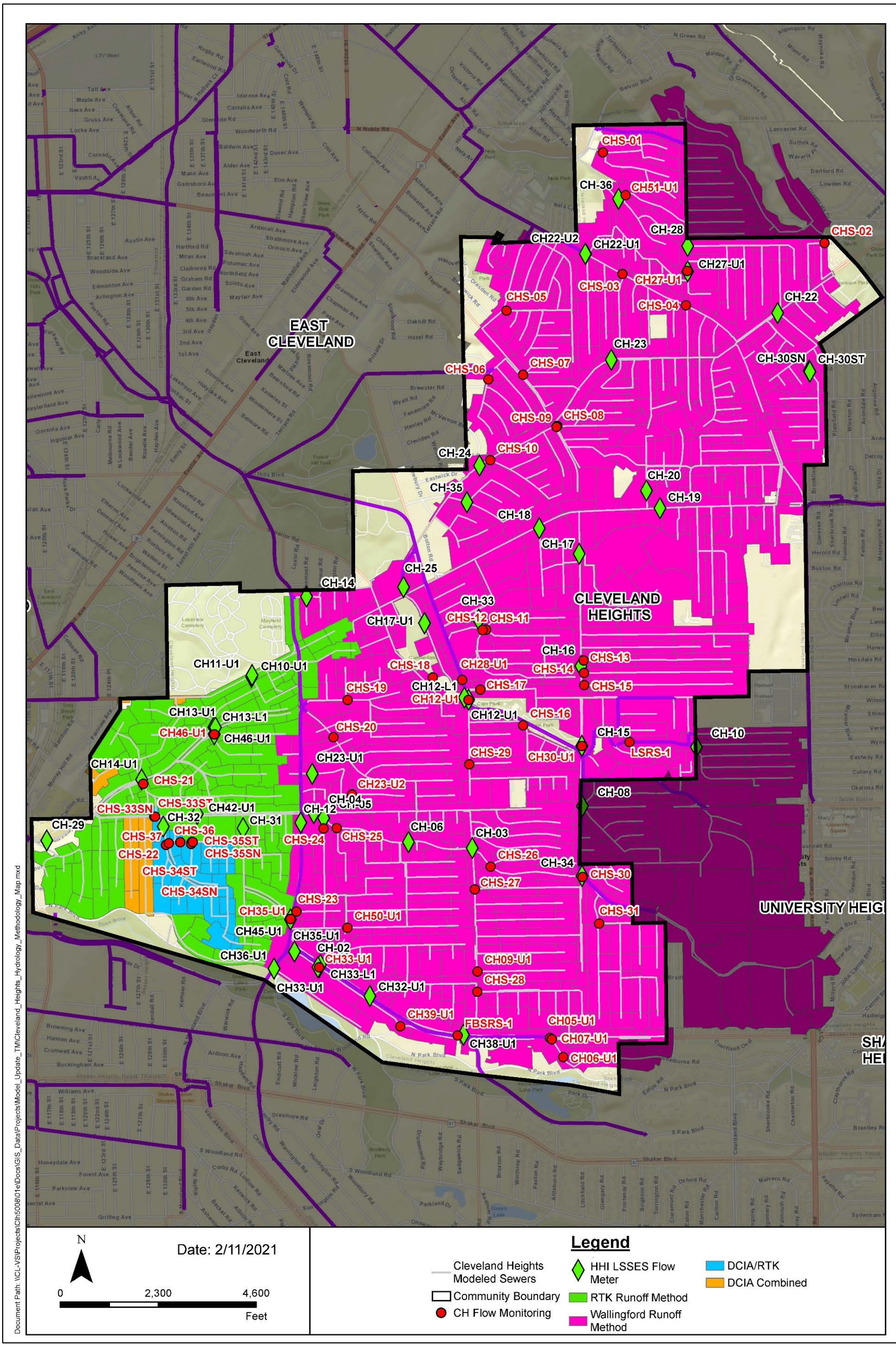


Table 4-2. Hydrologic Methodology Map with Flow Meter Locations

Flow Meter	Monitoring Project	Hydrology Type
CH-32	HHI	DCIA/RTK
CHS-22	CLH	DCIA/RTK
CHS-33SN	CLH	DCIA/RTK
CHS-33ST	CLH	DCIA/RTK
CHS-34SN	CLH	DCIA/RTK
CHS-34ST	CLH	DCIA/RTK
CHS-35SN	CLH	DCIA/RTK
CHS-35ST	CLH	DCIA/RTK
CHS-36	CLH	DCIA/RTK
CHS-37	CLH	DCIA/RTK
CH10-U1	HHI	RTK Runoff Method
CH11-U1	HHI	RTK Runoff Method
CH13-U1	HHI	RTK Runoff Method
CH14-U1	HHI	RTK Runoff Method
CH42-U1	HHI	RTK Runoff Method
CH-29	HHI	RTK Runoff Method
CH-31	HHI	RTK Runoff Method
CHS-21	CLH	RTK Runoff Method
CH05-U1	CLH	Wallingford Runoff Method
CH06-U1	CLH	Wallingford Runoff Method
CH07-U1	CLH	Wallingford Runoff Method
CH09-U1	CLH	Wallingford Runoff Method
CH12-U1	Both	Wallingford Runoff Method
CH-15/CH30-U1	Both	Wallingford Runoff Method
CH17-U1	HHI	Wallingford Runoff Method
CH22-U1	HHI	Wallingford Runoff Method
CH22-U2	HHI	Wallingford Runoff Method
CH23-U1	HHI	Wallingford Runoff Method
CH27-U1	Both	Wallingford Runoff Method
CH32-U1	HHI	Wallingford Runoff Method
CH33-U1	Both	Wallingford Runoff Method
CH39-U1	CLH	Wallingford Runoff Method
CH50-U1	CLH	Wallingford Runoff Method
CH51-U1	CLH	Wallingford Runoff Method
CH-02	HHI	Wallingford Runoff Method
CH-03	HHI	Wallingford Runoff Method
CH-04	HHI	Wallingford Runoff Method
CH-05	HHI	Wallingford Runoff Method
CH-06	HHI	Wallingford Runoff Method
CH-08	HHI	Wallingford Runoff Method
CH-10	HHI	Wallingford Runoff Method
CH-14	HHI	Wallingford Runoff Method
CH-18	HHI	Wallingford Runoff Method
CH-19	HHI	Wallingford Runoff Method
CH-20	HHI	Wallingford Runoff Method
CH-23	HHI	Wallingford Runoff Method
CH-24	HHI	Wallingford Runoff Method
CH-25	HHI	Wallingford Runoff Method
CH-30SN	HHI	Wallingford Runoff Method
CH-33	HHI	Wallingford Runoff Method
CH-34	HHI	Wallingford Runoff Method
CH-35	HHI	Wallingford Runoff Method
CH-36	HHI	Wallingford Runoff Method
CH36-U1	HHI	Wallingford Runoff Method
CHS-01	CLH	Wallingford Runoff Method
CHS-02	CLH	Wallingford Runoff Method
CHS-03	CLH	Wallingford Runoff Method
CHS-04	CLH	Wallingford Runoff Method
CHS-06	CLH	Wallingford Runoff Method
CHS-08	CLH	Wallingford Runoff Method
CHS-09	CLH	Wallingford Runoff Method
CHS-10	CLH	Wallingford Runoff Method
CHS-11	CLH	Wallingford Runoff Method
CHS-12	CLH	Wallingford Runoff Method
CHS-13	CLH	Wallingford Runoff Method
CHS-14	CLH	Wallingford Runoff Method
CHS-15	CLH	Wallingford Runoff Method
CHS-17	CLH	Wallingford Runoff Method
CHS-18	CLH	Wallingford Runoff Method
CHS-19	CLH	Wallingford Runoff Method
CHS-20	CLH	Wallingford Runoff Method
CHS-23	CLH	Wallingford Runoff Method
CHS-24	CLH	Wallingford Runoff Method
CHS-25	CLH	Wallingford Runoff Method
CHS-26	CLH	Wallingford Runoff Method
CHS-27	CLH	Wallingford Runoff Method
CHS-28	CLH	Wallingford Runoff Method
CHS-29	CLH	Wallingford Runoff Method
CHS-30	CLH	Wallingford Runoff Method
CHS-31	CLH	Wallingford Runoff Method
FBSRS-1	CLH	Wallingford Runoff Method
LSRS-1	CLH	Wallingford Runoff Method
OF8-U1	HHI	Wallingford Runoff Method

Wallingford Method

The Wallingford routing method was used in the original HHI-OEP model and retained in the subsequent HHI-LSSES model. The method routes flow through two equal linear reservoirs in series to create a hydrograph. The hydrograph shape is controlled by rainfall intensity, contributing area, surface slope, and runoff routing value. The rainfall, contributing area, and surface slope were treated as fixed values. A series of hydrographs was used to replicate the system response.

Two methods were used to determine runoff volume in conjunction with the Wallingford routing: Fixed Percent Runoff (PR) and NewUK. Fixed PR was used for the faster response, impervious area. NewUK was used for the slower response, pervious area. The Fixed PR method determines runoff volume by assuming a fixed percentage of runoff after initial losses. The NewUK method determines runoff volume by calculating the infiltration capacity of the soil based on the previous 30 days of rainfall.

A set of runoff surfaces was used to replicate the system response. **Table 4-3** summarizes the normal breakdown of runoff surfaces. Not all runoff surfaces were used for every meter while some used additional surfaces as needed.

Table 4-3. Typical Runoff Surface Breakdown

Runoff Surface	Representative Response	Typical Routing Value	Runoff Volume Method	Initial Loss Value (in)	NewUK Depth (ft)
1	Very Fast Response	1	Fixed PR	0.04	
2	Fast Response	10	Fixed PR	0.04	
3	Medium Response	75	Fixed PR	0.04	
4	Miscellaneous surface. Typically used for either an additional curve to fill out the shape or as extra fast response for larger events.	1 – 125	Fixed PR	0.04 – 1.0	
5	Slow Response	125 – 300	NewUK		0.3
6	Very Slow Response	300 – 1000	NewUK		0.164-0.328

The following WWF parameters were adjusted in the calibration approach:

- Runoff Area Percentage: This parameter affects primarily the peak and volume of runoff generated. The model uses a series of runoff surfaces to replicate the system response. The value controls the portion of the rainfall routed to each surface (or area).

- Runoff Routing Value: This parameter affects primarily the shape of the wet weather response. The larger the routing value, the longer and less pronounced the response. Typical values for the short, medium, and long-term responses were 1-20, 50-75, and 125-1000, respectively.
- Initial Loss Value: This parameter affects small to moderate events. The value typically represents the depression storage available on the surface. The value was typically equivalent to 0.04-0.1 inches. For some areas, the value was used to represent additional short-term response during larger events. For those areas, runoff surface was added with a short routing value and a loss typically equivalent to 0.5-1.0 inches.
- NewUK Depth: This parameter affects the amount of response from pervious areas. The value represents the moisture depth parameter, which controls when runoff begins and the runoff volume. A depth of 0.164 to 0.328 feet was typical.

RTK Method

The RTK method was used for the Easterly model and is the preferred method based on the District's standards used to simulate the Rainfall Dependent Inflow and Infiltration (or RDII) response. The RTK method generates a hydrograph based on a set of three triangles (unit hydrographs), which represent the short, medium, and long-term rainfall responses. The triangles are defined by three parameters:

- R: area under the wet-weather flow component of the system hydrograph, which represents the proportion of rainfall that enters the system
- T: time to peak from start of rainfall
- K: ratio of the time to recession to the time to peak

Figures 4-9 and **4-10** illustrate the RTK method. The major limitation of the RTK method in InfoWorks ICM is the lack of an initial abstraction parameter, which is part of the reason for not calibrating the HHI model portion of the model with this method.

In addition to the RTK method, the Wallingford method with NewUK was used to simulate the slow response, carried over from the HHI-LSSES model.

Figure 4-9. RTK Parameters

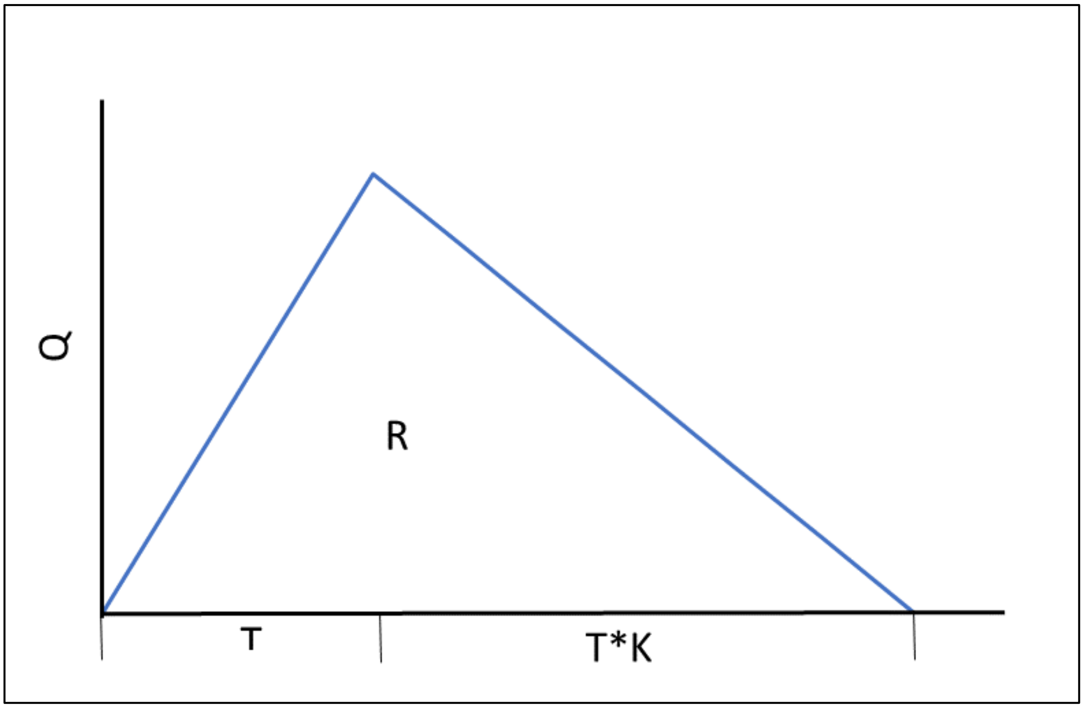
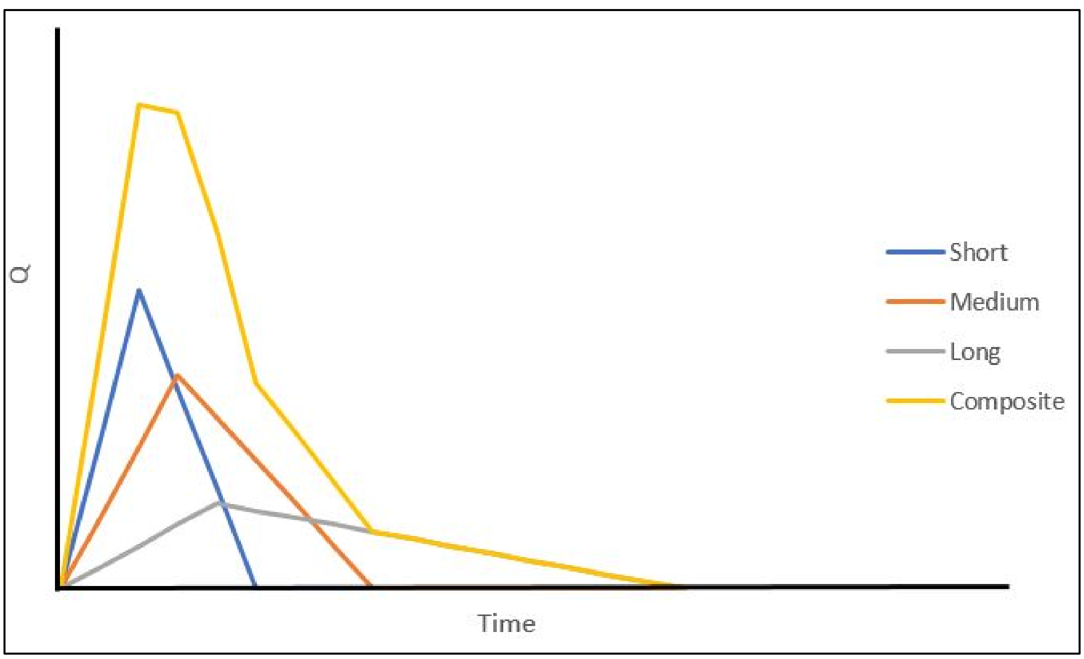


Figure 4-10. RTK Unit Hydrograph



DCIA (Directly Connected Impervious Area)

Directly connected impervious area methodology was used for the stormwater subcatchments in the Delamere area, which is typical for combined sewer areas per District standards. The DCIA uses a series of runoff surfaces to simulate the tributary area runoff from both pervious and impervious surfaces using the SWMM routing method. Pervious area infiltration was simulated using the Horton Method from SWMM. WWF parameters adjusted in the calibration approach include the following:

- Directly Connected Impervious Area (DCIA): This parameter affects primarily the peak and volume of runoff generated. This is represented in the model as Runoff Surfaces 1 and 2, which represent the two types of impervious areas (with and without depression storage, respectively). Runoff surface 3, which represents the pervious area, was adjusted accordingly so the total percent area between the three surfaces equaled 100. Percent impervious was adjusted along with subcatchment width to match the magnitude and timing of peak flow and volume and shape of wet weather response over a range of rainfall events. During smaller events, no runoff is typically calculated from pervious areas.
- Catchment Slope: This parameter affects primarily the shape of wet weather response. The slope was estimated using county GIS elevation contours.
- Dimension (Catchment Width): This parameter affects primarily the shape of wet weather response. Therefore, catchment widths were adjusted to match the timing of the hydrograph peaks.
- Soil Infiltration Parameters: These parameters affect the wet weather response from pervious areas (i.e., Runoff Surface 3). The SWMM-Horton parameters were adjusted based on larger rainfall events.
- Subcatchment Manning's Roughness: This parameter is used in the runoff routing over the subcatchment surface prior to entering the hydraulic model representation. The roughness was adjusted as necessary to change the rate of runoff to match the model timing for large rainfall events.

Runoff Approach

Calibration I/I parameters were typically uniformly applied among the direct tributary areas. In select cases, an uneven distribution of parameters was applied. Two common cases are described in the following sections. When available, micrometer data was used to refine the model calibration. The I/I parameters were varied by micrometer tributary area when indicated by flow data.

Several metersheds contained a combination of common trench and separate trench sewers. The separate trench sewers were typically downstream of the common trench sewers and at the flow monitoring locations. Previous projects have found that separate trench sewers produce significantly less I/I than common trench sewers. The common trench sewer response often creates a unique hydrograph shape. Because of the differences between the two system types, equal distribution of parameters often resulted in a poor match for the hydrograph shape. Therefore, the parameters were varied to provide a better match of hydrograph shape and more realistic representation of I/I sources. The separate trench subcatchments runoff was checked against the separate trench runoff calibrated during the HHI-LSSES project, to ensure that reasonable values were calibrated, and the separate trench contribution was not underestimated.

Hydraulics Approach

Pipe roughness and head losses were adjusted within accepted ranges to calibrate the model water depths to monitored values. Depths for each meter were calibrated to match the velocity versus depth scatterplots. Sites near regulators/flow dividers were especially important since depths determine the amount of flow going to the dry weather outlet (DWO) and stormwater outlet (SWO) pipes. Roughness changes were applied to all pipes upstream and downstream of the meter site of the same size and shape, except when the scatterplot indicated otherwise. It was assumed that pipes of the same size, in the same area, installed at or around the same time would have similar roughness. Some exceptions to this rule were applied. The following sections explain several common hydraulic strategies used in the model.

Diversion Structures

At some diversion structures, the system representation was changed to better match meter flows and depths when minor losses and roughness adjustments alone did not match depths well. The alternative approaches included adding sediment in a link element or adjusting pipe inverts. These changes at diversion structures could suggest that an obstruction is present downstream of the meter. These were checked and confirmed in the field where feasible, but some could not be confirmed in the field.

System Flow Restrictions

At several locations throughout the system, the meter data suggested the existence of sewer restrictions, such as sediment, roots, debris, etc. These locations were investigated in the field to verify any restrictions. The flow restrictions were added to the model, represented as link sediment or an orifice or sluice element, to best match the depths and flows. The flow meter schematic in **Appendix 6** includes locations of system flow restrictions modeled.

Common Trench Sewers and Flow Limit Model Elements

Common trench sewer configurations presented unique system responses. The flow monitoring indicated cross-filtration flows can pass between the storm and sanitary sewers in many locations during wet weather. Dyed water testing and field investigations found that this cross-filtration occurs at missing/displaced invert plates, leaky mainline joints, and lateral connections.

In many common trench sewers, the meter data showed that the sanitary pipe is filled and operating in a backwater condition for most moderate sized rainfall events. Once the sanitary sewer is full, little additional stormwater can enter the sewer as the HGL in the storm and sanitary sewers equalizes. Further flow increases are then conveyed in the storm sewer until that capacity is exceeded. It is also likely, and has been observed by others in selected projects, that the trench volume surrounding the sewers can also fill with water and function as a temporary inline storage volume. As discussed in **Section 2.2**, a coupled modeling pilot effort was completed under the HHI-LSSES project to attempt development of an integrated sanitary and storm sewer model for two common trench subareas. This concluded that development of an integrated storm sewer and sanitary sewer model in common trench areas is infeasible for the greater Cleveland Heights area and would be of limited use because potential improvements would significantly change the existing conditions model.

As mentioned in the report **Section 2.2 Common Trench Sewer System Model Elements**, the common trench sewers were found to have innumerable small and randomly distributed sources of I/I, both in mainline sewers and at points of service lateral connections. This made it impossible to model the numerous interconnections discretely, as it was not feasible to accurately locate and quantify the I/I sources. This also indicated that the improved system conditions could not be represented by “removing” the discreet sources for the same reason. The flow limit elements were an approximation used in locations where needed, and the modeling approach produced relatively good calibration results for the existing system to allow approximation of existing system performance and identification of SSO activity and projected basement backups (BBUs). The flow limit elements also allow for the estimate of system responses to upstream and downstream improvement. For example, if downstream capacity is increased, the upstream sewer may allow additional flow into the system. If half an upstream sewer is rehabbed, the non-rehabbed portion may allow twice as much flow in the system. The flow limit elements provide a simplified estimate of these interactions.

Detailed modeling of the storm sewer and trench rather than using the flow limit elements may produce slightly more refined results but would not improve the system understanding or improvement recommendations because it would still be an assumed interaction. This more complicated method was attempted early in the HHI-LSSES project and was abandoned due to complexity and erratic and unreliable results, as well as the unavailability of specific I/I sources. It would also require significantly more flow monitoring throughout the storm sewer system, as well as ambient trench water level monitoring and significant related cost, for little if any defined benefit.

Post-Rehabilitation Peak Runoff Assumptions

Instead of trying to identify and quantify the discrete I/I sources to be removed in the improved conditions model (e.g., where sewer system and/or I/I rehab is proposed), targeted flow monitoring was used in areas where rehab improvements had been made to define per acre peak flows that could be assumed for the improved and unimproved areas of the system. This proved to be of limited success, as the project rehab improvement details were not well documented, there was little pre-construction monitoring data available, and resulting performance levels were inconsistent.

A variation of this approach analyzed flow monitoring data from common trench and separate trench areas of various age ranges and percentages of each trench type to define reasonable assumptions for improved and unimproved common and separate trench systems. This analysis reviewed flow monitoring data from the HHI-LSSES sewer systems with varying age and percentages of separate/common trench configurations to better understand the range of existing peak flows for these varying parameters. The next step was to estimate what flows could be expected in these systems if proposed system rehabilitation improvements could improve high flow areas to the average or typical response for the system type. This was viewed as a conservative assumption (i.e. actual results would tend to be better than this), in that the proposed sewer system rehabilitation and replacement projects address both the public sanitary sewer system and private property service leads within the ROW.

Based on the analysis and on the broader calibration monitoring and micromonitoring completed for the project, the following peak runoff assumptions were developed to simulate the system improvements and resulting performance in the system for the 5-year design rainfall:

- Existing separate trench sewers in primarily common trench areas generate an existing peak flow response of 20,000 GPAD.
- Common trench rehabilitation and/or separation in the public right-of-way (ROW) reduces peak flows to 35,000 GPAD. For example, in an area with 100% common trench sewers that have been completely rehabilitated within the ROW, the peak flow rate is reduced to 35,000 GPAD.
- In areas with mixed common and separate trench sewers, the peak flow rate is reduced based on trench type percentages. For example, after rehabilitation in the public ROW, an area with 70% separate trench (assumed response of 20,000 GPAD) and 30% common trench (assumed response of 35,000 GPAD) would have a remaining peak flow of 24,500 GPAD. Conversely, an area with 30% separate trench and 70% common trench would have a remaining peak flow of 30,500 GPAD.
- Common trench areas with private property I/I remediation in addition to public system rehabilitation, or private property remediation in separate trench areas would reduce peak flows to 10,000 GPAD. The private property response rates did not need to vary between separate and common trench types since the value applied to both.

The following **Figure 4-11** and **Table 4-4** summarize the hydrologic responses assumed for modeling of common trench and private I/I remediation based on monitoring of several completed projects in the HHI study area. In the InfoWorks model, hydrologic runoff parameters were adjusted to achieve the target runoff values summarized in the preceding list. Only the parameters impacting flow magnitude were adjusted so the shape of the runoff hydrograph was maintained. The changes were typically only applied to the shorter-term runoff parameters, impacting the peak of the event and not the long-term infiltration.

Figure 4-11. Hydrologic Responses Assumed for Modeling of HHI Proposed Improvements

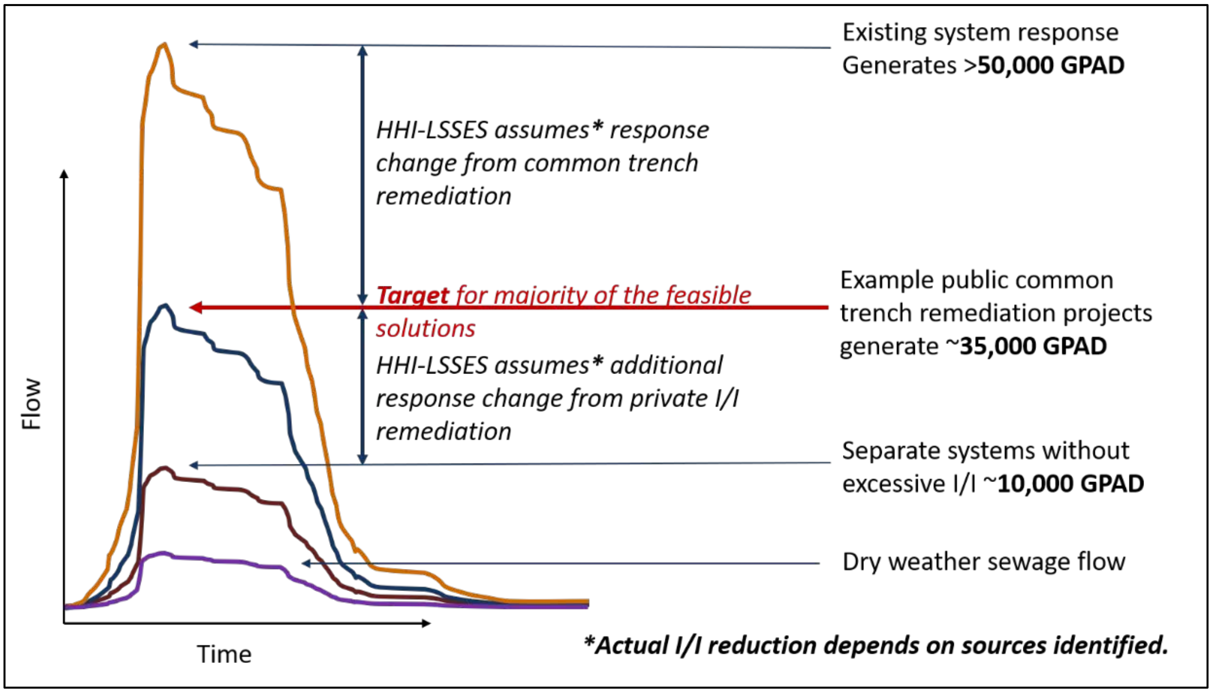


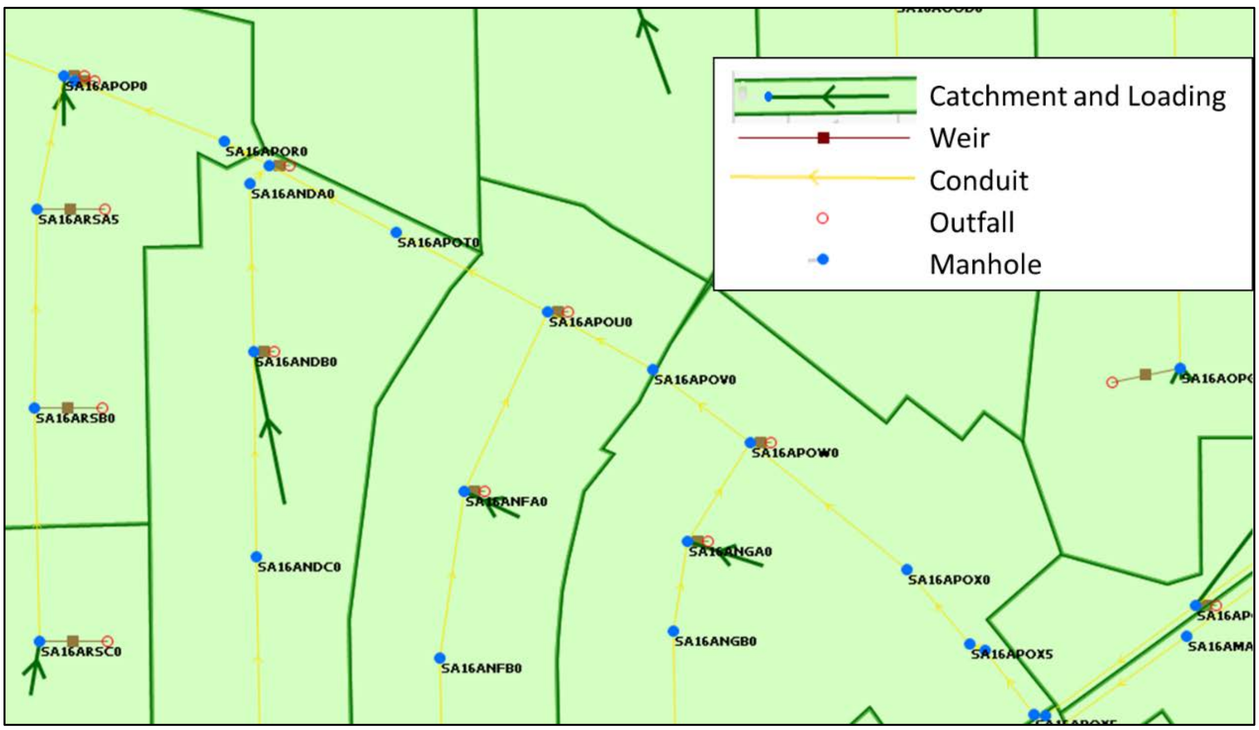
Table 4-4. Modeling Assumptions for Sewer System Improvements

System Condition	Common Trench Flow Response, GPAD	Separate Trench Flow Response in CT Areas, GPAD	Notes
Existing	Variable to over 500,000	20,000	Based on calibration flow monitoring
CT sewer rehabilitation or separation	35,000	20,000	Modeled catchment area weighted by trench type
Private Property I/I Remediation	10,000	10,000	Modeled catchment area weighted by trench type

Flow limit model elements were primarily used to assist in calibration of the leaky common trench sewer areas. The hydrology was first calibrated to smaller rainfalls (typically less than 0.3 inches) to establish the shape and magnitude of stormwater runoff and/or infiltration. Weirs discharging to outfalls were then added to selected nodes in the system to reflect the common trench characteristic of filling the sanitary sewer, and then the storm sewer as the HGL rises during larger rainfalls. The weir "flow limit" inverts were set to the approximate middle of the storm pipe (invert plus half the diameter). The middle of the storm pipe was approximated from record drawings when available or estimated based on typical manhole type configuration. The sewer roughness values and weir invert elevations were then adjusted as needed to match the flow cutoff rates and depths. The medium and long-term hydrology terms were adjusted based on moderate to large rainfall events (typically more than 0.5 inches).

Figure 4-12 shows an example of a modeled area with this flow limit method for representing the common trench system. **Figure 4-13** compares model and meter results using meter CHS-04 as examples to show different ideas. The figure shows flow hydrographs for the small event used for initial calibration on the wet weather flow parameter, and the larger event with the hydrograph limited by the sanitary sewer capacity. The depth vs. time graph also shows that while the surcharge depths are close, the model does not replicate the full range of depth, rather depth jumps to the weir height and is controlled at this level. **Figure 4-14** shows the locations of the modeled infiltration limit elements in the common trench areas. The flow meter schematic in **Appendix 6** includes locations of flow limit model elements.

Figure 4-12. Example Model Area with Weir/Orifice Flow Limits in Common Trench System



This method provides a simple representation of the flow transfer between the two systems that allows approximation of the existing system performance, but likely does not completely reflect the storm sewer/common trench system HGL. A potential result of this method is that the HGL in areas with the flow limits may be underestimated by constraining the depth to just above the weir crest. The trench storage volume surrounding both sewers is believed to provide a dampening effect, which would limit the system HGL increases.

This potential issue does not affect SSO frequencies or volumes. The flow limit elements were located far enough away from the SSOs to avoid limiting the HGL at the SSO weir. During calibration of meters located at the SSOs, flow limit elements were added (when necessary) far enough up or downstream to match the observed flow hydrograph shape, peak, and volumes. The downstream and diversion hydraulics were adjusted to match the meter scatterplot shapes and depth hydrograph to ensure the proper activation level (flow) and the proper diversion of flow between the DWO and SWO.

The HHI-LSSES and Cleveland Heights SSES projects have attempted to strike an appropriate balance in the existing system modeling to provide reasonable results at a planning level with an appropriate level of modeling effort and cost. As improvement projects proceed in Cleveland Heights and other District communities, the pre-construction and resulting system performance will be determined in more detail using flow monitoring and model calibration updates to track project success. This accumulated information will be used with each successive project to update and improve assumptions for modeling improved system performance.

Figure 4-13. Examples of Common Trench Flow Calibration – Meter vs Model

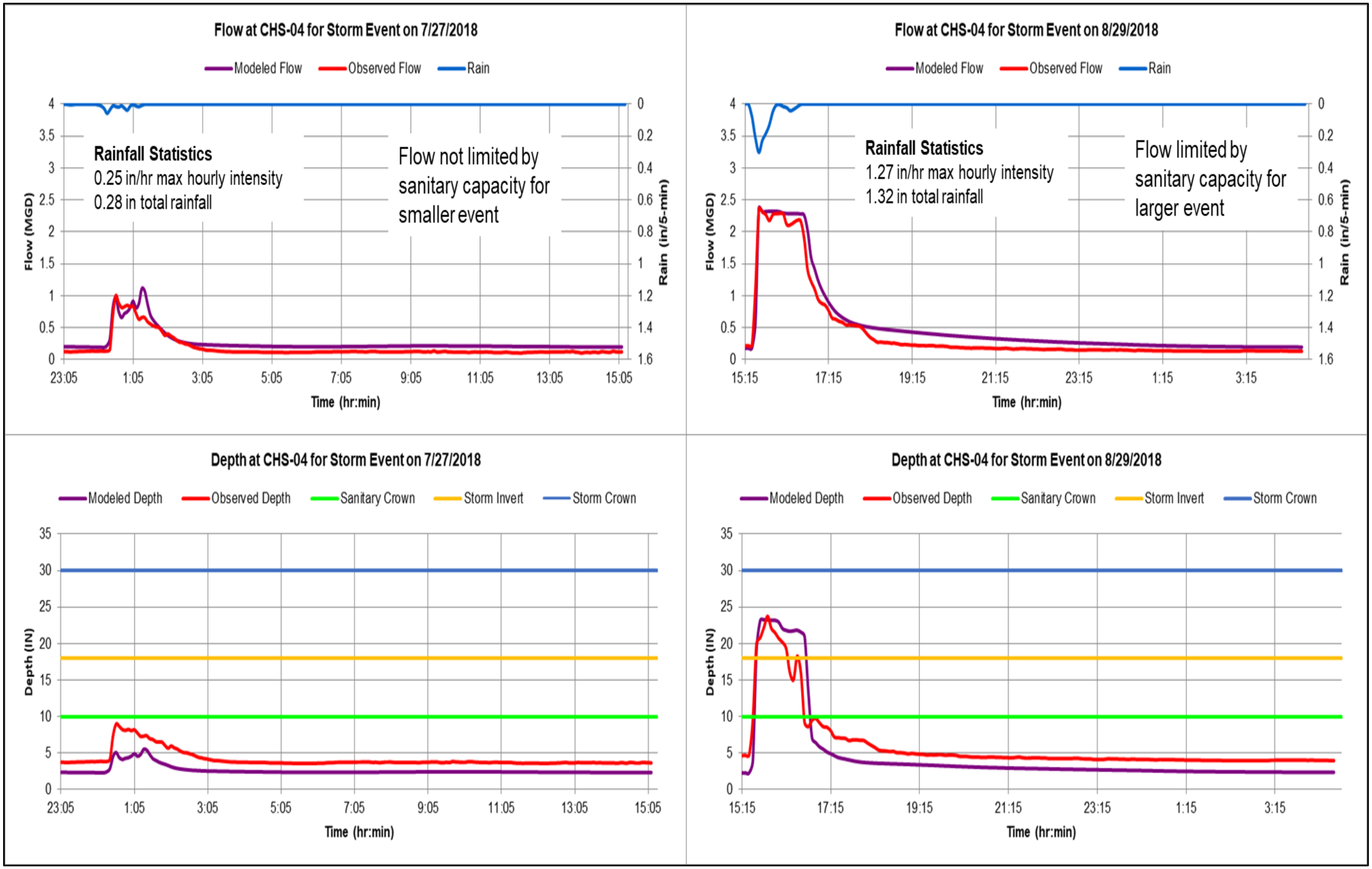
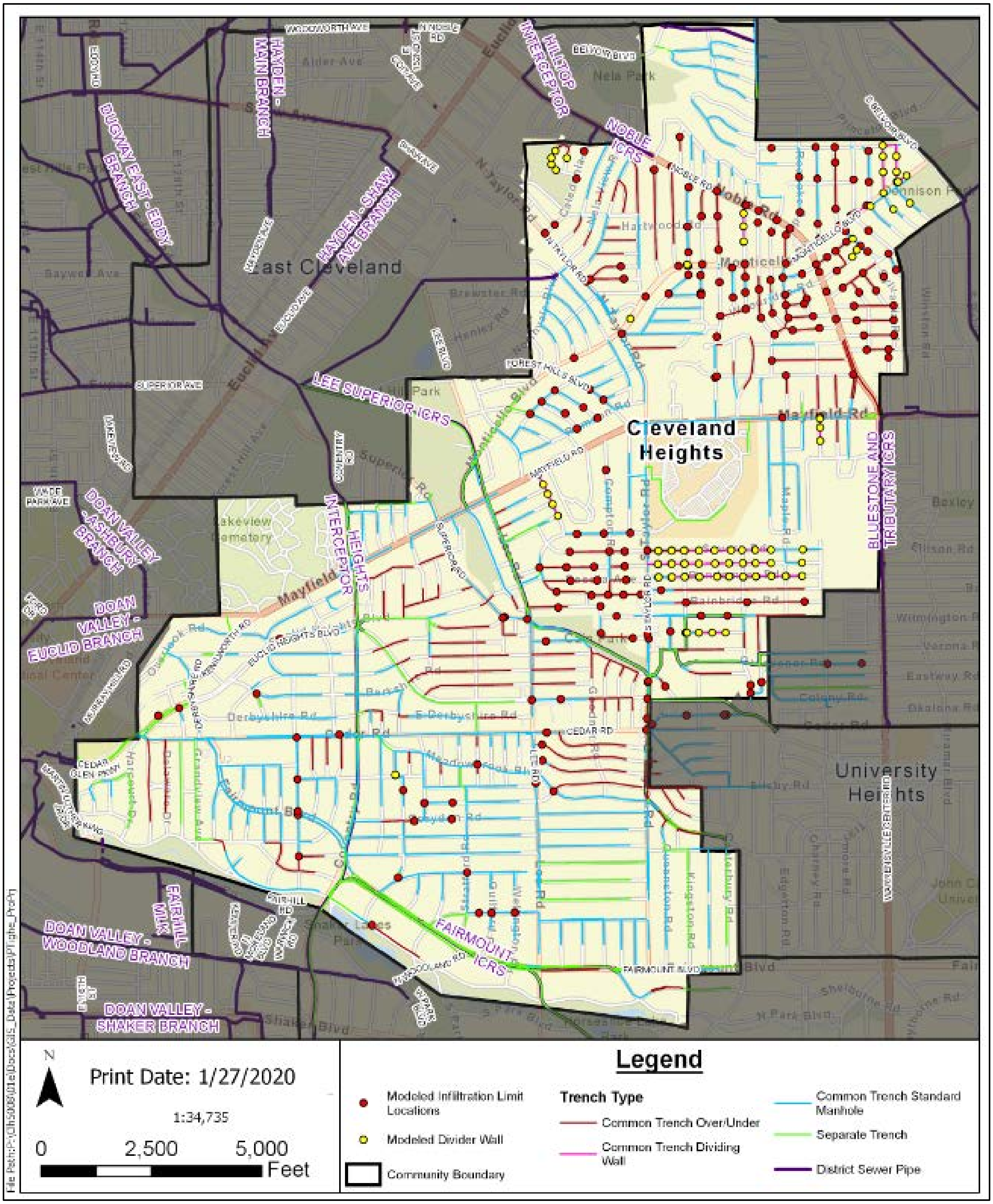


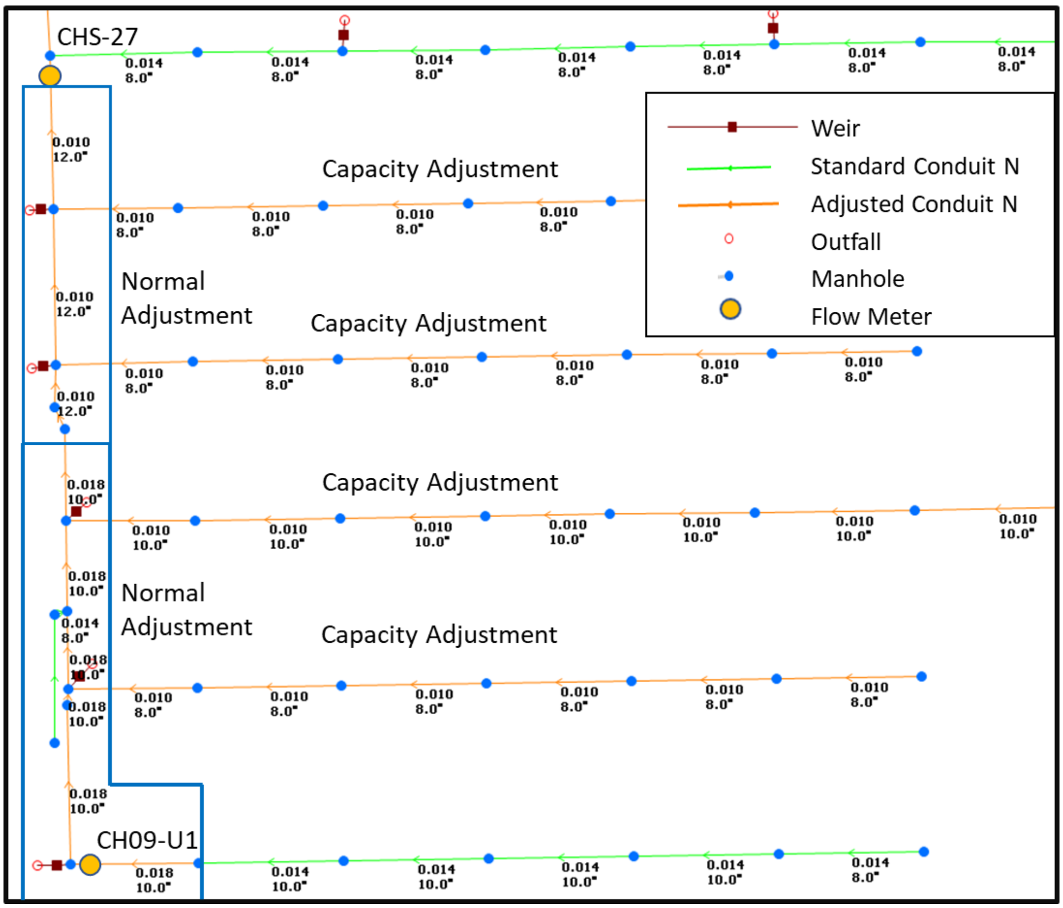
Figure 4-14. Locations of Modeled Infiltration Limit Elements and Dividing Wall Manholes



Sewer Roughness

In some cases, the modeled sewer roughness was changed within acceptable ranges upstream and downstream of the meter site. In some locations, all pipes between two meters were updated. In others, more pipes upstream of the meter site were calibrated to provide the required capacity for flow to the meter site. The roughness was only changed in the pipes necessary to provide the capacity required. Sensitivity analysis was conducted in such areas to ensure that the roughness was changed in pipes only when necessary. **Figure 4-15** shows an example of the extents of the calibrated roughness at meters CHS-27 and CH09-U1.

Figure 4-15. Upstream Roughness Updates for Capacity Calibration



4.2.2 Selection of Calibration Events

The CD requires that the calibration process be based on 3 or more calibration events and 3 or more verification events. Rather than separate events into calibration and verification, all qualifying events were used for calibration and the continuous simulation for the whole flow monitoring period was calibrated to account for the antecedent moisture content and back-to-back storms. This approach follows current standard modeling practice and is the approach suggested in the District standards. Continuous simulation is also described in the System Modeling Plan, November 2018, approved by EPA.

For the 2018 monitoring period, 10 rainfall events were selected for calibration based on the District's standards criteria. Some rainfall events identified as appropriate for calibration were grouped with other rainfall events into a single calibration event to ensure that the flow data returned to DWF conditions after the rainfall event. One event on September 8, did not meet District standards for peak intensity, but the total rainfall volume was larger than most other calibration events. For most meters, 10 rainfall events were available.

For the 2016 monitoring period, the events selected during the HHI-LSSES project were used for this project as well. Due to event grouping and a dry monitoring period, most meters had less than 6 total calibration events; however, all qualifying events were used in the calibration process.

Rainfall events were used for calibration as summarized in **Table 4-5**. The available meter data varied between meters; therefore, not all meters were calibrated to the same set or number of events.

Table 4-5. Rainfall Events Used for Model Calibration (based on 12-hr inter-event period)

Calibration Event ID	Rain Gauge Average				
	Start Date	End Date	Duration (hr)	Total Rain (in)	Peak 1-Hr Intensity (in/hr)
2016 Events					
2	5/12/2016 22:50	5/14/2016 23:50	49	1.51	0.31
3	5/29/2016 20:55	5/30/2016 6:29	10	0.74	0.73
4	7/29/2016 12:45	7/31/2016 14:05	49	0.98	0.31
5	8/9/2016 20:55	8/15/2016 10:39	134	1.75	0.51
6	8/25/2016 0:50	8/25/2016 3:50	3	0.97	0.95
7	9/7/2016 6:50	9/7/2016 10:50	4	0.49	0.45
8	9/8/2016 14:50	9/9/2016 5:15	14	0.70	0.65
9	9/10/2016 5:05	9/11/2016 1:30	20	0.85	0.48
10	9/17/2016 3:20	9/17/2016 15:54	13	1.11	0.69

Table 4-5. Rainfall Events Used for Model Calibration (based on 12-hr inter-event period)					
Calibration Event ID	Rain Gauge Average				
	Start Date	End Date	Duration (hr)	Total Rain (in)	Peak 1-Hr Intensity (in/hr)
11	9/28/2016 20:25	9/30/2016 18:55	46	1.48	0.32
2018 Events					
13	7/23/2018 14:40	7/25/2018 6:20	40	0.50	0.29
14	7/26/2018 17:50	7/27/2018 10:10	16	1.03	0.59
15	7/27/2018 23:05	7/28/2018 15:20	16	0.38	0.32
16	8/6/2018 13:05	8/9/2018 15:30	74	2.00	0.87
17	8/21/2018 1:45	8/23/2018 15:00	61	1.21	0.48
18	8/29/2018 15:15	8/30/2018 4:45	13	1.09	1.03
19	9/5/2018 18:45	9/6/2018 21:55	27	0.30	0.24
20	9/8/2018 3:50	9/11/2018 23:10	91	1.94	0.21
21	9/24/2018 16:35	9/26/2018 23:35	55	1.94	0.55
22	10/6/2018 6:15	10/7/2018 18:05	36	0.87	0.51

A review of the meter data found data quality issues of varying degree at some meters. The system conditions have changed over time as well; an expansive sewer cleaning effort and several system projects have been completed in the last few years. The changing system conditions made some meters from 2016 obsolete and some portions of data from 2018 less useful. The list below summarizes the meters that were not used for calibration. For some sites, the data was used for depth only or general guidance, while others were set aside completely. **Table 4-6** lists the meters with less extensive data issues and summarizes events with missing or unreliable data for individual meters.

- CH45-U1: This meter was not used for this calibration due to changing hydraulics upstream (caused by shifting roots over time). The hydraulics were updated based on field data and surveys. The hydrology was calibrated to CH35-U1.
- CH35-U1: This meter cannot be considered fully calibrated due to changing hydraulics upstream. Calibration of this flow meter concentrated on the September 24 and October 6 events from 2018. The hydraulics are accurate, but the hydrology should not be considered fully calibrated.
- CH-12: This meter was not used for calibration due to changing hydraulics upstream. The hydrology and hydraulics were maintained from the HHI-LSSES model.
- CH38-U1: This meter was not used for calibration. The Fairmount Boulevard Sanitary Relief Sewer collects flows just upstream of the site, making the meter obsolete. Local hydraulics and directly tributary hydrology were maintained. The area intercepted by the relief sewer was calibrated to new meter data.
- CH23-U2: The site did not have an adequate amount of reliable data to be considered fully calibrated, but the data was sufficient to make model adjustments to the area. The area overall should be considered calibrated to the downstream meter CH23-U1, with this meter used for model calibration refinement.
- CH-16: This meter was not used for this calibration effort due to changing hydraulics upstream. The hydrology and hydraulics were calibrated based on surrounding meters.
- CHS-16: The model was only roughly calibrated as the reliable dataset was not large enough to confidently consider the model calibrated.
- CH-22: The site did not have an adequate amount of reliable data to be considered fully calibrated, but the data was sufficient to make model adjustments to the area. The area overall should be considered calibrated to the downstream meter CH-23, with this meter used for model calibration refinement.
- CH46-U1: This meter cannot be considered fully calibrated. The hydraulics are accurate, but the hydrology should not be considered fully calibrated.
- CHS-05: This meter can be considered fully calibrated for depth, but not flow due to questionable velocity. The higher velocity may be accurate and was therefore used for general validation of higher flows.
- CHS-07: This meter can be considered fully calibrated for depth, but not flow due to questionable velocity. The higher velocity may be accurate and was therefore used for model adjustments to the area. The area overall should be considered calibrated to the downstream meter OF08-U1, with this meter used for model calibration refinement.
- CH-28: This meter was not used for calibration. The area was calibrated to the downstream meters, CH51-U1 and CH-36.

- CH-32: All flow for CH-32 came from areas monitored and calibrated using the 2018 flow data. The upstream meters observed a similar max out of flow as this meter, however, the cumulative max rate is higher for the upstream meters than the downstream.
- The data set from 2018 is better quality, as a better range of rainfall events were observed. Therefore, priority was given to the 2018 meters.

Table 4-6. Summary of Missing or Unreliable Data

Meter	Date	Reason
CH-33	8/9/2016 8/25/2016	Meter data for these events was unreliable due to an issue with the meter clock. Smaller events on June 4th and July 15th were added as calibration events for CH-33.
CH-19	8/9/2016 8/25/2016	Individual scatter plot for these are different than the early events.
CH05-U1	10/6/2018	Individual scatter plot was different compared to earlier events.
CH07-U1	7/26/2018 7/27/2018 9/24/2018	Meter data showed a large jump in depth with no corresponding drop in velocity (resulting in a jump in flow) near the peak of the event
CH33-U1	8/29/2018 9/5/2018 9/8/2018	The meter performance summary noted that the velocity data for this event was edited. The data was edited in a way inconsistent with other events.
CHS-08	7/23/2018 7/26/2018	Meter depth data for was unreliable due to a malfunction with the pressure depth sensor. The velocity data is reliable; since the depths max out at full pipe, the flow information was still usable.
CHS-09	10/6/2018	Abnormal reaction to depth, event was considered unreliable.
CHS-11	8/6/2018	The meter performance summary noted that the velocity data for this event was edited. The data was edited in a way inconsistent with other events.
CHS-14	7/26/2018 7/27/2018 8/29/2018	Recorded peak flow was not proportional to similar events.
CHS-15	7/27/2018	Recorded peak flows and depths were not proportional to the size of the rainfall event compared to other events
CHS-34SN	8/29/2018	No meter data recorded; meter was removed for sewer cleaning.
CHS-34ST	8/29/2018	
CHS-35SN	8/29/2018	

Table 4-6. Summary of Missing or Unreliable Data

Meter	Date	Reason
	9/5/2018	
CHS-35ST	8/29/2018	

4.2.3 Wet Weather Calibration Criteria

The following criteria defined in the District's modeling standards attached in **Appendix 3** were used as a guideline for the WWF calibration:

- Observed versus model-predicted WWF calibration comparisons shall closely follow each other both in shape and magnitude, until the flow has substantially returned to dry weather flow rates.
- Observed and model-predicted hydrographs shall meet the following criteria in at least 60% events:
- Timing of the peaks and troughs shall be similar to the event durations.
- Peak flows at each significant peak shall be in the range of -15% to +25%.
- Volume of flow shall be in the range of -10% to +20%.
- Surcharged flow depths shall be in the range of -0.32 to +1.64 feet.
- Unsurcharged flow depth shall be within the range of ±0.33 feet.
- Preliminary model calibration based on a continuous simulation of the entire monitoring period is preferred/recommended over discrete event simulations, but not required. Continuous simulations account for varying antecedent moisture conditions, as it tracks the surface storage availability and soil conditions. As a result, rainfall after a preceding rainfall event will produce a larger reaction than rainfall preceded by dry conditions.
- Final calibration comparisons of flows, depths, and volumes shall be based on continuous simulation of the entire monitoring period. Assessing whether calibration meets the District's criteria shall be based on continuous simulation results.
- Predicted flooding locations shall be substantiated by evidence of observed flooding or a clear explanation for there being none.
- An attempt should be made to reproduce flooding that was observed during flow monitoring. If observed flooding is not reproduced in the model, the potential cause(s) of flooding and potential reasons for not reproducing it in the model should be clearly identified and documented.

4.2.4 Wet Weather Calibration Results

For wet weather calibration, the goal was to have at least 60% within the target range for volume, peak flow, and peak depth to meet the District's standards. **Figure 4-16** shows the percentage of calibration events that meet the District's criteria for each meter. **Appendix 6** provides schematics of meter connectivity. **Appendix 7** provides monitored versus modeled wet weather comparison plots and a discussion of the calibration for each meter.

The District standards included as Appendix 3 of this report target meeting flow rate, volume, and depth parameters criteria for 60% of calibration rainfall events. **Table 4-7** summarizes the performance for the Cleveland Heights calibration meters by hydrology method. **Figure 4-8** shows the meters in each hydrology method area. Meters that did not meet the District targets for the calibration parameters are discussed in this section and in greater detail in the **Appendix 7** *Flow Meter Write Ups*.

Table 4-7. Summary of Calibration Meter Performance by Hydrology Method

	Calibration Meters Meeting District Standards, %			# Meters
Calibration Parameter	**Peak Flow Rate**	**Event Volume**	**Peak Depth**	
Hydrology Method				
DCIA/RTK	40%	40%	80%	10
RTK Runoff	75%	50%	88%	8
Wallingford Runoff	89%	63%	82%	65
All Meters	82%	59%	82%	83

The various model hydrology methods used result from the long-term development of the model as it was expanded for various studies. Meter calibration was most successful in Cleveland Heights for the RTK Runoff and Wallingford hydrology methods, primarily because the meters in those two areas tended to have larger tributary areas and good flow hydraulic conditions. Calibration was generally more challenging for the Cleveland Heights system than for a typical sanitary sewer system due to the existing sewer system varying configurations, age, and relatively high I/I levels.

Meters in the Delamere area where the DCIA/RTK approach was used had relatively small tributary areas and were subject to backwater conditions due to downstream system constraints. The DCIA/RTK method used in the Delamere area was intended to represent the system reaction more accurately by modeling the storm and sanitary sewers and interactions. This approach was attempted in this small area for preliminary design of the upcoming sewer system improvement project but proved difficult and significantly more complicated. The calibration was moderately successful in this area due to the complicated system interconnectivity, and because the tributary areas were small and subject to backwater conditions. This led the team to lean conservatively (higher peak flows, depths, and volumes) for design flows in this area.

Table 4-8 summarizes the meters meeting the District criteria. This section subsequently provides a summary, and Appendix 7 provides a detailed analysis of each flow meter location that was used for model calibration including a tabular summary of the meter-specific statistics and discussion supporting the conclusion that the model is "acceptable for the purposes of this project". This information includes the following for each meter location:

- Overview of the meter site with pertinent information of the site's physical aspects.
- Summary tables of events that were used for model calibration and the number of events that met the model calibration standards. This information is provided for both dry weather flow periods and wet weather events.
- Separate detailed discussions for dry weather flow calibration and wet weather flow events. These discussions analyze the calibration issues with flow meters or flow meter accuracy.
- Separate time series plots for both dry weather flow periods and wet weather calibration events. These plots show the comparison of model vs. measured data with accompanying tables of statistics for each event.
- Regression plots comparing measured and model results for volume peak and depth. The regression plots include error bands to identify events that fall within the District's standards.
- Scatter plots of velocity vs. depth compare observed, modeled, and theoretical manning's relationships.

The model calibration prioritized peak flow rates and depths to identify SSO activity and potential BBUs. The team observation, based on comparison to basement backup complaints and sewer system operations staff experience, is that the model is likely somewhat conservative in projecting performance for the larger rainfalls (i.e., actual flows and hydraulic grade line (HGL) elevations are lower than projected by the model). The existing model is a planning level tool, and as such, it is acceptable for the purposes of identifying existing system performance for purposes of identifying locations and types of sewer system improvements needed.

Information from completed rehabilitation and/or separation improvements in common trench sewer areas is still relatively sparse. Future improvement projects implemented by Cleveland Heights and other District communities will include pre-design monitoring and model updates as appropriate to serve as the basis of design. With each successive system improvement project, the post-construction monitoring and resulting model updates will then be used to improve successive preliminary design monitoring and modeling efforts. This is expected to continuously improve successive modeling and design efforts to optimize sewer system performance vs. project costs.

Table 4-8. Summary of Calibration Flow Meters Meeting District Criteria

Flow Meter	Peak Flow	Total Volume	Peak Depth	Flow Meter	Peak Flow	Total Volume	Peak Depth
CH05-U1	78%	44%	100%	CH36-U1	100%	33%	100%
CH06-U1	60%	60%	100%	CHS-01	70%	50%	40%
CH07-U1	43%	29%	100%	CHS-02	70%	50%	60%
CH09-U1	80%	50%	90%	CHS-03	60%	30%	50%
CH10-U1	25%	100%	100%	CHS-04	90%	50%	90%
CH11-U1	33%	100%	100%	CHS-05			50%
CH12-U1	69%	62%	69%	CHS-06	70%	70%	40%
CH13-U1	67%	67%	100%	CHS-07			90%
CH14-U1	60%	20%	100%	CHS-08	70%	60%	25%
CH-15/CH30-U1	93%	67%	73%	CHS-09	67%	44%	100%
CH17-U1	67%	67%	100%	CHS-10	80%	60%	50%
CH22-U1	100%	100%	100%	CHS-11	89%	78%	22%
CH22-U2	100%	100%	100%	CHS-12	80%	70%	20%
CH23-U1	67%	67%	100%	CHS-13	100%	70%	70%
CH27-U1	54%	23%	100%	CHS-14	71%	71%	100%
CH32-U1	100%	75%	100%	CHS-15	100%	67%	67%
CH33-U1	75%	67%	92%	CHS-17	100%	80%	100%
CH39-U1	80%	70%	100%	CHS-18	30%	10%	100%
CH42-U1	80%	60%	100%	CHS-19	100%	60%	80%
CH50-U1	40%	80%	80%	CHS-20	60%	70%	100%
CH51-U1	100%	0%	100%	CHS-21	60%	20%	60%
CH-02	80%	40%	100%	CHS-22	50%	50%	90%
CH-03	100%	40%	100%	CHS-23	60%	30%	90%
CH-04	100%	80%	40%	CHS-24	80%	70%	50%
CH-05	60%	60%	100%	CHS-25	70%	50%	70%
CH-06	40%	40%	100%	CHS-26	50%	50%	90%
CH-08	80%	60%	100%	CHS-27	80%	40%	70%
CH-10	100%	80%	100%	CHS-28	80%	60%	100%
CH-14	100%	60%	60%	CHS-29	100%	50%	25%
CH-18	60%	60%	80%	CHS-30	80%	70%	100%
CH-19	100%	67%	100%	CHS-31	80%	60%	50%
CH-20	60%	80%	100%	CHS-33SN	70%	80%	90%
CH-23	75%	75%	100%	CHS-33ST	0%	0%	100%
CH-24	75%	75%	100%	CHS-34SN	33%	33%	78%
CH-25	80%	60%	100%	CHS-34ST	44%	11%	44%
CH-29	100%	20%	40%	CHS-35SN	63%	38%	75%
CH-30SN	67%	67%	33%	CHS-35ST	56%	11%	67%
CH-31	100%	20%	100%	CHS-36	67%	67%	0%
CH-32	40%	60%	100%	CHS-37	100%	67%	100%
CH-33	100%	67%	100%	FBSRS-1	50%	50%	100%
CH-34	71%	57%	100%	LSRS-1	70%	50%	70%
CH-35	100%	14%	86%	OF8-U1	75%	75%	100%
CH-36	100%	71%	100%				

Overall, the model calibrates well for timing, hydrograph shapes, and peak flow rates. Explanations are provided below for the meters that do not meet the peak flow rate, volume, and peak depth criteria. Although these specific meters do not meet the District's established standards, the model is within the calibration criteria, and is acceptable for the purposes of this planning level project.

Wet Weather Calibration Events

For some of the system, the model was calibrated to moderate rainfall events, with the largest event having an approximate 6-month return frequency. A concern of using a model calibrated with moderate rainfall events to understand system performance under larger design rainfall conditions is that the proportion of rainfall entering the collection system as RDII[1] for larger events may change significantly. Decreased I/I per unit rainfall may result as I/I source capacities are exceeded because only so much I/I can enter through a pipe crack, and the soil infiltration rate is also limited. Alternatively, increased I/I per unit rainfall may result as new sources begin to contribute for larger rainfalls, e.g., submerged manholes may begin to leak significantly as ponding increases.

The following meters did not meet the goals for peak flow:

- CH07-U1, CH50-U1, CHS-26, CHS-34SN, CHS-34ST, CHS-35ST, FBSRS-1: The 2018 summer events (first 6 events) were considered higher priority than the 2018 fall events (last 4 events). For some meters, a large amount of groundwater/trench water impact was observed during the fall events. This could be due to seasonal variation in groundwater or the fact that the monitoring period was abnormally wet. When accounting for only the first 6 events, the model and meter peak flows meet the district's targeted guidelines.
- CH27-U1: The peak flows were difficult to match due to data quality issues. The velocity data was generally lower than the meter's design range due to constant backwater. The model was calibrated to match most data, overestimating for some events, and underestimating for others.
- CHS-18: Due to the tributary area being small (less than 2 acres) the flow and depth data were extremely low, calling into question the reliability of the radar-rainfall and meter data for this meter. Calibration of this meter therefore focused on the larger events on August 6 and 21.
- CHS-22: The large peak flows were difficult to match due to data quality issues. Peak flow was calibrated to cap at around 1.8 MGD. Recorded data points above this cap were deemed unreliable.
- CHS-33ST: The meter is in a storm sewer. Storm sewers typically have little or no baseflow and are more difficult to calibrate. The meter has lower accuracy than a normal sanitary sewer calibration meter. The calibration concentrated on depths and, more importantly, frequency of flow exiting from the sanitary to the storm sewer.

[1] Rainfall Derived Infiltration and Inflow

- CH-06, CH10-U1: The large peaks were not met while also meeting the smaller peaks. The calibration focused on the larger peaks and sacrificed the smaller.
- CH11-U1: Due to a meter issue during the July 29, 2016 event, the meter recorded no reaction during the largest rainfall portion of the event. This occurred during the second half of the event. However, the first half of the event is matched.
- CH-32: Peak flows are generally high, however, reducing the peaks would negatively impact the upstream meter calibrations.

Figure 4-16. Percentage of Calibration Events per Meter Meeting District Criteria

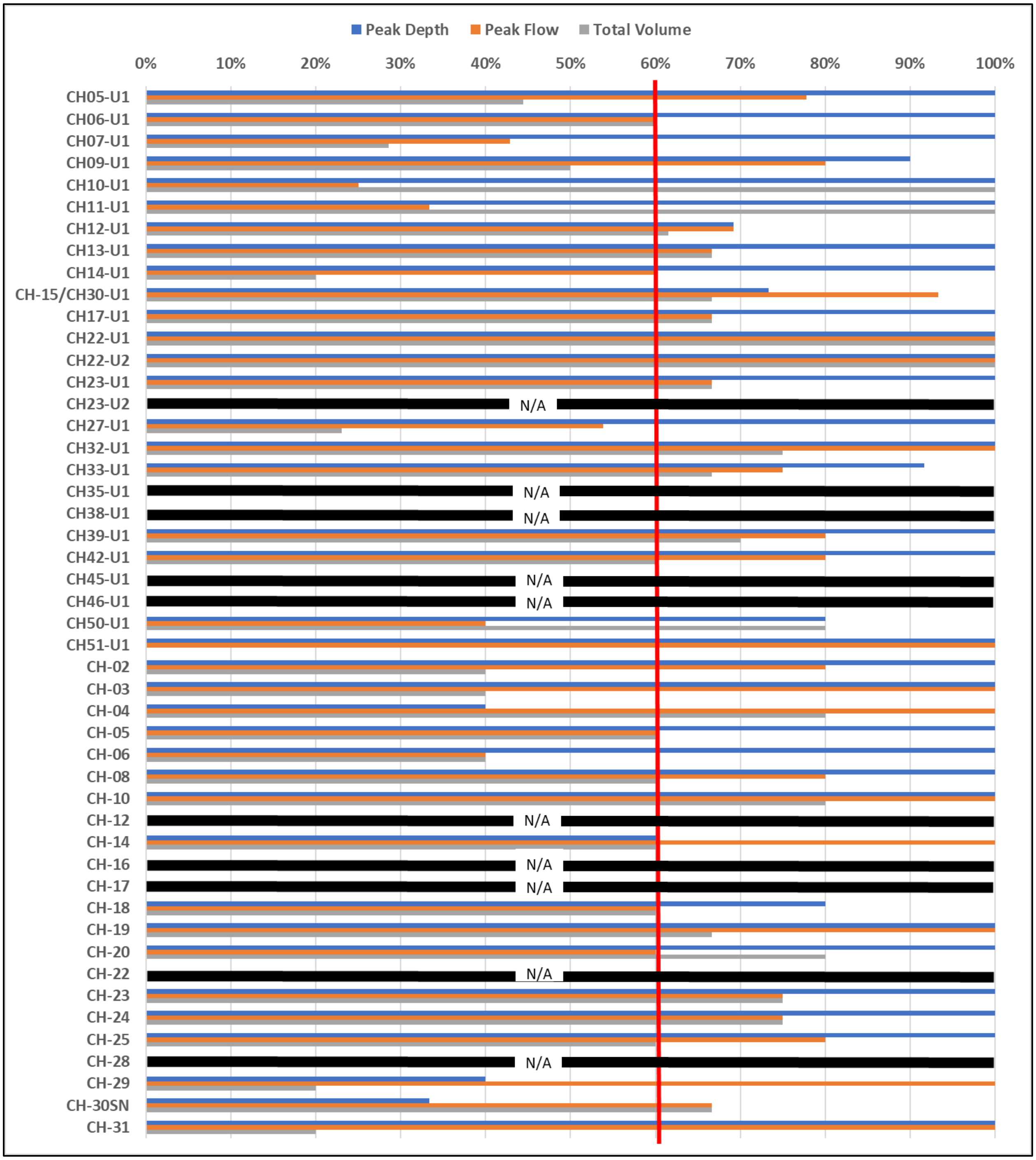
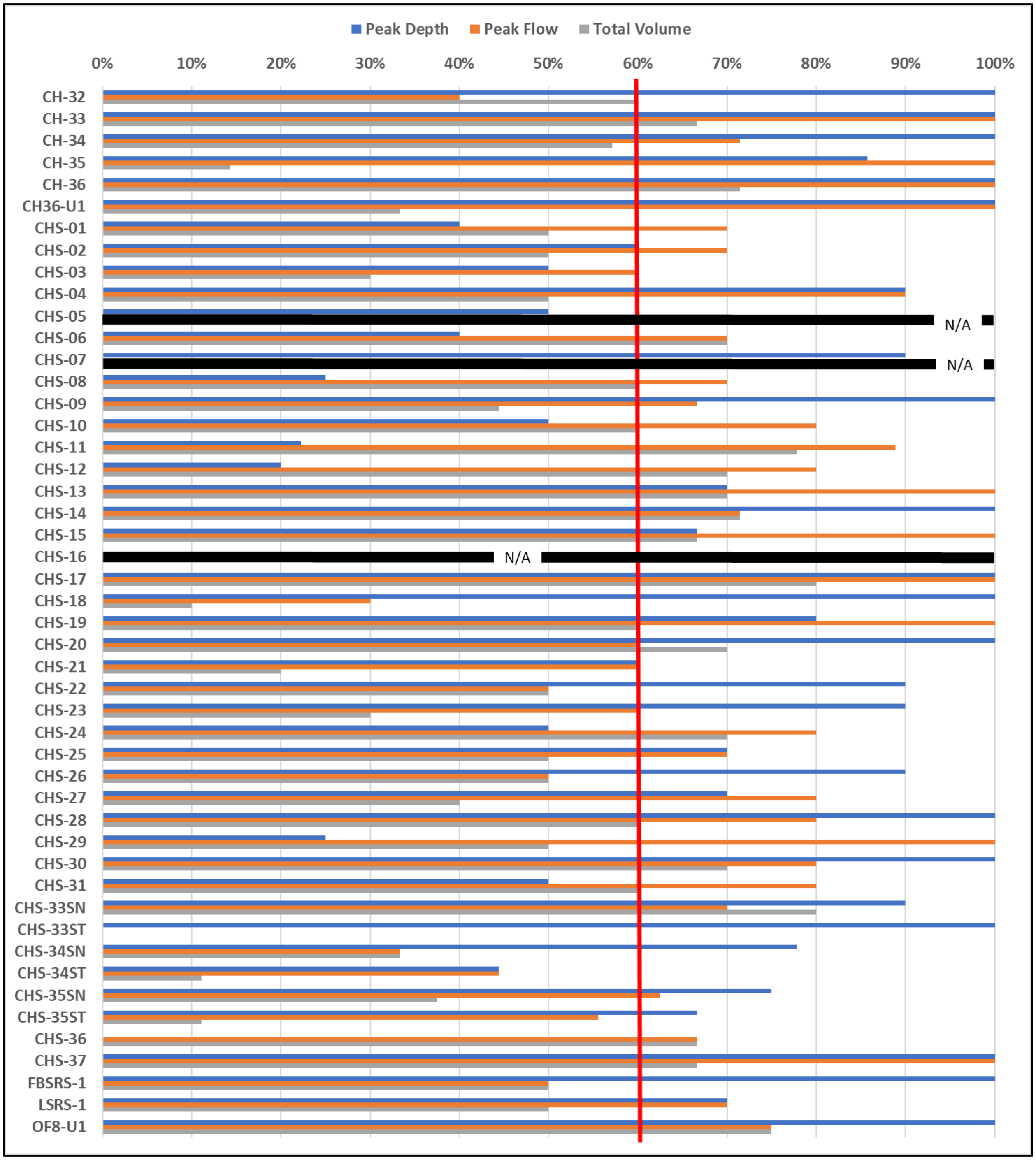


Figure 4-16. Percentage of Calibration Events per Meter Meeting District Criteria – Cont'd



The following meters did not meet the goals for volume:

- CH05-U1, CH07-U1, CH09-U1, CHS-01, CHS-02, CHS-04, CHS-08, CHS-09, CHS-22, CHS-25, CHS-26, CHS-27, CHS-29, FBSRS-1, LSRS-1: The 2018 summer events (first 6 events) were considered higher priority than the 2018 fall events (last 4 events). For some meters, a large amount of groundwater/trench water impact was observed during the fall events. This could be due to seasonal variation in groundwater or the fact that the monitoring period was abnormally wet. When accounting for only the first 6 events, the model and meter volumes meet the District's targeted guidelines.
- CHS-18: Due to the tributary area being small (less than 2 acres) the flow and depth data were extremely low, which resulted in frequent data dropouts and called into question the reliability of the meter data for this meter. Calibration of this meter therefore focused on the larger events on August 6 and 21.
- CH27-U1: The volumes were skewed due to frequent data dropouts during lower flows. The model was calibrated to match the hydrograph shape and ignored the volume metric.
- CHS-34SN, CHS-35SN: The tributary area (6 acres) was smaller than recommended for monitoring, as the DWF in small areas are typically not large enough to properly calibrate the velocity and depths are often lower than the sensor height. As a result, volume comparison was inaccurate for some events in which drop-outs are prevalent. The calibration concentrated on the peak flows and depths hydrograph shape, to replicate the model surcharge and complicated hydraulics.
- CHS-34ST, CHS-35ST: Volumes are generally underpredicted due to medium term flows which the model did not replicate. The flows are likely from extended runoff, sump pumps, or infiltration. Because the flows do not impact the peak of the event and the limited accuracy of the model, this portion of the hydrograph was considered low priority.
- CHS-33ST: There is no tributary area for this storm sewer meter, which is not recommended for monitoring, as the flows in the sewer are typically not large enough to read flows properly. Therefore, the meter has lower accuracy than a normal calibration meter.
- CH51-U1: Volume comparisons were skewed due to unstable velocity during lower flows.
- CHS-23: Volumes were not matched due to the prevalence of data dropouts during multiple events.
- CHS-21: Volumes were skewed due to the variation of baseflow throughout the calibration period as well as varying long-term infiltration.

- CH-03, CH14-U1, CH-29, CH-31, CH36-U1: Volumes were skewed due to the variation of baseflow throughout the calibration period.
- CH-34: The flow balance between this meter from 2016, and upstream meters CHS-30 and CHS-31 from 2018 did not match. The flow balance between CHS-30 and CHS-31 makes sense, with twice the baseflow downstream and twice the tributary area. Therefore, the low flows were considered unreliable for this meter. Accounting for the difference in recorded baseflow, the volumes would match.
- CH-35: Calibration concentrated on the earlier events, as they observed the largest amount of rainfall, to be consistent with the nearby meters. The later events were not able to be matched while matching the earlier events.
- CH-02: Due to schedule constraints, calibration was more focused on matching monitored peak flow and peak depth with a lower priority on matching monitored volume to better serve the Cleveland Heights project objectives.
- CH-06: Calibration was focused on meeting the largest magnitude peaks. The smaller peaks could not be met while also meeting the larger, later events.

The following meters did not meet the goals for peak depth:

- CH-04, CH-29, CH-30SN, CHS-08, CHS-21, CHS-33SN, CHS-34ST: The model matches the meter scatterplot shape well. The peak depths were not consistent and fall below the District's targeted guidelines.
- CHS-01, CHS-03: Due to sediment or roots varying over time, the peak depths fall below the District's targeted guidelines. However, the model matches the meter scatterplot shape well.
- CH-31: The roughness of the monitored pipe was calibrated to provide the required capacity for flow to the meter site. The peak depths were not always matched; however, the scatterplot shows an acceptable match.
- CHS-11: The model matches the meter scatterplot well when flows are low. The high depths possibly caused by downstream backwater were not replicated in the model.
- CHS-12: The model matches the meter scatterplot well for depths up to 60 inches. The scatterplot shape suggests that the depths are impacted by adjacent and/or downstream flows as well, for which there is limited information.
- CHS-29: The peak depth calibration was challenging due to regular backwater and a flow split between CHS-29 and CH12-U1. The peak depths were not well matched; however, the scatterplot shows an acceptable match.
- CHS-36: CHS-36 was only installed for 3 of the fall events and has no unique tributary area. Calibration of the upstream meters was done for the summer events. The peak

depths were not well matched however the scatterplot showed a good match between the meter and model.

Recurrent Calibration Issues

Several recurring issues were encountered during calibration. The following sections discuss these common issues and how they were addressed.

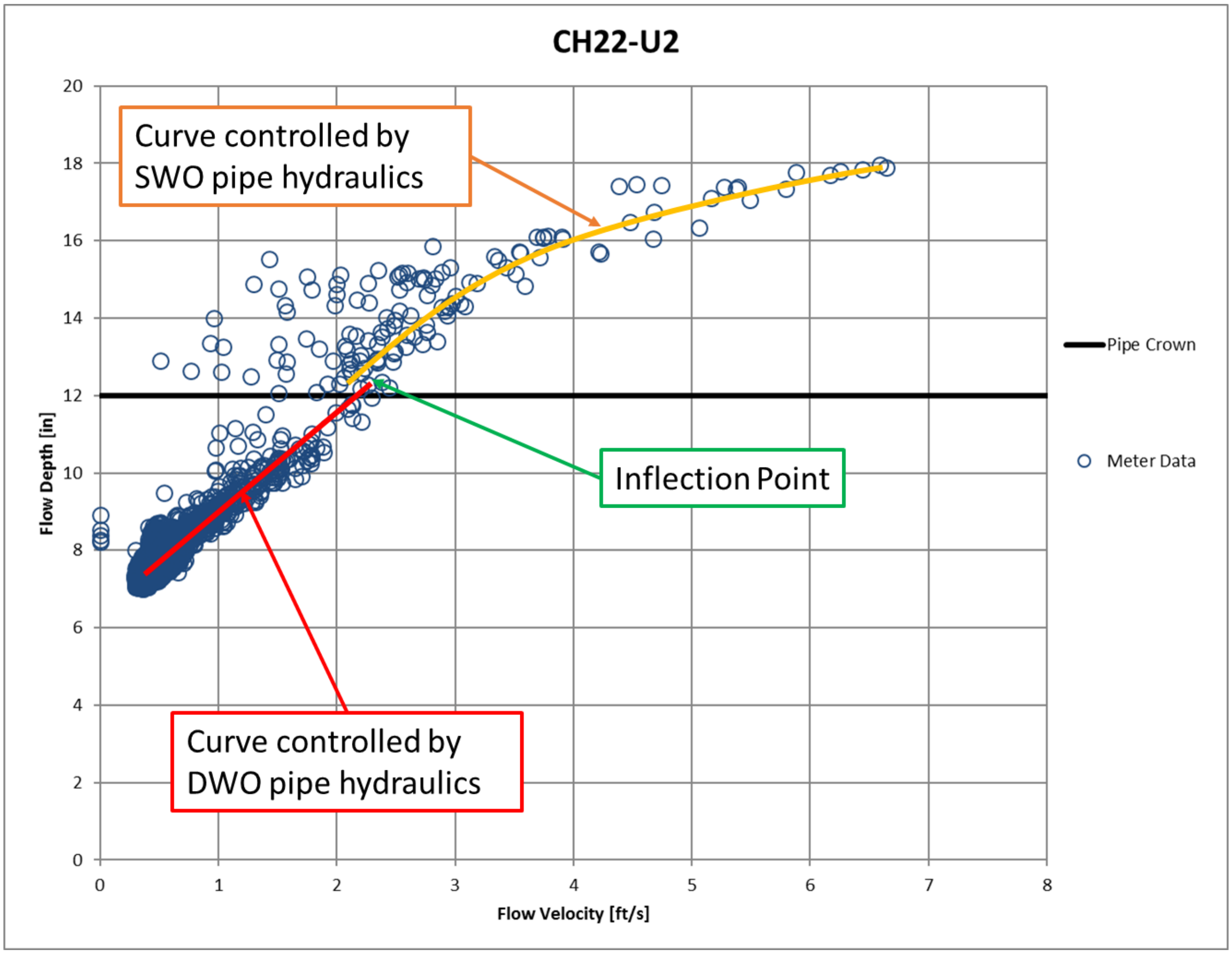
Hydraulic Structures

At some hydraulic structures, drawings and/or field investigation contained conflicting information. Hydraulic structures include regulators, flow splits, diversion structures, SSO structures, and pump stations. Some drawings were unclear regarding inverts and sizes of various elements. Metered data and field investigations were used to verify or refine the diversion hydraulics. Meter data near or inside the structures provided valuable information. Scatterplots just upstream of a diversion structure showed evidence of the height of overflows, weirs, high pipes, etc. for some locations.

Head losses and flow characteristics at hydraulic structures are complicated to model accurately within a collection system model. Collection system models are generally unable to account for momentum and rapid changes in velocity head. Although weir height and length play a role in the hydraulic performance of a chamber, the losses are also governed by minor losses associated with abrupt expansions, contractions, surcharge, bends, and orifice losses. At the chamber locations, the goal is to model hydraulic performance based on all influencing factors. For this project, the measured hydraulic data (flow, depth, and velocity) was assumed to be an important gauge of the hydraulic characteristic of the system that can be more important than physical field measurements. Therefore, at locations with conflicting information, the physical attributes of the system were developed or modified based on the hydraulic behavior of the system using field collected meter data. For example, weir crest elevations can be determined based on the abrupt change in the measured head discharge relationship characteristics as flow begins to breach the weir crest. When necessary, field crews were deployed to collect physical measurements of the system, and/or clear up significant discrepancies.

Figure 4-17 shows a scatterplot from a meter in a diversion structure. The drawings show a 12-inch offset between the chamber invert and the SWO. The scatterplot supports the drawing, showing the scatterplot curve inflection point at 12 inches deep.

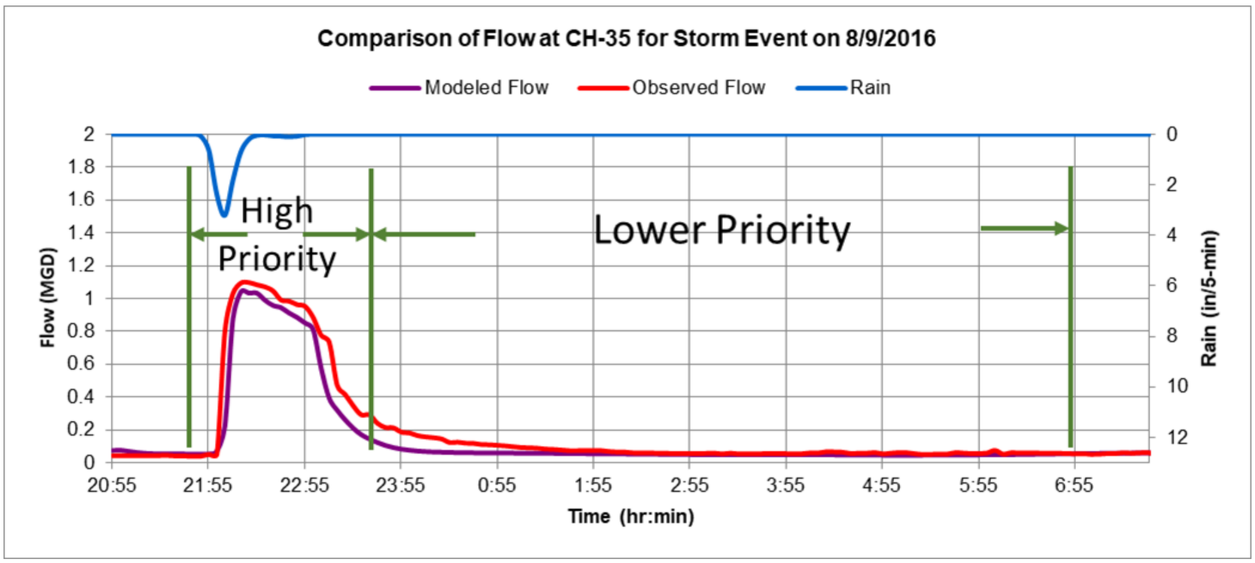
Figure 4-17. Scatterplot at Diversion Structure



Calibration Approach for 2016 Calibration Period

The 2016 monitoring period contained a limited set of rainfall events. Most events also show significant spatial variation. Because of these two issues, calibrations from some of the 2016 period were challenging to meet the desired criteria. Therefore, wet weather flow calibration focused on matching monitored peak flow rates and depths, with a lower priority on matching monitored volume to focus on the Cleveland Heights project objectives of providing adequate peak flow capacity and eliminating SSOs for at least a 5-Year rainfall. Peak flow and depth conditions trigger sewer surcharging/basement flooding and overflows, which are the primary focus of the project. **Figure 4-18** illustrates the higher and lower priority portions of the hydrograph. The volume was matched when possible; however, for many sites, the volumes could not be matched due to seasonal variation of the DWF likely due to groundwater/trench water, and hydrograph recessions associated with common trench systems. This approach is consistent with the original HHI-LSSES calibration approach.

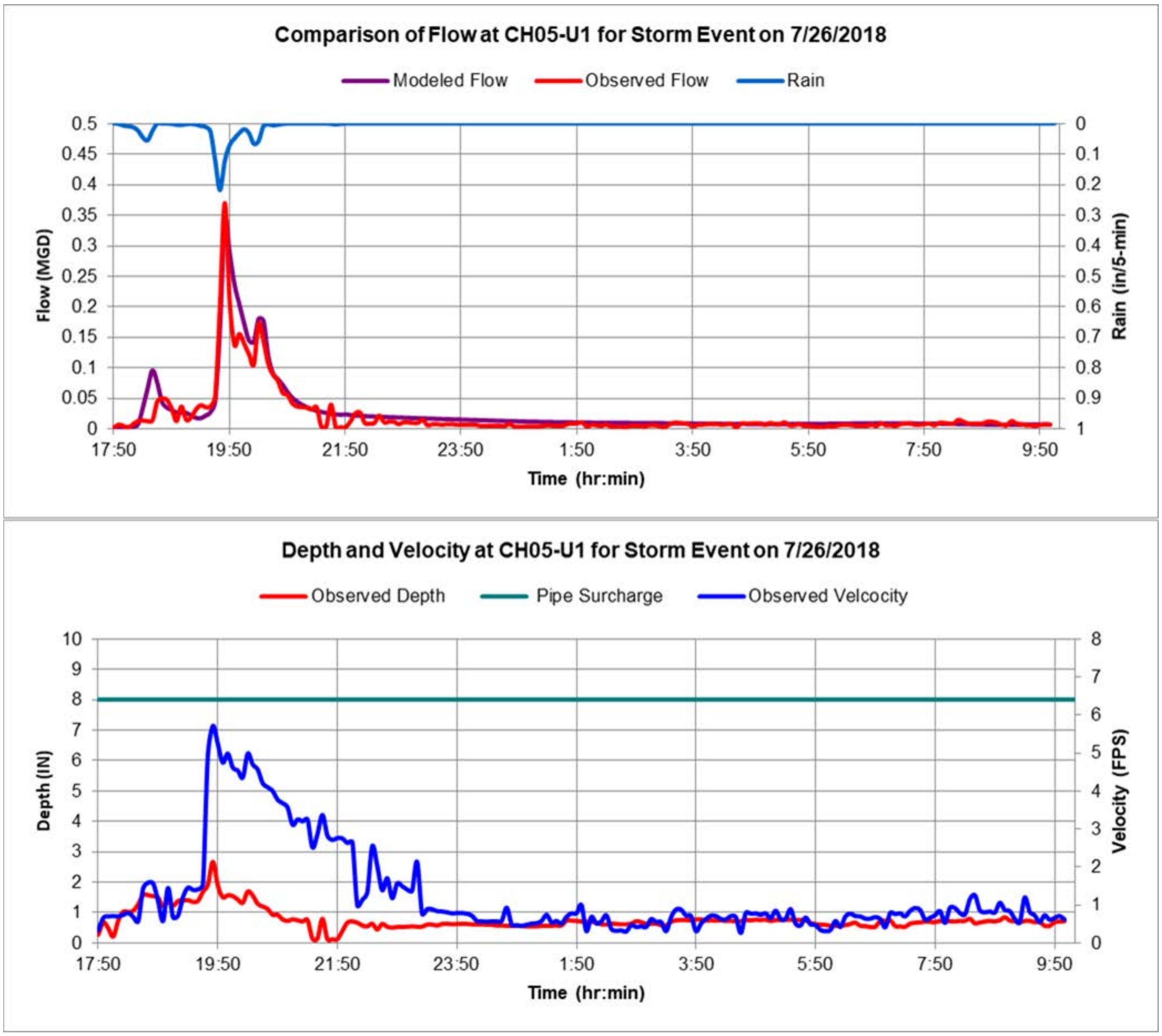
Figure 4-18. Hydrograph Breakdown and Priorities for Calibration



Small Tributary Areas

During the 2018 calibration period, several flow meters measured tributary areas smaller than recommended for monitoring. The DWFs in small areas are frequently not large enough to properly calibrate because the flow depths are often less than the sensor height. The results are often inaccurate low flows or unstable data. For some meters, these data issues caused the monitored event volume to be misrepresented, resulting in a poor match between the modeled and monitored event volumes. **Figure 4-19** shows an example of unstable flow data and the comparison to smooth model results.

Figure 4-19. Small Tributary Data Example



DWF Variation

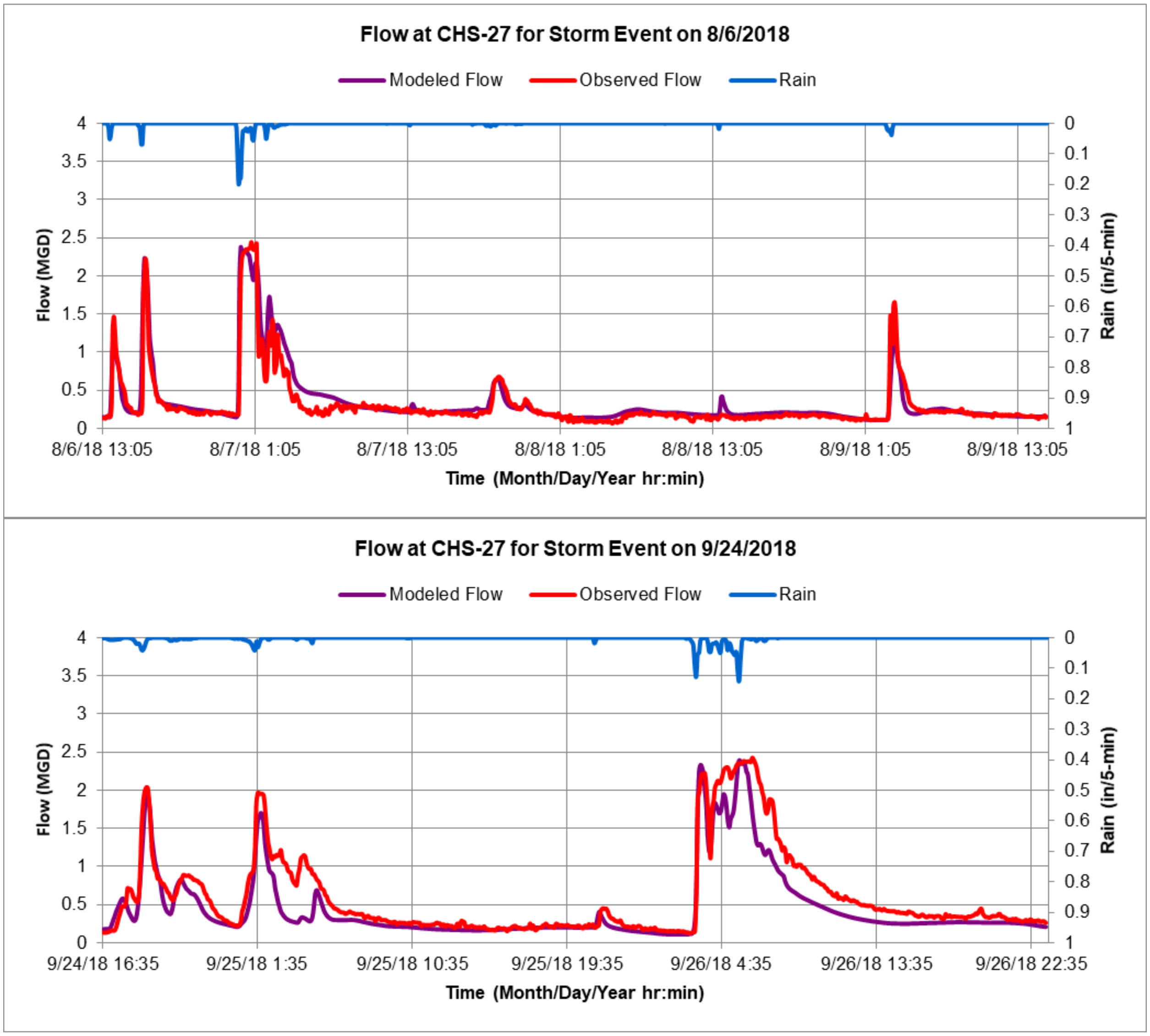
For some meters, the DWF varied over the monitoring periods both due to seasonal variation and data quality issues, as discussed in **Section 4.1.4**. The differences skewed the comparisons of monitored and model event volumes. The model was calibrated to match the overall hydrograph shape. The recession limb of the hydrograph was not adjusted to compensate for the difference in DWF and the discrepancy was allowed to remain.

WWF Seasonal Variation

During the 2018 monitoring period, portions of the Cleveland Heights system showed a much larger reaction to rainfall during the fall months (September-October) than the summer months (July-August), as shown in **Figure 4-20**. This could be due to seasonal variation in groundwater/ trench water or the fact that the monitoring period was abnormally wet. **Figure 3-5** in **Section 3.2** shows that the summer months produced average rainfall depths while the fall months observed about 50% higher than average rainfall amounts. The groundwater module or runoff with the NewUK method may have been able to account for the wet conditions; however, these were not pursued as the schedule constraints and lack of required supporting data did not allow for a more extensive calibration. Incorporating a groundwater module would have required significant effort and data that the project schedule and budget would not accommodate. It has also been noted that local groundwater levels are well below sewer elevations, so antecedent soil moisture and trench water are the more likely sources of this flow increase.

The discrete design events (at durations of 6-Hour and 1-Hour) for which the system will be evaluated are more relevant for summer rainfall events. Therefore, the summer events were considered higher priority than the fall events. When possible, the model was calibrated to all events. Otherwise, the summer events were prioritized for calibration.

Figure 4-20. Wet Weather Seasonal Variation Example



The summertime rainfalls were part of a normal rainfall period and fall was wetter than normal. Only 13% of the meters (7 of 55 total 2018 monitoring locations) favored summertime rainfalls over fall rainfalls. This means that for these meters the calibration more closely agrees with the summertime/normal rainfall events. When possible, the model was calibrated for both summer and fall. Summertime rainfalls are typically more like the shorter duration 1-hour to 6-hour events that are being considered for the IOCMP. The summer rainfall events observed tended to be larger and more intense events producing the peak rates and distributions like design storms. Ultimately this model is intended to be used for system improvements using design storms. Based on this information it was more appropriate to focus on historic summer storms for model calibration.

Project definition investigations are proposed, particularly in common trench improvement areas, to help identify and quantify the I/I sources in more detail and better define the proposed planning level improvements prior to preliminary design.

A safety factor concept will be used during design, based in part on model uncertainty in the project area, and particularly for flow reroute projects. Upsizing conveyance projects does not typically result in major cost increases, as within a few pipe sizes, cost is not very sensitive to pipe size. The District, however, may limit the peak design event/peak flow rates that can be conveyed to their system. This means that to design for larger rainfalls may tend to require additional more costly system rehabilitation, replacement and/or extensive work on private property. The City will include the identification and consideration of such additional measures in its evaluation of alternative controls for larger rainfall events.

Determination of safety factor magnitudes and/or the possibility of designing for larger rainfall patterns or events will also be refined during preliminary design in conjunction with permitting discussions with the District and will likely be based on more detailed flow and rainfall monitoring conducted at that time.

A key factor in implementation of the IOCMP improvements will be the post-construction flow monitoring results to prove what the peak flow rates will be in an improved system. For system rehab and I/I reduction projects, the resulting post-construction flow monitoring will be used to update methods and modeling for successive projects.

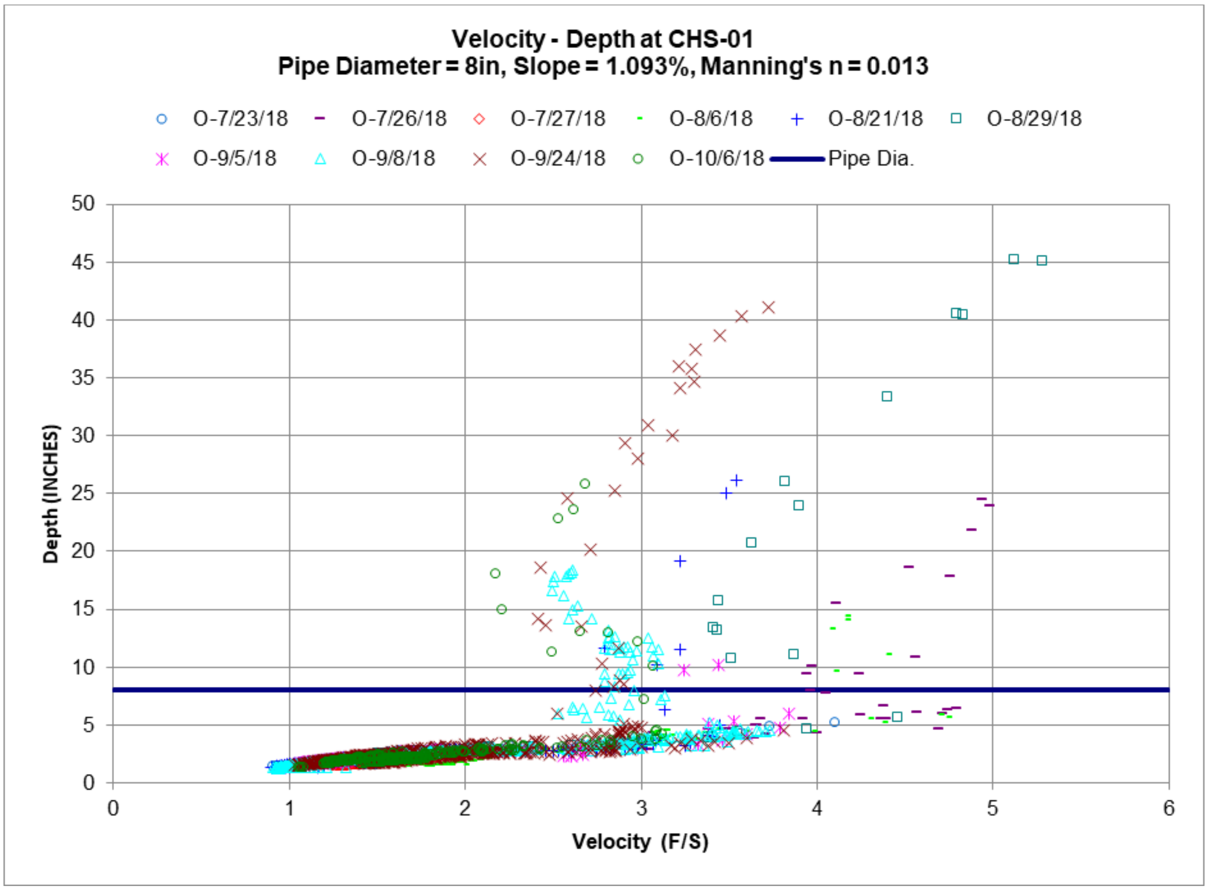
The following notes summarize the 7 meters that were outside of the District target range (see Section 4.2.3).

- CH07-U1: The model matches the three largest observed peaks.
- CH50-U1: Calibration is balanced. Overpredicts some events and underpredicts other large events. Flow meter data was of moderate quality.
- CHS-26: Small (13-acre) tributary area that responds more to high-intensity rainfalls
- CHS-34SN: small tributary area, under backwater, therefore data is rough. Fall peaks and volumes are inconsistent, with some over-predicted and some under-predicted for different events. Model matches the largest two observed events.
- CHS-34ST: Small stormwater flow tributary area for Delamere system that responds more to high-intensity rainfalls.
- CHS-35ST: Only slightly underpredicted (matches two other large events).
- FBSRS-1: The model matches 4/5 of the largest observed peak events. The largest fall event is only slightly underpredicted at -20%.

Sewer System Debris

Flow meter data showed evidence of changing sediment and/or root conditions over the course of the 2018 monitoring period as well as between 2016 and 2018. This is likely a result of sewer cleaning, roots growing over time, sediment and debris build-up over time, and sediment/debris washed out by wet weather flows. Cleveland Heights has been working to clean the sewers and implement a regular cleaning program. Field investigations found several locations of heavy roots which were reported to Cleveland Heights and removed. Generally, the model was calibrated to the most recent hydraulic condition. **Figure 4-21** shows an example, illustrating the shifting of the velocity-depth relationship over time for CHS-01.

Figure 4-21. Example Scatterplot of Shifting Roots



5.0 CAPACITY EVALUATION

The Cleveland Heights sewer system capacity was evaluated for the sanitary sewer system and MS4[2]. The sanitary sewer system was evaluated for existing dry-weather flows, anticipated future dry-weather flows based on a 20-year population projection, and peak wet-weather flows during the rainfall events listed below. For wet weather events, the rainfall amounts and rainfall intensity time-distributions were based on the District's design storm hyetographs for the following rainfalls as described in the modeling standards and protocols TM (Appendix 3).

- 2-Year/1-Hour rainfall
- 5-Year/1-Hour rainfall
- 10-Year/1-Hour rainfall
- 10-Year/6-Hour rainfall
- 25-Year/1-Hour rainfall

The storm sewers were evaluated separately using a GIS analysis as discussed in **Sections 2.2** and **5.2**.

5.1 SANITARY SEWER SYSTEM CAPACITY AND PERFORMANCE

Projected sanitary sewer system capacity and performance were evaluated primarily based on two criteria: SSO activation and basements at risk of backups.

- The determination of activation status for known SSOs and predicted overflows assumes that any overflow volume projected by the model indicates overflow, and mitigation measures will be provided to control the SSO. Although model accuracy is likely inadequate to characterize some small SSO events, this analysis assumes that any projected overflow must be resolved per the project approach.
- A basement was considered at risk of flooding due to sanitary sewer surcharging, referred to as a basement backup (BBU), if the predicted sanitary sewer hydraulic grade line (HGL) was within 1 foot of the estimated basement floor elevation.

The District uses design events with both 1-hour and 15-minute rainfall intervals. The system was evaluated with the 15-minute interval for all rainfall events. **Figure 5-1** illustrates the District's 5-Year, 1-Hour (15-Minute) hyetograph, which represents 1.46 inches of total rainfall depth. **Figure 5-2** illustrates the District's 10-Year, 6-Hour (15-Minute) hyetograph, which represents 2.55 inches of total rainfall depth.

[2] Municipal Separate Storm Sewer System

Figure 5-1. 5-Year, 1-Hour (15-Minute) Design Storm Hyetograph (1.46 inches)

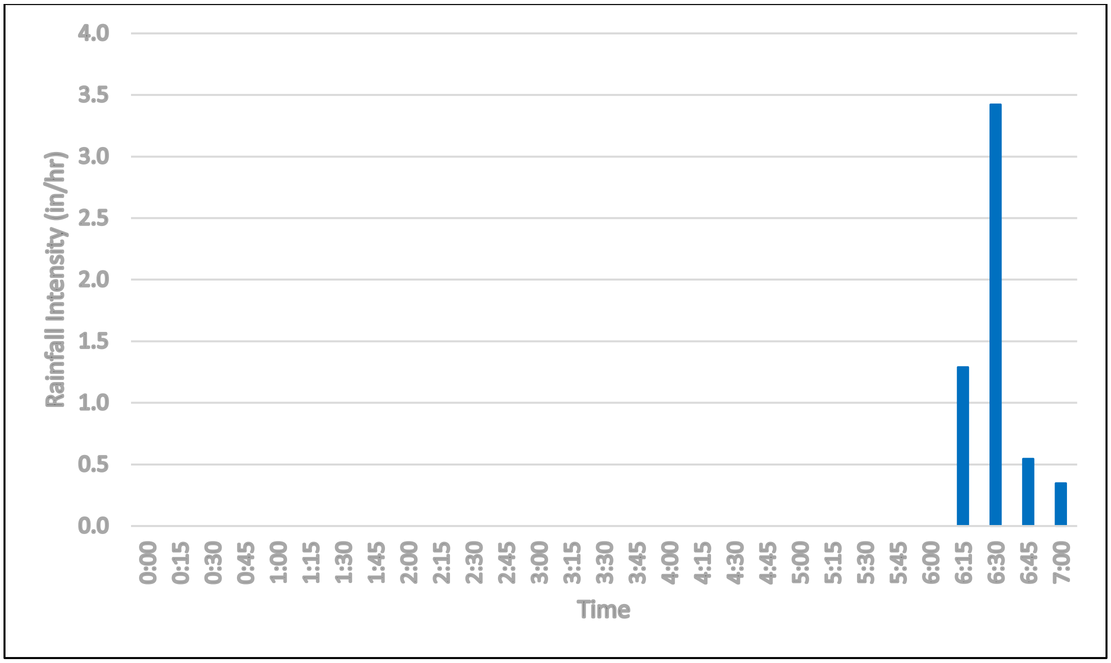
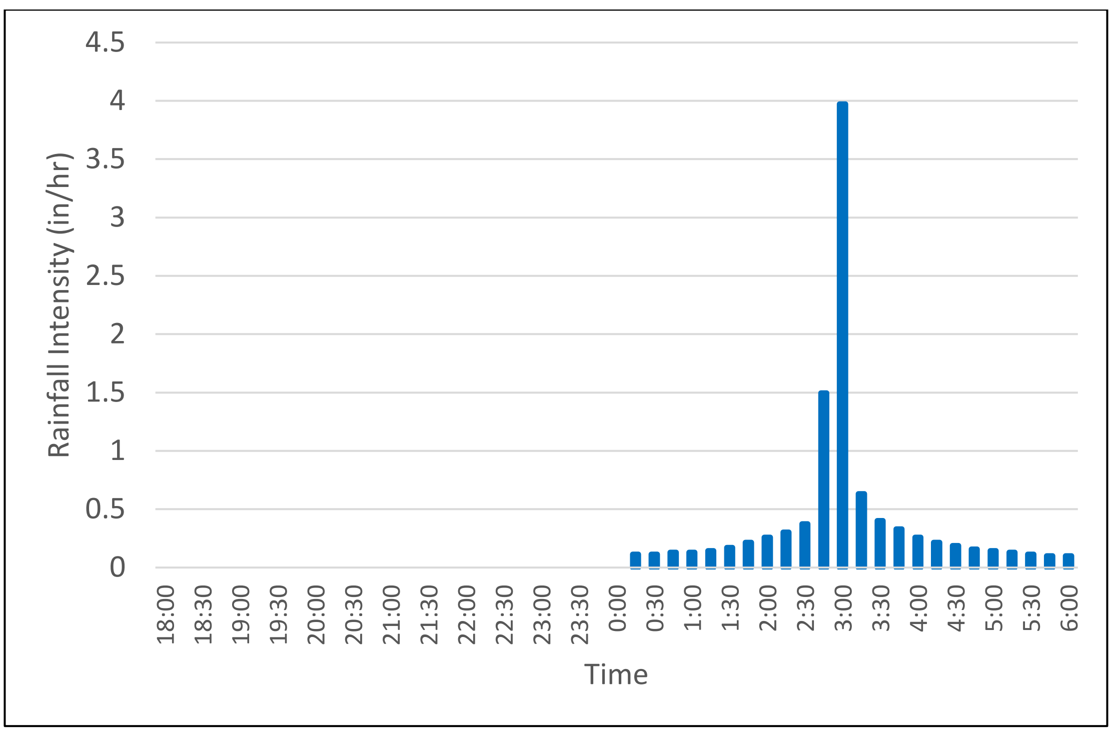


Figure 5-2. 10-Year, 6-Hour (15-Minute) Design Storm Hyetograph (2.55 inches)



5.1.1 Methodology

The Cleveland Heights modeling used one 7-day dry period and the 5 design storms. Field information collected during the project found prevalence of roots and other system obstructions impacting sewer capacity. The City has since removed the obstructions. The model was generally calibrated to the most recent system conditions known at the end of the flow monitoring period. The effectiveness of system cleaning after the end of the monitoring period could not be completely determined. Field investigation photos did confirm an obstruction at the intersection of beechwood Avenue and Euclid Heights Boulevard that had severely restricted the flow had been removed as of August 21, 2019. The model was updated to assume this pipe area as clear.

For projecting BBUs, the model HGL was compared to the estimated basement floor elevation. Model HGL results at the estimated lateral connection location were used, with the HGL calculated by interpolating the HGL model results from the upstream and downstream manholes. The basement was considered at risk for backup if the HGL is projected within 1 foot of the estimated basement floor level and the pipe is surcharged. For some buildings, 1 foot below the estimated basement level was lower than the crown of the sewer. The basement was only considered at risk if the sewer was surcharged. The following sections summarize the approach to estimate the basement elevations and building lateral locations along the sewers.

Model Boundary Conditions – District and Upstream Community Sewers

Except in rare instances, the Districts sewer flows and hydraulic grade lines (HGLs) remain well below the Cleveland Heights local sewers, so there is little impact. The few cases where District sewer flows have some impact are entirely within the City of Cleveland Heights and are represented in the model.

All tributary areas from other communities that flow into Cleveland Heights local sewers or the District sewers conveying Cleveland Heights flows are represented in the Cleveland Heights model using the fully dynamic InfoWorks ICM model elements from the original HHI-LSSES model. The only exception is the Shaker Heights contributions to the Heights Interceptor; the Heights Interceptor has adequate capacity and significant depth to convey current and improved flows without impacting the local Cleveland Heights and Shaker Heights systems.

Estimation of Basement Floor Elevations

Basement floor elevations were estimated using GIS analysis. Building locations were identified within the study area using 2016 Cuyahoga County building GIS data from AGOL. Many of the buildings are either not served by sewers (e.g., detached garages and storage buildings) or do not have basements. Buildings without basements were identified using the Cuyahoga County parcel data and GIS analysis. **Figure 5-3** shows an example area of buildings with sewer service and basements highlighted in red. The analysis excluded buildings based on the following criteria.

- Disregard building footprints less than 600 sq. ft. (see graph of building area in **Figure 5-3**). All building areas are sorted from small to large and plotted on a graph (see **Figure 5-**

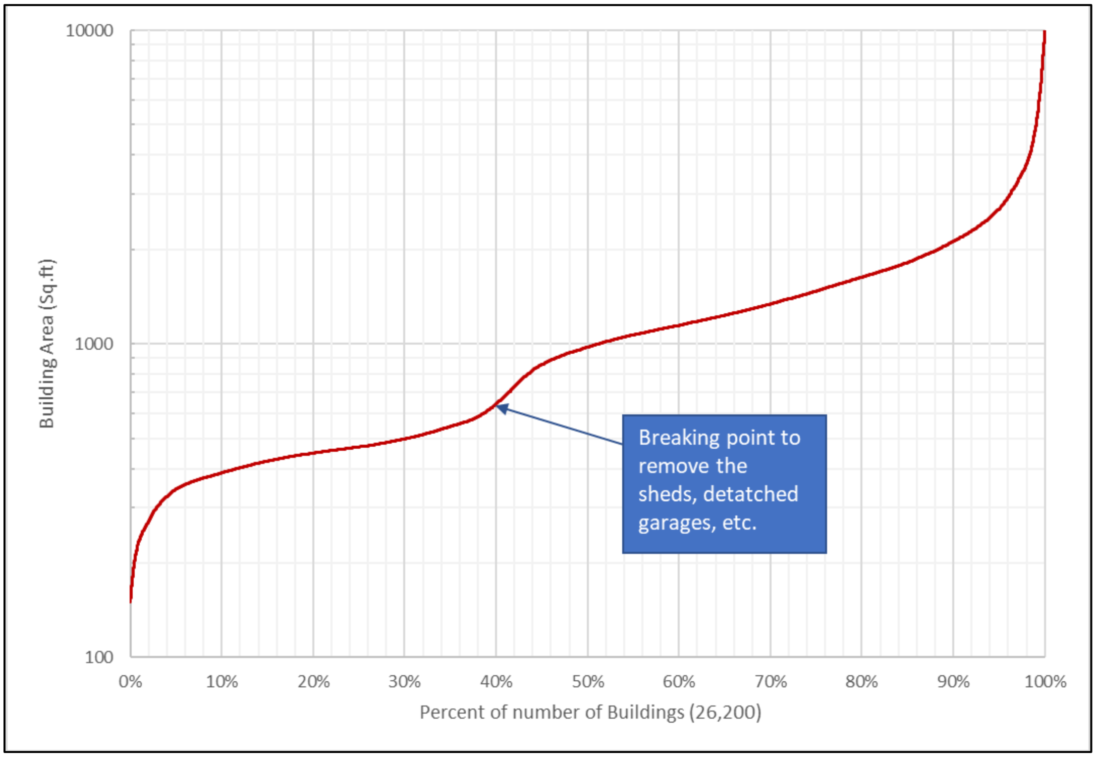
4) and a breaking point of 600 sq. ft. was found at the highest slope. This breaking point distinguished between houses versus detached garages or sheds and was confirmed on Google Earth. After removing all buildings with areas less than 600 sq. ft., the manual checks were used to remove some detached garages larger than 600 sq. ft., parcels having more than one building, etc.

- Disregard buildings identified by Cuyahoga County parcel data as slab construction or having no basement.

This process identified 13,200 buildings with basements that are served by the Cleveland Heights sanitary sewer system.

Figure 5-3. Example Area of Buildings with Sewer Service and Basements

Figure 5-4. Distribution of Building Area



The basement floor elevations were established by determining the ground surface elevation at the entrance to the building, adding 2.0 feet assuming 3 steps for each building, and subtracting an assumed 8 feet for basement depth below the first-floor elevation. The following sections detail the process.

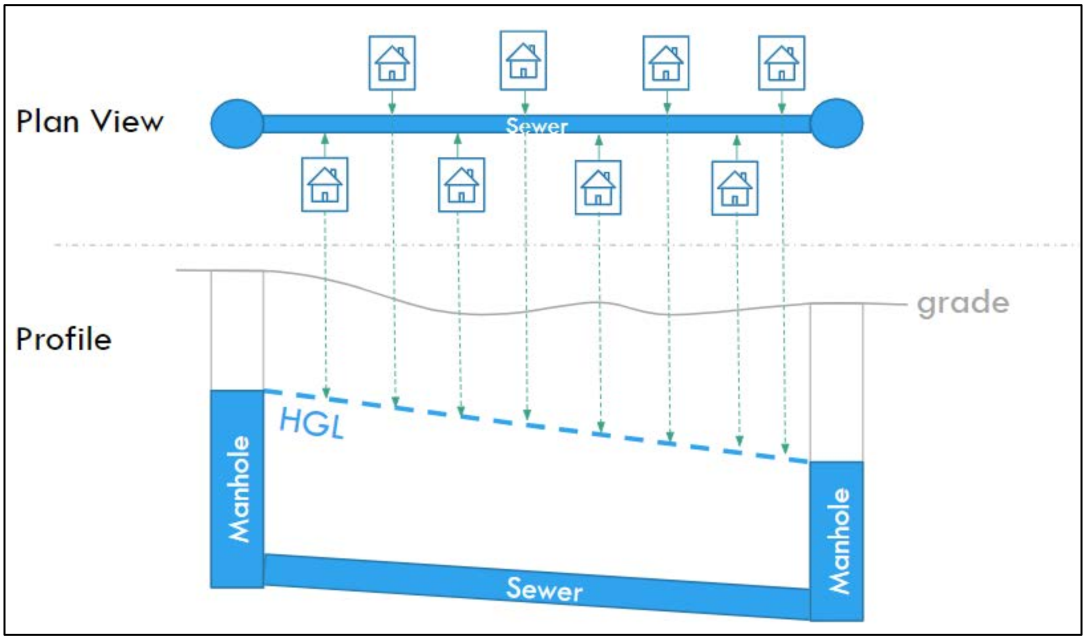
1. A topography analysis was performed to establish the ground surface elevation for each building. The analysis was performed by "clipping" the master image of the DEM and converting each clip to a set of elevation points. Using this set of elevation points, the minimum, maximum, and average building surface elevations were computed for each building in the study area. The maximum building surface elevations were used, assuming that the stairs are connected to the highest elevation around the building.
2. In Cleveland Heights, most buildings have stairs up to the first/ground floor. To take this additional elevation into account for determining basement flooding risk, Google Earth was used to check the number of steps of the building stairs for 10 representative streets across Cleveland Heights. The step count ranged from 3 to 5 steps, with a mean, median, and mode of 4.1, 4, and 5 steps, respectively. A slightly conservative assumption was used and a height of 2.0 feet (three 8-inch steps) was added to the maximum ground surface elevation to establish the approximate building first floor elevation.

3. The basement floor elevations were then estimated by subtracting 8 feet from the first-floor elevation.

Estimation Sewer HGL at Building Lateral Connections

The Cleveland Heights sewer network and buildings were grouped within each subcatchment. In each subcatchment, the building sanitary sewer laterals are assumed to discharge to the nearest modeled local sanitary sewer (perpendicular to the sanitary sewer). **Figure 5-5** shows an example area of the HGL interpolation at the building sewer laterals. The interpolated HGL elevations along the sewer at these locations are then used for comparison to the estimated basement floor elevation at each parcel with a basement.

Figure 5-5. Profile Example of HGL Interpolation



5.1.2 Results Summary

The wet weather flow capacity evaluation established the activation status of the 45 known SSOs, 70 dividing walls, and 17 piped access manholes. The 13,200 basements were assessed for backup risk. For SSOs, the total overflow volume was tabulated for each location. **Table 5-1** summarizes the activation status for each overflow and the quantities of basements at risk for each design storm. **Table 5-2** summarizes the individual SSO statistics for each rain event. **Figures 5-6** through **5-10** further illustrate the projected hydraulic capacity results for each rain event.

Table 5-1. Wet Weather Flow Capacity Evaluation Summary				
Category	Structural SSOs	Dividing Wall Manholes	Piped Access Over/under Manholes	Basement Backups
Total # Structures	45	70	17	13,200
Design Storm	Projected Active	Projected Active	Projected Active	Projected
Current DWF	0	0	0	0
Future DWF	0	0	0	0
2-year 1-hour	25	12	7	1,341
5-year 1-hour	27	17	8	2,027
10-year 1-hour	30	20	9	2,583
10-year 6-hour	30	21	9	2,868
25-year 1-hour	32	22	9	3,402

Table 5-2. Individual SSO Statistics					
SSO ID	2-yr, 1-hr (15min) overflow volume (MG)	5-yr, 1-hr (15min) overflow volume (MG)	10-yr, 1-hr (15min) overflow volume (MG)	10-yr, 6-hr (15min) overflow volume (MG)	25-yr, 1-hr (15min) overflow volume (MG)
CH-1	0	0	0	0	0
CH-2	0.005	0.013	0.019	0.037	0.028
CH-3	0	0	0	0	0
CH-4	0	0	0	0	0
CH-5	0	0	0	0	0
CH-6	0	0	0	0	0
CH-7	0	0	0	0	0
CH-9	0.087	0.108	0.127	0.222	0.158
CH-10	0	0	0.005	0.007	0.021
CH-11	0	0	0	0	0.000
CH-12	0.034	0.038	0.042	0.106	0.047
CH-13	0.028	0.040	0.049	0.067	0.065
CH-15	0	0	0	0	0
CH-17	0	0.001	0.004	0.005	0.010

Table 5-2. Individual SSO Statistics

SSO ID	2-yr, 1-hr (15min) overflow volume (MG)	5-yr, 1-hr (15min) overflow volume (MG)	10-yr, 1-hr (15min) overflow volume (MG)	10-yr, 6-hr (15min) overflow volume (MG)	25-yr, 1-hr (15min) overflow volume (MG)
CH-22	0.024	0.028	0.032	0.048	0.036
CH-23	0.009	0.016	0.022	0.036	0.035
CH-24	0.003	0.004	0.004	0.006	0.006
CH-25	0	0	0.003	0.006	0.008
CH-26	0	0	0	0	0
CH-27	0.050	0.080	0.106	0.136	0.149
CH-28	0.001	0.002	0.004	0.005	0.007
CH-30	0.066	0.075	0.081	0.156	0.087
CH-32	0	0.002	0.005	0.009	0.011
CH-33	0.036	0.045	0.063	0.218	0.113
CH-35	0.027	0.038	0.047	0.094	0.066
CH-36	0.003	0.004	0.006	0.010	0.008
CH-37	0.028	0.040	0.050	0.079	0.068
CH-38	0	0	0	0	0
CH-39	0.035	0.051	0.066	0.118	0.088
CH-42	0	0	0.000	0.001	0.005
CH-45	0.019	0.025	0.032	0.058	0.043
CH-46	0.025	0.038	0.048	0.059	0.066
CH-47	0	0	0	0	0
CH-49	0.006	0.011	0.015	0.023	0.022
CH-50	0.028	0.037	0.045	0.072	0.059
CH-51	0.176	0.207	0.232	0.476	0.272
CH-52	0	0	0	0	0.000
CH-54	0	0	0	0	0
CH-55	0.003	0.006	0.009	0.010	0.014
CH-56	0.114	0.131	0.146	0.283	0.169
CH-57	0.037	0.044	0.050	0.108	0.059
CH-58	0.030	0.037	0.042	0.068	0.049

Table 5-2. Individual SSO Statistics

SSO ID	2-yr, 1-hr (15min) overflow volume (MG)	5-yr, 1-hr (15min) overflow volume (MG)	10-yr, 1-hr (15min) overflow volume (MG)	10-yr, 6-hr (15min) overflow volume (MG)	25-yr, 1-hr (15min) overflow volume (MG)
CH-59	0	0	0	0	0
CH-60	0	0	0	0	0
CH-61	0.016	0.024	0.034	0.066	0.049
Total Volume	0.891	1.144	1.386	2.590	1.819

Evaluation of the existing peak dry weather flows concluded that no SSOs, dividing walls, or piped access pipes are active, and no basements are at risk.

Figure 5-6. Sanitary Sewer Capacity Evaluation for 2-Year, 1-Hour (15-Minute) Rainfall

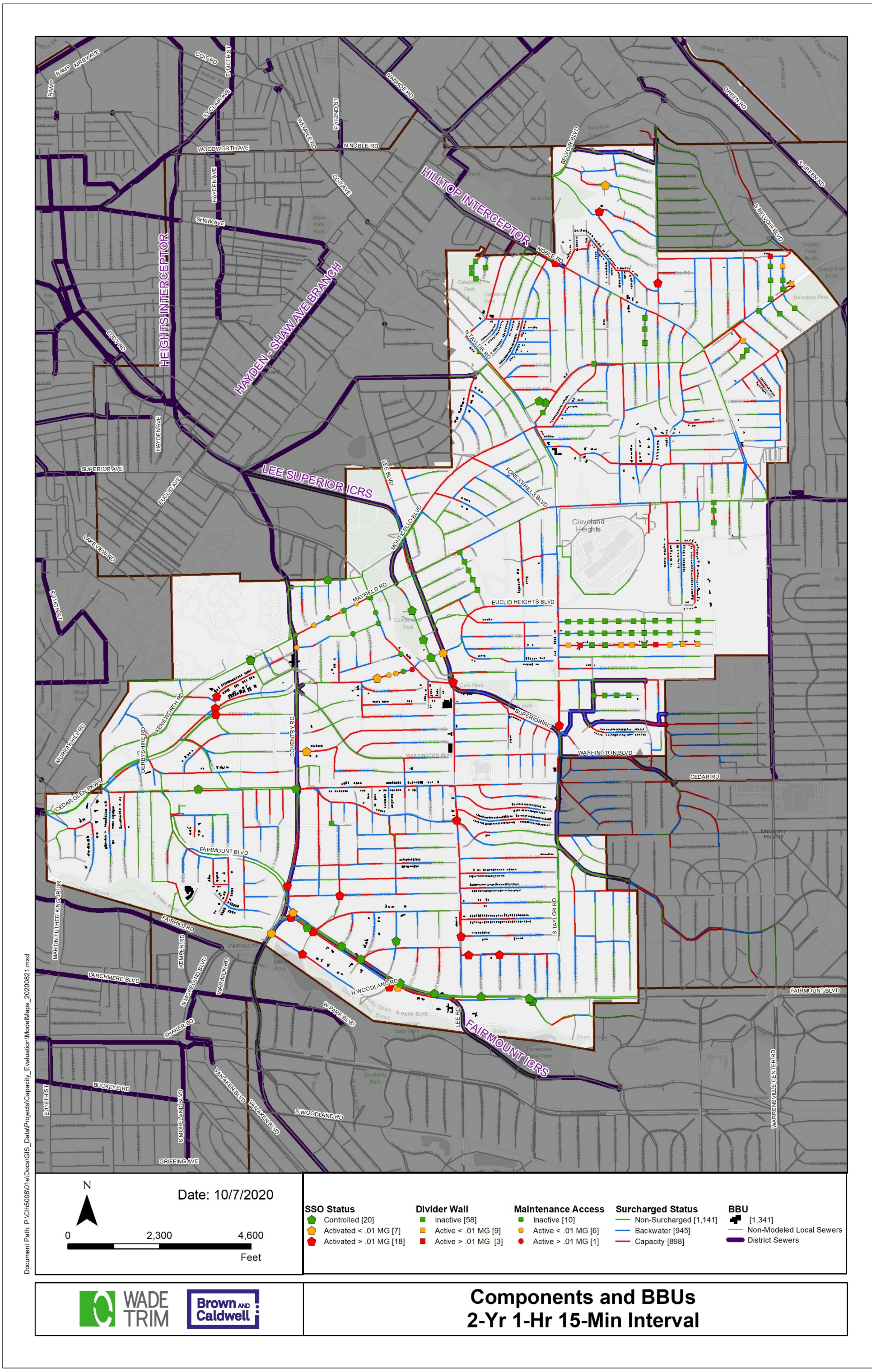


Figure 5-7. Sanitary Sewer Capacity Evaluation for 5-Year, 1-Hour (15-Minute) Rainfall

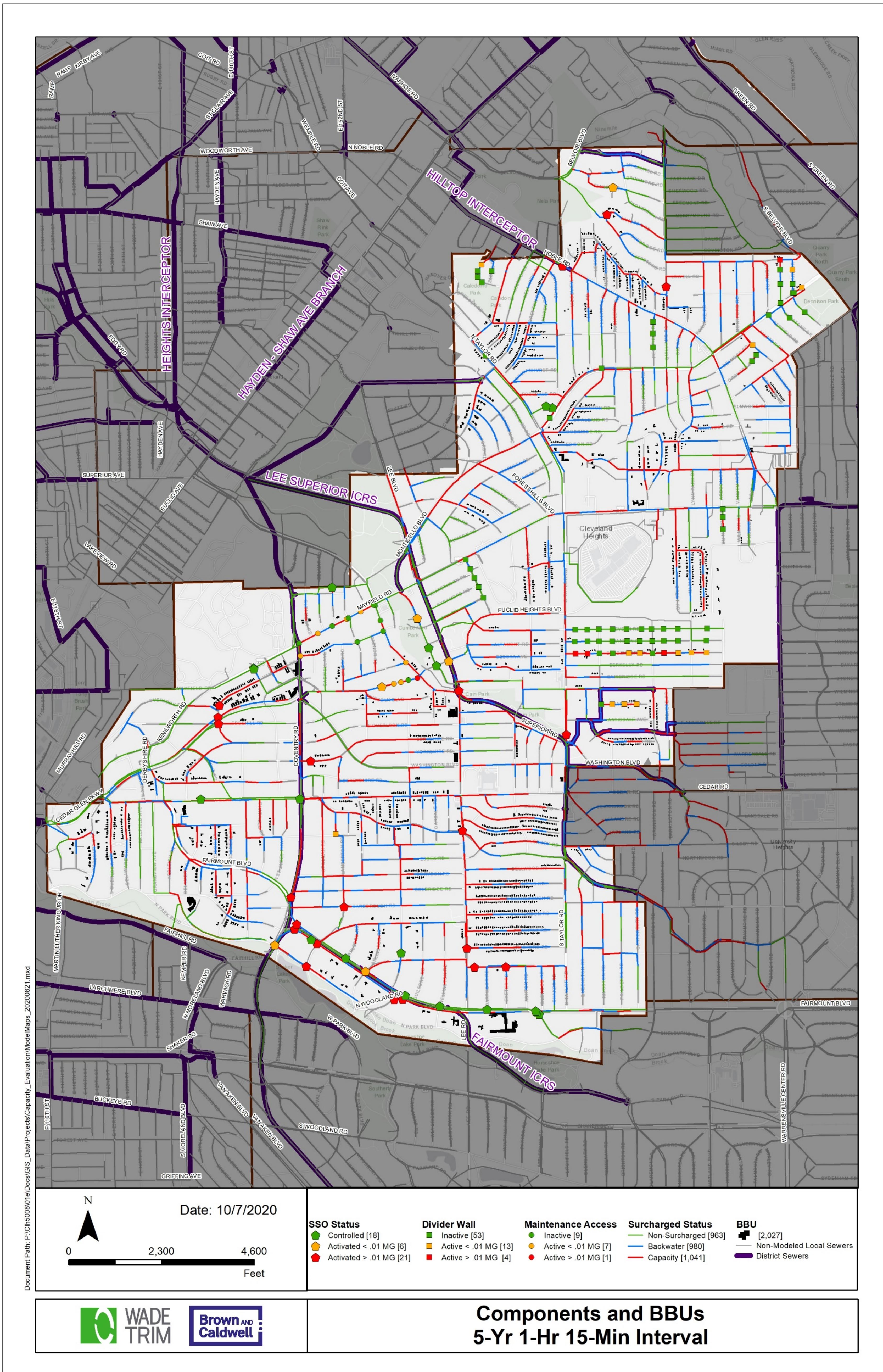


Figure 5-8. Sanitary Sewer Capacity Evaluation for 10-Year, 1-Hour (15-Minute) Rainfall

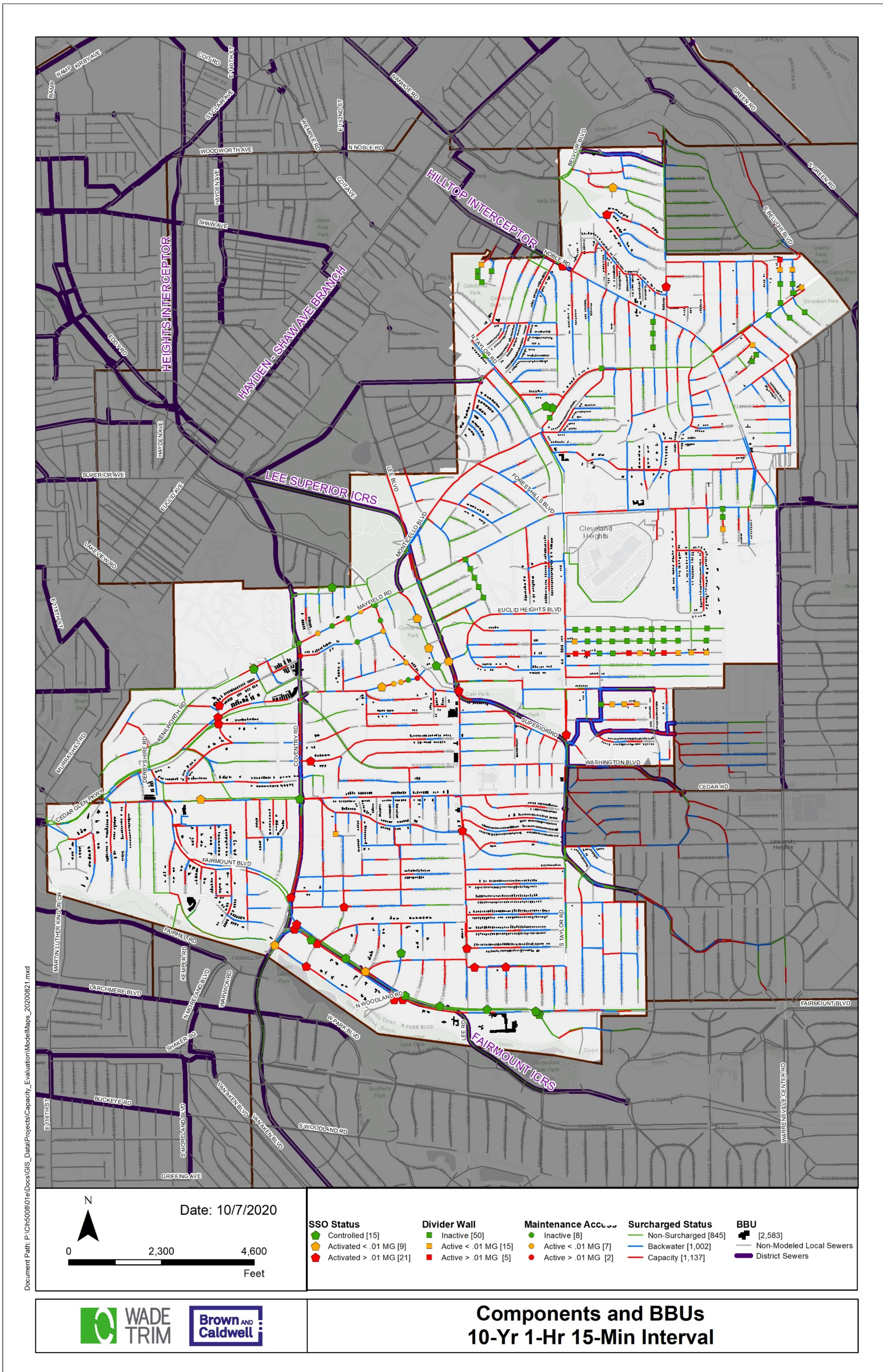


Figure 5-9. Sanitary Sewer Capacity Evaluation for 10-Year, 6-Hour (15-Minute) Rainfall

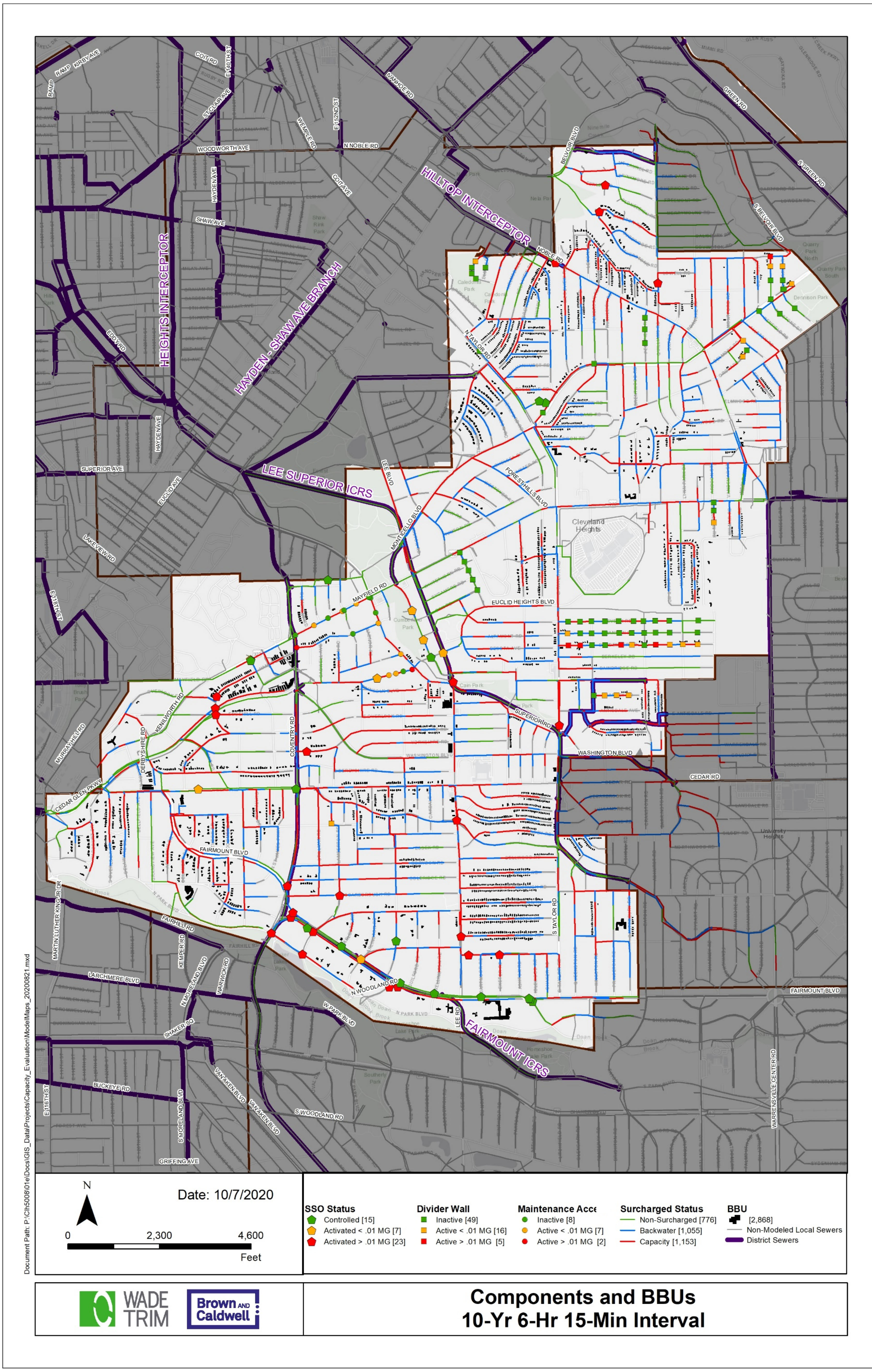
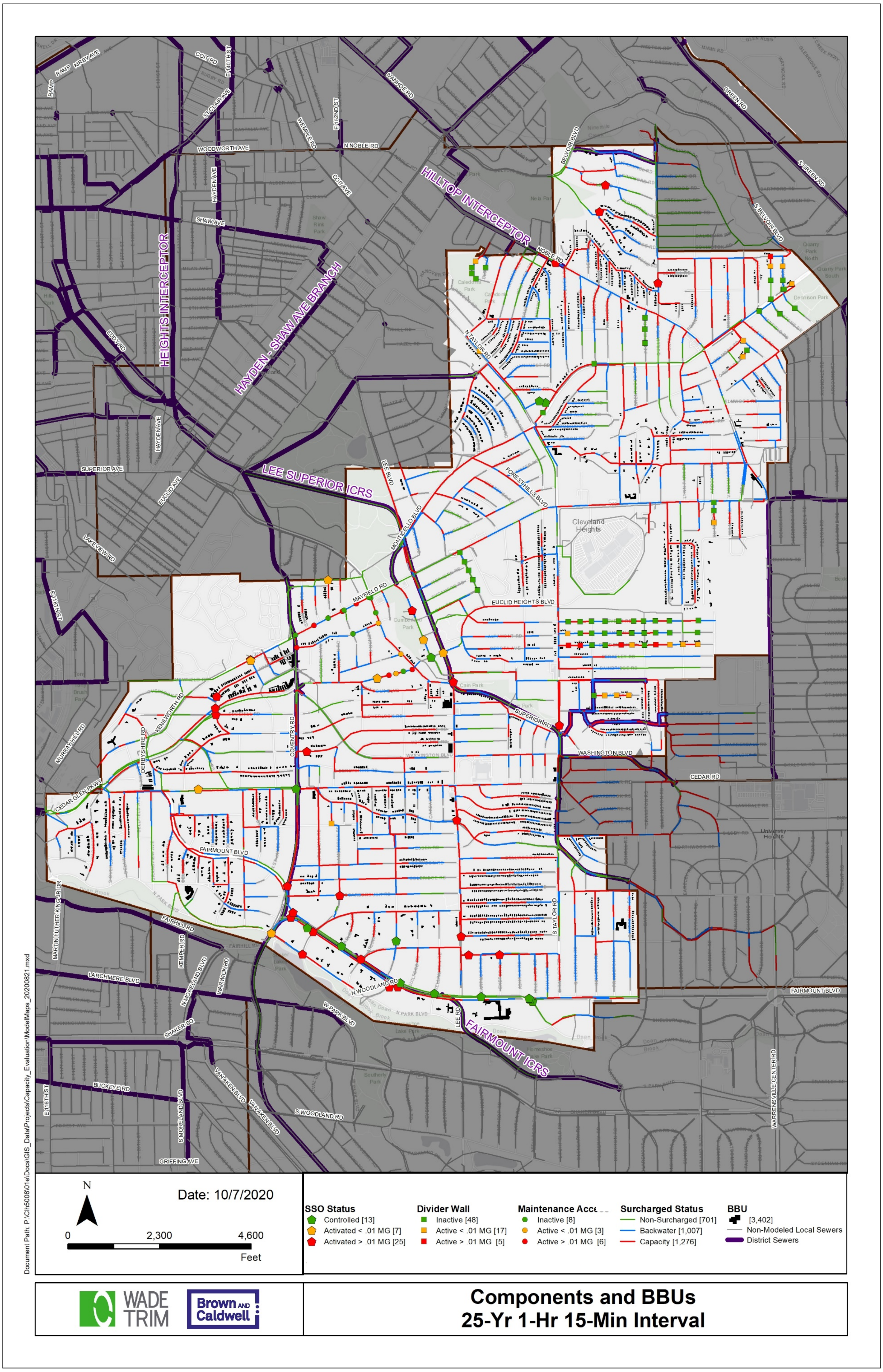


Figure 5-10. Sanitary Sewers Capacity Evaluation for 25-Year, 1-Hour (15-Minute) Rainfall



5.1.3 Future Sewage Flow Increases

Because Cleveland Heights is almost fully developed, the population is not expected to change significantly over the next 20 years. Cleveland Heights provided information for a few planned developments which was considered during analysis of alternatives, but significant future development is not forecast. Cuyahoga County does not have any population projections for Cleveland Heights and State of Ohio projections available at the county level are not useful for this analysis.

5.2 MUNICIPAL SEPARATE STORM SEWER SYSTEM (MS4) CAPACITY ANALYSIS

A separate analysis was performed to determine the approximate capacity of the municipal separate storm sewer system (MS4) using hydrology developed for previous District stormwater models in conjunction with the existing sewer system GIS. The following steps were performed for this analysis.

- Model subcatchment polygons from the District's Chagrin River and Lake Erie Tributaries Stormwater Master Plan were used as a base to divide the stormwater network. Subcatchments that shared a common outfall were combined. **Figure 5-11** shows the local stream watersheds and the associated drainage subcatchments based on the existing MS4 piping. **Figure 5-12** shows the same figure with the storm sewer network included.
- Storm sewers were loaded in the GIS geometric network and the flow accumulation tool from the Water Utility Network Reporting toolbar was used to calculate upstream tributary pipe lengths.
- Pipe lengths within each catchment were divided into total area to generate areas in acres per linear foot of pipe per subcatchment group.
- Pipes were assigned unique IDs for use in geoprocessing and summarizing steps. Pipes with missing pipe sizes were flagged and their pipe sizes assumed by viewing the pipe sizes of nearby connected pipes. The surface elevations of the pipe ends were extracted from the Cuyahoga County DEM and added as pipe attributes. The surface elevations of the pipe ends were used to attribute surface slope for each pipe. The standard minimum allowable pipe slopes were calculated for the pipe sizes present in the network, and then added as an attribute of each pipe.
- Pipes in the MS4 GIS network generally lack invert elevation and pipe slope attributes, therefore full pipe conveyance capacity cubic feet per second (cfs) was calculated using two methods: 1) if a pipe's associated ground surface slope was equal to or exceeded the standard minimum allowable pipe slope for the pipe's diameter, the Manning's full pipe normal flow equation (using n=0.013) was used with the ground slope to calculate full pipe conveyance capacity, or 2) if a pipe's ground surface slope was less than the standard minimum allowable pipe slope for the pipe's diameter, the pipe size and an assumed velocity of 2 feet per second (fps, Q=VA) were used to calculate full pipe

conveyance capacity. **Figure 5-13** shows pipe capacities in CFS per acre based on the estimated full-pipe capacities and the areas tributary to them.

- Peak runoff flows (cfs) for each subcatchment are based on the District stormwater models' hydrology for each watershed. Runoff for individual pipes was estimated for rainfall events from 2-year to 25-year based on proportionate tributary area. Peak runoff flow (cfs) for individual pipes was estimated using the following equation: Peak pipe flow = peak subcatchment runoff (cfs) x the pipe's upstream tributary area (acres) / total subcatchment area (acres).
- Level of service for each pipe was determined by comparing the pipe's estimated peak runoff flow from the modeled storm events to the full pipe conveyance capacity in CFS/acre. **Figure 5-14** displays the results. The figure shows that while many of the larger culverted streams and some local storm sewers provide capacity for 10-year and larger rainfalls, many of the local storm sewers provide capacity for less than the 5-year rainfall. This is consistent with anecdotal information about local stormwater drainage performance.

Figure 5-11. Cleveland Heights Storm Sewer System Watersheds and Subcatchments

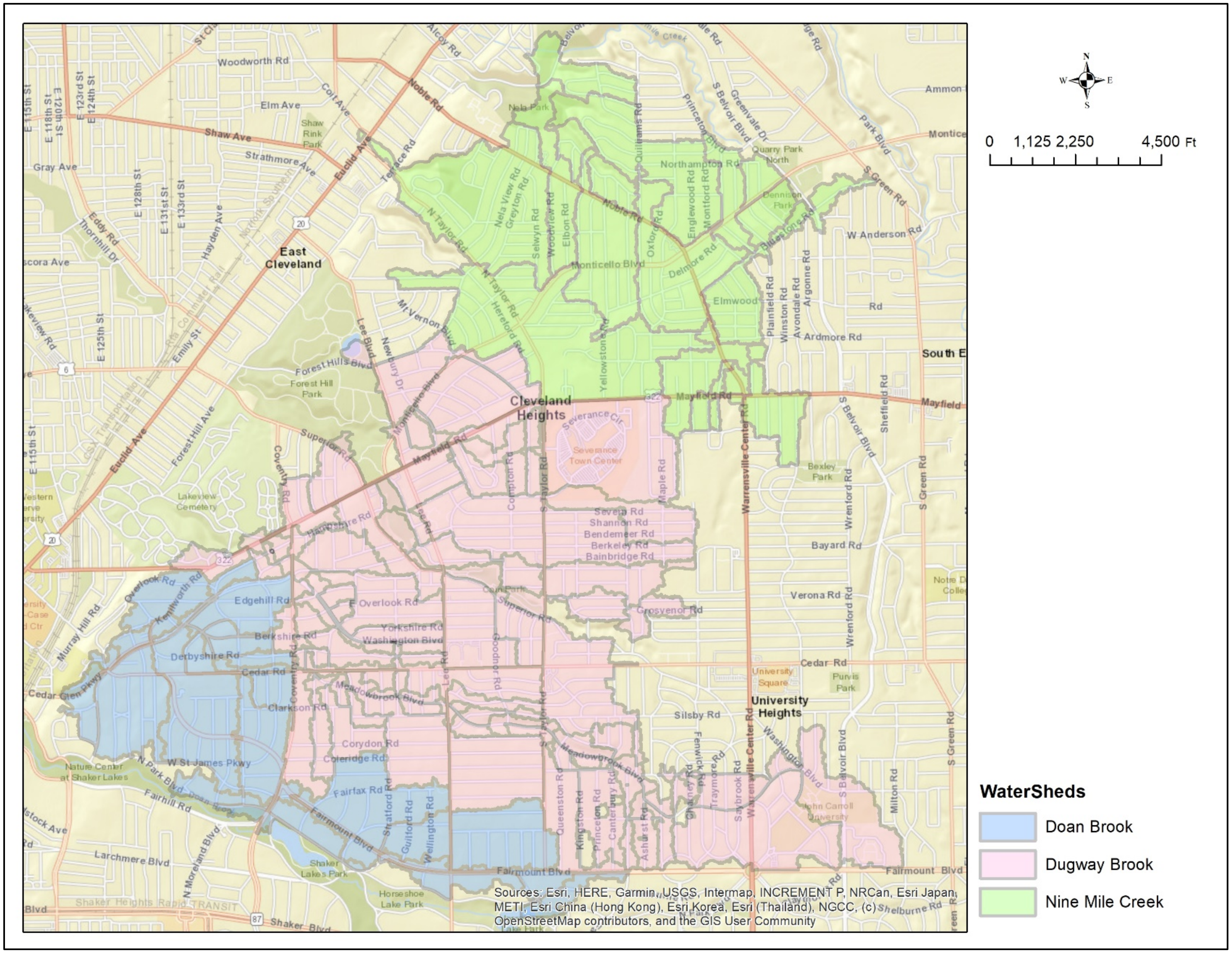


Figure 5-12. Cleveland Heights Storm Sewer System and Watersheds

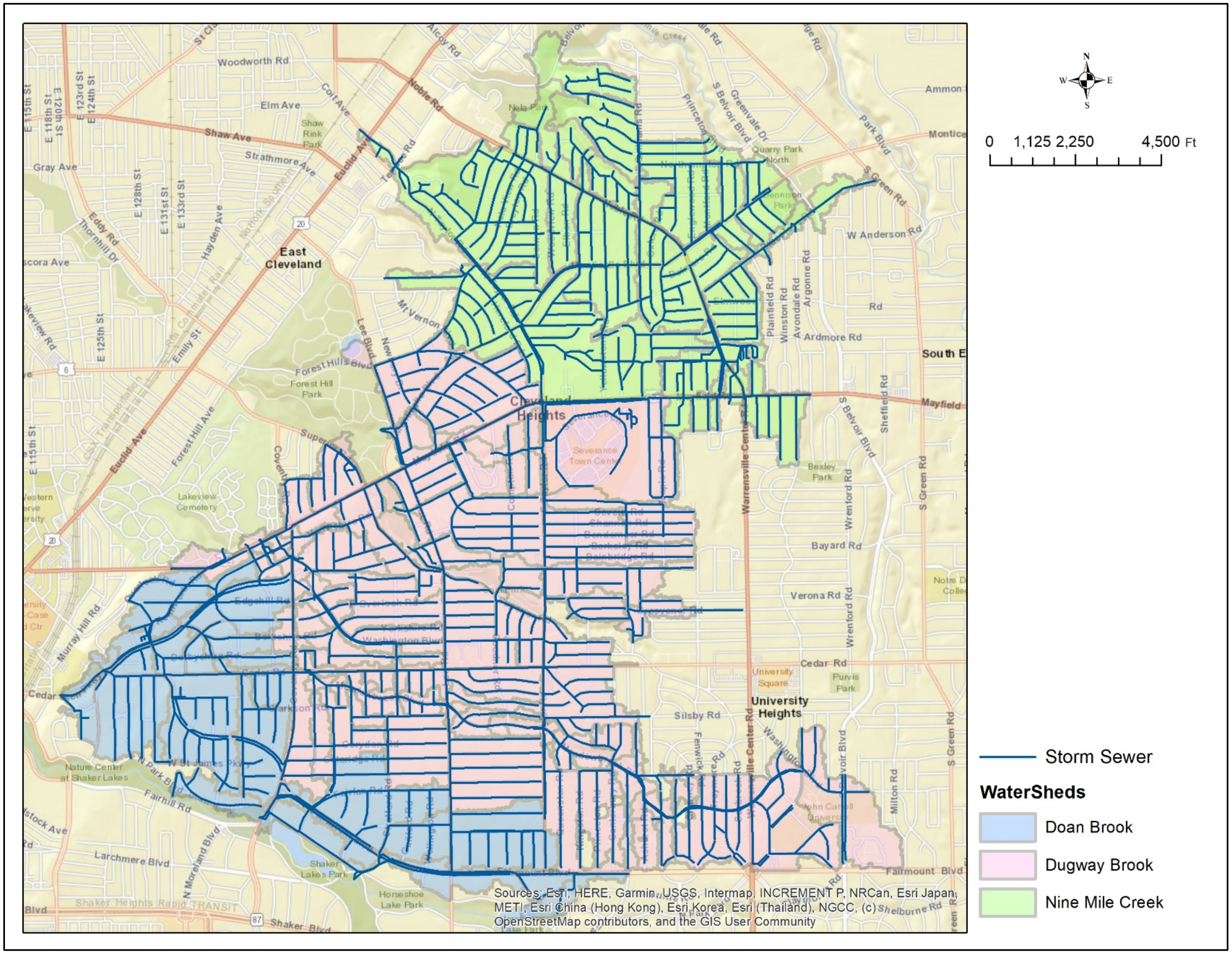


Figure 5-13. Cleveland Heights Storm Sewer System Approximate Capacities (CFS per acre)

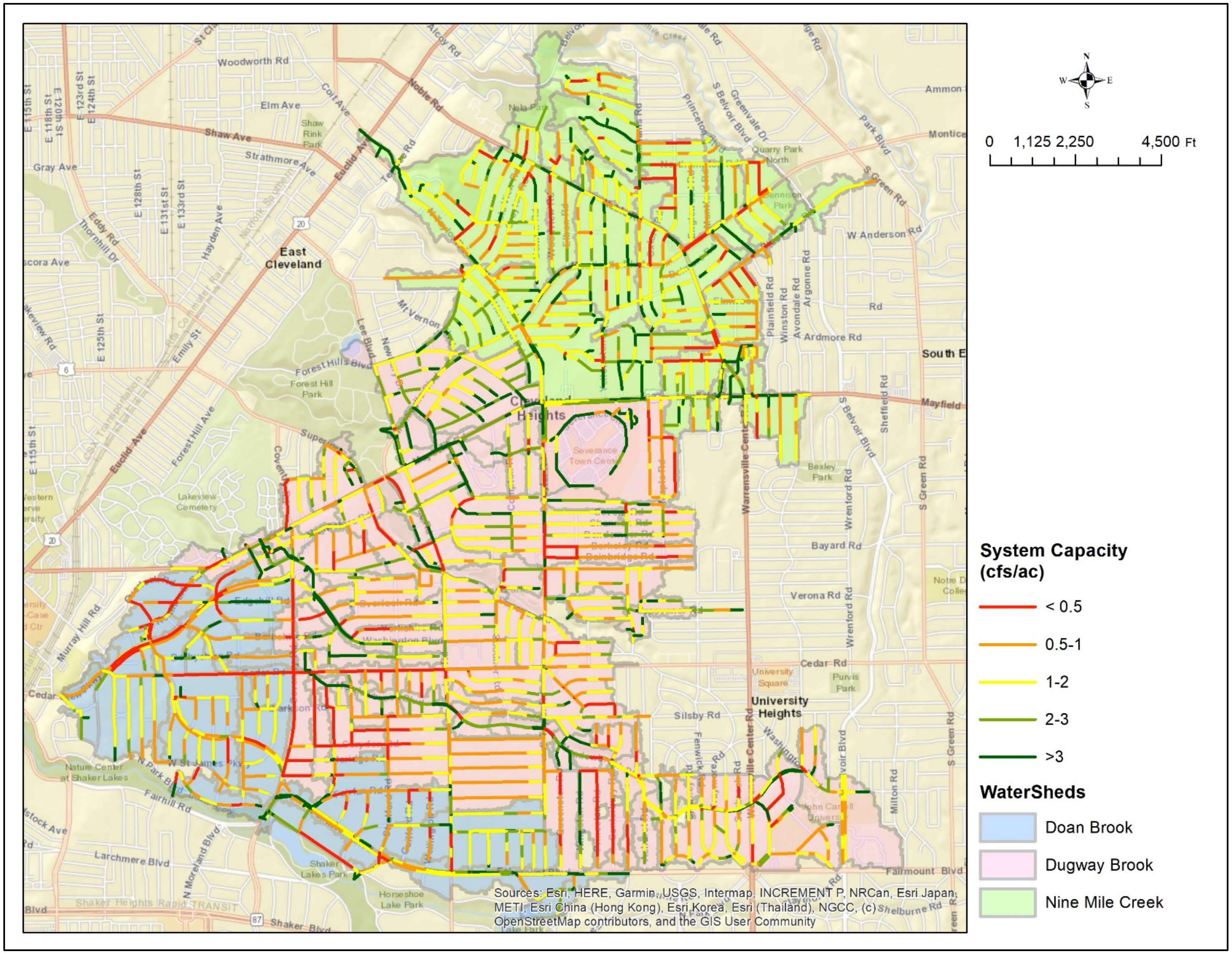
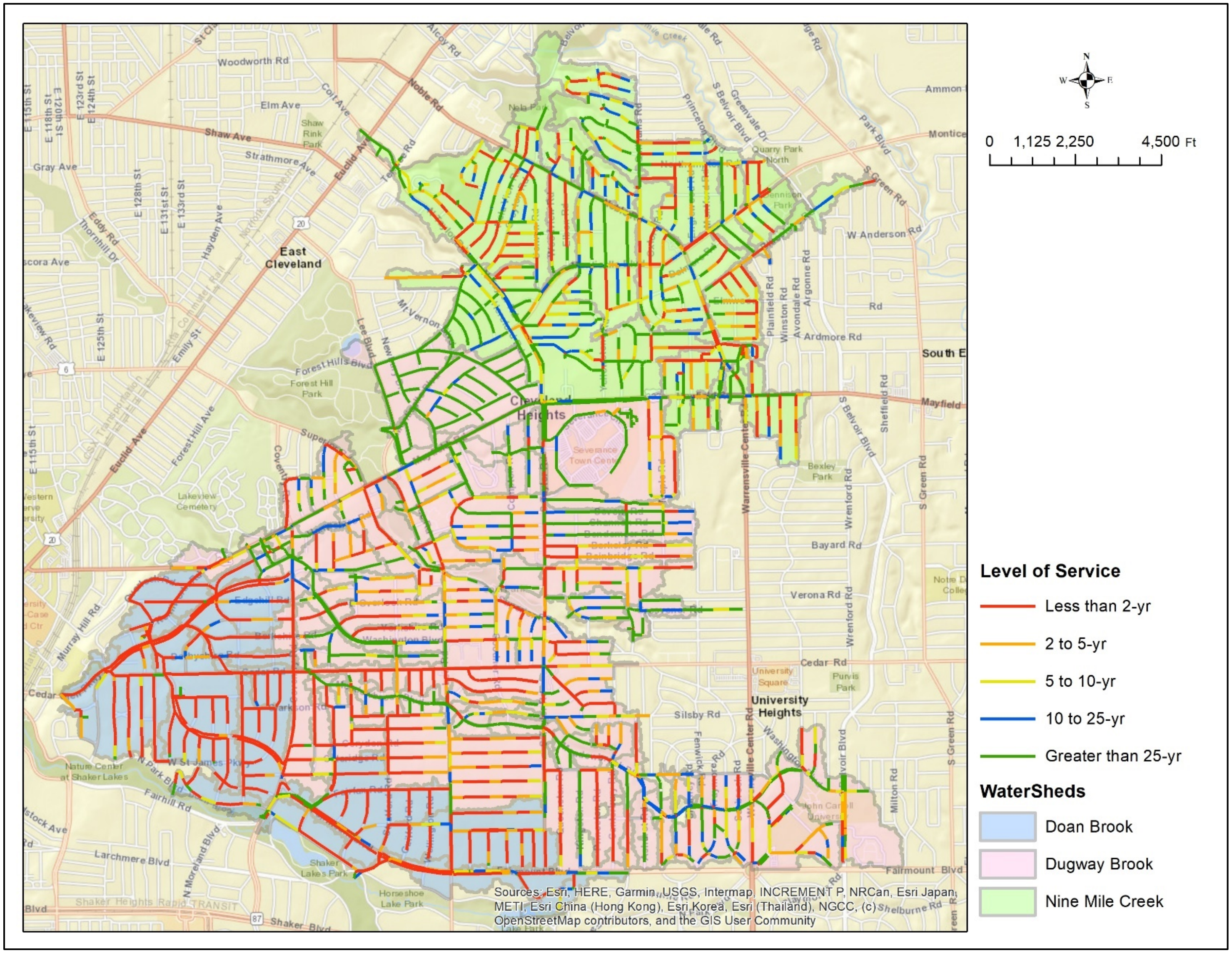


Figure 5-14. Cleveland Hts Storm Sewers Approximate Level of Service (return frequency)



5.3 CAPACITY AND PERFORMANCE DISCUSSION

This section summarizes observations and conclusions from the capacity assessment analysis.

1. The Cleveland Heights sewer system and most other predominantly common trench systems in the District service area have proven challenging to model for existing conditions. This is primarily due to the often-numerous distributed infiltration sources that allow water to pass from the higher storm sewers to the lower sanitary sewers in the common trench areas. This is further compounded by a similar configuration along the private property storm and sanitary service laterals.
2. Counteracting the leaky systems to varying extent are the annular sewer trench volumes along the sewers and on private property that are believed to provide significant temporary storage volume for wet weather flows that may exceed the sanitary and storm sewer system capacities. This appears to dampen the peak flow response and lower the peak HGL elevation during larger rainfalls.
3. The stormwater drainage system analysis indicates that much of the local storm sewer system likely provides less than a 5-year rainfall capacity (**Figure 5-14**), so to the extent the system defects allow sanitary sewer infiltration from the storm sewers, the relatively low stormwater drainage system capacities would tend to increase the storm sewer exfiltration and sanitary sewer infiltration rates.

   SSOs and basement backups are the two primary concerns for Cleveland Heights. Each improvement project will also consider localized stormwater drainage problems and potential improvements needed, including substantial increases in localized stormwater capacity, during project definition investigations and preliminary design, but a system-wide stormwater drainage capacity increase to provide control for 10- or 25-year rainfalls is not expected to be cost-effective or affordable. Cleveland Heights expects that in most, if not all cases, however, the SSOs, all of which have relatively small flows and volumes, can likely be controlled via diversion to District sewers, even during larger rainfall events such as the 5-year and 10-year events. The District supports this approach but has also indicated that they will require long-term I/I reduction efforts in areas with excessive wet weather flows. They are currently revising their Title III Separate Sanitary Sewer Code, which is expected to reflect this requirement. Prior to completion of the evaluation of control measures, Cleveland Heights will coordinate with the District to ensure that likely District limitations are considered during the evaluation and selection of controls.

   Where improvements are proposed to address basement backups, a combination of I/I reduction and additional capacity and/or inline storage may be considered. The projects will be designed to accommodate the agreed upon design event based on the calibrated model, and successive post-construction monitoring and analysis will determine if more aggressive I/I control is needed and where it should be applied. A key factor over the course of the IOCMP improvements will be to monitor and adapt the successive designs to optimize performance and minimize cost, while meeting the agreed upon design level of service and SSO control performance.

4. Nevertheless, there have been remarkably few basement backup complaints registered with the City, particularly since starting the CMOM and SSES cleaning and televising efforts. A proposed survey to check on sewer system performance problems should help confirm this performance.
5. The capacity evaluation figures (**Figures 5-6** through **5-10**) for the 2-year to 25-year rainfalls indicate that while the number of BBUs and SSOs and SSO volumes increase for the larger rainfalls, they tend to remain primarily in the same areas.
6. The capacity assessment and associated model adequately define the projected overflows and potential capacity problem areas to allow development and comparison of potential remedial measures. However, projection of system performance for the larger 10-year and 25-year rainfall events may be significantly less accurate because neither the local sanitary nor storm sewer system has been calibrated to the larger rainfalls. As such, the inclusion of safety factors for control measures for these larger events will be particularly important. In considering the routing of overflows from the larger storms to District sewers, Cleveland Heights will also consider the magnitude of those flows as compared to the available capacity in the District sewers, as well as any likely future District limitations on the amount of I/I to be accepted by the District.
7. Also, because much of the local storm and sanitary sewer systems do not have capacity for the 10- to 25-year rainfalls, the actual sanitary sewer system performance may be significantly worse than projected for larger events, particularly in common trench areas. This implies that sewer separation and/or significant sewer system rehabilitation and increased sanitary sewer and stormwater drainage capacity would likely be needed in the public ROW and on private property in many areas to significantly improve performance for the larger rainfalls. These conditions were considered during the alternatives development, costing, and comparison as part of the IOCMP development and will also be considered during project definition and preliminary design phases of each project. As noted elsewhere, the IOCMP program and successive projects will benefit from performance information learned from each completed project.

8. It has also been observed that inadequate maintenance of private property stormwater and sanitary service laterals may contribute significantly to high I/I rates and performance problems. Local plumbing contractors have observed that stormwater service laterals are often not adequately maintained, leading to obstructions caused by leaves and other materials washed from roofs and yard drains. The aged, plugged stormwater laterals then tend to discharge impounded stormwater to the common trench and into leaky sanitary service laterals.
9. Based on the District and Cleveland Heights project analyses to date, identification, and prioritization of potential remedial measures as part of the IOCMP will likely include consideration of reported vs. projected problems, SSO frequency/activation rainfall and volume, sewer system physical condition, and known operations and maintenance issues.

6.0 DEVIATIONS FROM THE SYSTEM MODELING PLAN

The following items describe the deviations from the system modeling plan.

- All qualifying rainfall events were used for calibration rather than selecting at least three storm events for verification. This is consistent with current industry practice.
- The model was developed in Innovyze InfoWorks ICM 9.5 model (Version 9.5.1.19011 Unicode December 2018) rather than InfoWorks ICM 7.5 (Version 7.5.0.15014 Unicode November 2016). The newer version was used per the updated District modeling standards.

7.0 UPCOMING DELIVERABLES

This section is no longer needed in this report, as all required deliverables were submitted on or before the respective due dates.

~~Cleveland Heights will be using this capacity assessment with the findings of the SSES and District LSSES projects to develop the Integrated Overflow Control Master Plan (IOCMP). The IOCMP will:~~

- ~~Use a first-stage screening process to identify technically practical controls to meet the CD requirements~~
- ~~Identify the sizes of such practical controls required to provide adequate capacity in each of the storm events included in Section V of Appendix A of the Consent Decree~~
- ~~Provide estimates of the (1) capital, operation and maintenance, and present-value costs and (2) time required for design, construction, and implementation for each measure identified as technically practical after the first-stage screening process, year-specific dollars~~
- ~~Identify the specific remedial measures the City will undertake that will (1) result in the control of SSOs; and (2) ensure that there is adequate capacity in the sanitary sewer system to collect and convey anticipated peak flows under current and future conditions~~
- ~~Propose an implementation schedule for the selected remedial measures including dates for the notice to proceed, beginning of construction, completion of project, and placement in operation~~
- ~~Identify a plan for monitoring and modeling to evaluate success of the remedial measures.~~

~~The IOCMP is due to USEPA on or before June 1, 2021. The Phase 2 SSES efforts are to be completed by June 30, 2021, with the Phase 2 SSES report due on or before September 30, 2021. Any significant findings from the Phase 2 SSES will be included in the IOCMP.~~

Appendices

APPENDIX 1: SYSTEM CHARACTERIZATION MONITORING PLAN

APPENDIX 2: SYSTEM MODELING PLAN

APPENDIX 3: DISTRICT MODELING STANDARDS

APPENDIX 4: SITE INSTALLATION SHEETS

APPENDIX 5: SUMMARY MATRIX OF METER PERFORMANCE

APPENDIX 6: METER SCHEMATIC OF CONNECTIVITY (REVISED)

APPENDIX 7: METER VS MODEL STATISTICS, PLOTS, AND DISCUSSION OF EACH CALIBRATION METER