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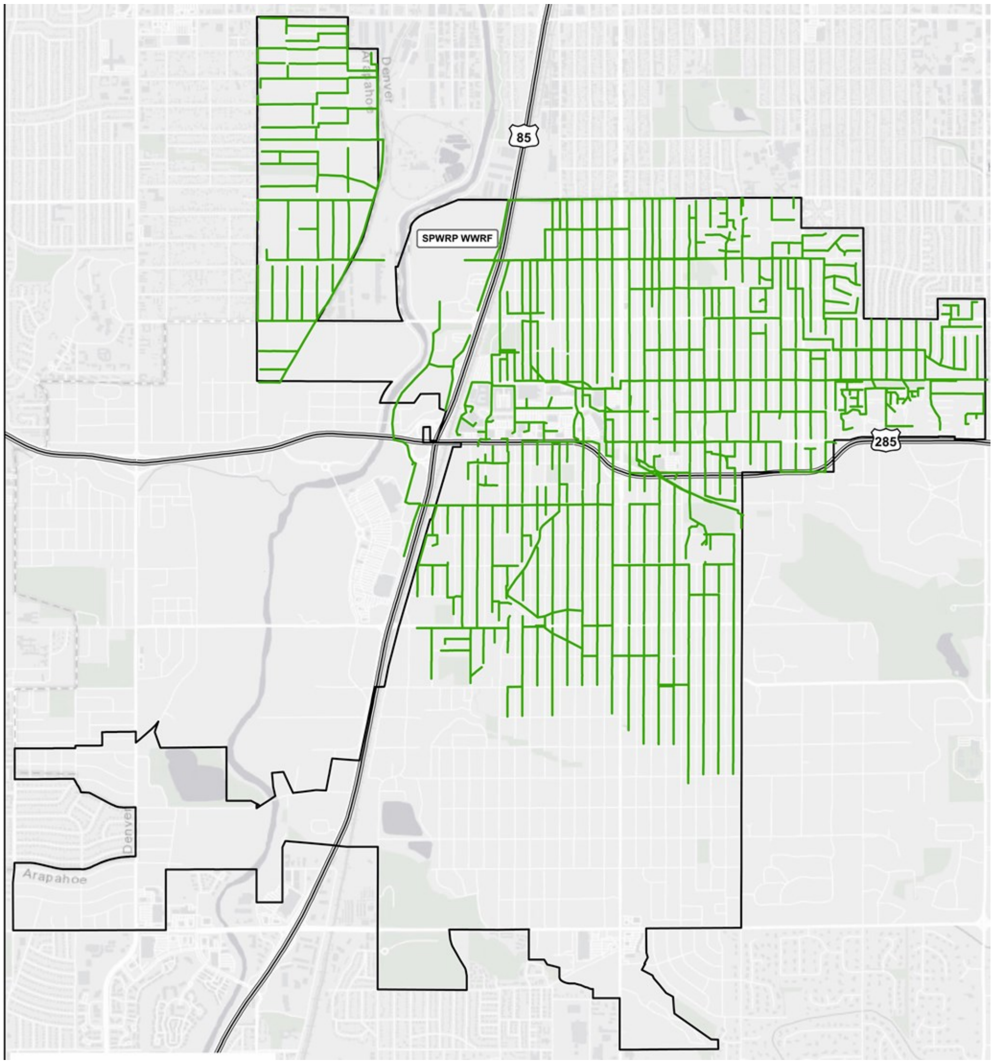

City of Englewood Sewer System Master Plan

Final Plan
Hazen No. 70035-000
May 2020

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List of Acronyms

Abbreviation	Definition
AACEi	Association for the Advancement of Cost Engineering International
AWWA	American Water Works Association
BDCI	Big Dry Creek Interceptor
CAMP	Comprehensive Asset Management Program
CCTV	Closed Circuit Television
CIP	Capital Improvement Plan/Capital Improvement Program
CIPP	Cured-In-Place Pipe
CMMS	Computerized Maintenance Management Systems
CO	Certificate of Occupancy
CoF	Consequence of Failure
DEM	Digital Elevation Model
d/D	depth/Diameter
EAM	Enterprise Asset Management

Abbreviation	Definition
EPA	Environmental Protection Agency
ft	feet
FTE	Full-Time Equivalent
ft/sec, ft/s	feet per second
GIS	Geographic Information Systems
GPD	Gallons Per Day
HDPE	High-Density Polyethylene
HGL	Hydraulic Grade Line
in	inches
I/I	Inflow/Infiltration
LF	Linear Feet
LoF	Likelihood of Failure
MACP	Manhole Assessment Certification Program
MGD	Million Gallons per Day
MH	Manhole
MWRD	Metro Water Reclamation District
NASSCO	National Association of Sewer Service Companies
O&M	Operation and Maintenance
PACP	Pipeline Assessment Certification Program
PVC	Polyvinyl Chloride
QC	Quality Control
RCP	Reinforced Concrete Pipe
RDII	Rainfall Dependent Infiltration and Inflow
R/R	Repair and Replacement
SPWRP	South Platte Water Renewal Partners
SSO	Sanitary Sewer Overflow
SSOAP	Sanitary Sewer Overflow Analysis and Planning

Abbreviation	Definition
VCP	Vitrified Clay Pipe
WaPUG	Wastewater Planning Users Group
WRRF	Water Resource Recovery Facility
WWTP	Wastewater Treatment Plant

Executive Summary

Scope and Purpose

The City of Englewood (City) has chosen to initiate a comprehensive Sewer Master Plan for the sewer collection system owned and maintained by the City. In September 2019, the City selected Hazen and Sawyer (Hazen) and our teammate Bai Engineers (Bai) to develop the Sewer Master Plan (Plan). This report establishes an initial Master Plan for the City's sewer collection system, providing an overall evaluation of the system and an understanding of existing and future needs. The Master Plan includes a proposed 15-year Capital Improvement Plan (CIP). This Plan will serve as an adaptive and evolving instrument for the City to use for long-term planning. It is intended that amendments or updates to the Plan will be developed as new information becomes available about the system and/or as the physical system or needs evolve.

An overview of the tasks included in this study is provided below, and each task is described in further detail throughout the report:

- Reviewed existing information available for the sewer collection system
- Collected level and rainfall monitoring data
- Developed and calibrated a sewer hydrologic/hydraulic model
- Conducted capacity evaluations and identified deficiencies
- Performed a desktop risk assessment on sewer interceptors
- Developed recommended programs (and costs) to increase sewer system reliability and effectively allocate sewer system funds and City resources
- Facilitated prioritization workshops with City staff
- Recommended a 15-year CIP

Existing System Review

Seven utilities own sanitary sewer mains within Englewood's City limits. The existing sewer collection system owned and maintained by the City consists of approximately 80 miles of pipe. The majority of wastewater flows collected within the City's system are treated at the South Platte Water Renewal Partner's (SPWRP) Water Resource Recovery Facility (WRRF). A small portion of the City's collection system discharges to the Metro Wastewater Reclamation District.

Level and Rainfall Monitoring

Five level monitors and one rain gauge were installed to collect data from October 18, 2019 to December 11, 2019 in order to characterize system operation during dry and wet weather conditions. This data was used to calibrate the sewer model. No rainfall events were recorded during the monitoring period. The system's response to snow melting events was observed.

Sewer Model Development

The sewer system model developed for this Plan includes sewer mains 15 inches in diameter and larger, with some smaller sewers included for connectivity. The model database was populated with sewer network data from the City's GIS database. Where GIS data were missing or contained obvious errors, the model was updated based on available records or field surveys. The model includes gravity mains and manholes as appropriate to represent the collection system. There are no pump stations or diversion structures in the system. The model is a subset of the actual collection system, and as such contains nine (9) miles of gravity sewer.

The model was calibrated within industry standard Wastewater Planning Users Group (WaPUG) guidelines for error tolerance, under dry weather conditions. Wet weather calibration could not be performed due to the lack of rainfall events recorded during the monitoring period.

Capacity Evaluation

The model was used to simulate the system's response to dry and wet weather flows. Wet weather was simulated for five design storms using peaking factors applied to the average dry weather flow. The peaking factors were obtained from the 2011 Littleton/Englewood Wastewater Treatment Plant Infiltration/Inflow Study. A capacity evaluation was conducted for dry weather and the five design storm events. System velocities were also assessed under dry weather conditions. Future flow projections were based on an assumed uniform three percent increase in flows across the sewer system by year 2030, as required by the scope for this Master Plan.

Low velocities (less than 2 feet per second) were identified throughout the collection system even during peak hour flow under dry weather conditions. The sewer mains with lower velocities (nearly 50 percent of the system) are more susceptible to debris accumulation. These areas should be monitored more frequently, and the cleaning frequency optimized based on monitored results.

No dry weather surcharging was predicted by the model under the baseline or future (Year 2030) scenarios. During wet weather, surcharging was predicted starting at the 10-year, 6-hour storm under baseline conditions and the magnitude of surcharging increased for the larger design storms and future conditions. Sanitary sewer overflows (SSOs) are not predicted by the model until the 50-year, 6-hour storm event under the future scenario.

Overall, most of the modeled sewer system is able to convey current and future dry and wet weather flows without pipe surcharging. However, confidence in the wet weather capacity assessment is limited due to the lack of rainfall events and associated system response recorded during the monitoring period. Additional flow and rainfall monitoring during the Spring season should be performed for model verification and validation of wet weather capacity evaluation results. In addition, local capacity restrictions are possible in the smaller diameter sewers that were not modeled. In areas where localized capacity is a concern, particularly in areas of planned or on-going re-development, it is recommended that the model be expanded to include the collection system serving these areas.

System Risk Assessment

A desktop risk assessment was conducted for the City's sewer interceptors (15 inches in diameter and larger). The purpose of the risk assessment was to establish the existing condition of critical assets and to identify and prioritize repair and replacement (R/R) projects to be included in the CIP. Each asset was assigned Likelihood of Failure (LoF) and Consequence of Failure (CoF) scores. These scores were then combined to form overall risk scores, which were used to recommend the best management approach for each asset. LoF was based on pipe age (where available) and pipe material. CoF was based on the pipe's location, depth, and diameter.

There is very limited CCTV inspection data available for the assets within the risk assessment. Due to the low cost of sewer main inspection relative to the cost of rehabilitation or replacement, it is recommended that the City perform comprehensive CCTV inspections of the sewer system before identifying R/R projects. The CCTV inspections should be prioritized according the asset risk ratings developed under this Master Plan and the City's institutional knowledge of the system. Following completion of the CCTV inspections, the LoF scores for each asset should be updated to incorporate the inspection results. R/R projects can then be developed by leveraging the CCTV inspection results.

Key Master Plan Findings

The following describes the key findings used to develop the 15-year CIP. These are the top priority issues found during this project.

- The collection system is aging and the subject of corrective maintenance instead of the more preferred preventative maintenance practices.
- Limited CCTV and manhole inspection data for the sewer system is available. The existing condition of most assets is unknown.
- A formal sewer/manhole rehabilitation program to renew assets based on condition/criticality assessments does not exist.
- The utility will need formal programs to proactively assess, maintain and upgrade aging infrastructure.
- Existing policies do not adequately address the type of redevelopment that the City is experiencing.

Sewer Program Identification

The City can make significant improvements to the existing sanitary sewer system through the establishment of formal programs and the execution of specific capital improvement projects. Programs are on-going activities intended to proactively maintain and upgrade infrastructure. They vary in size and cost with several continuing indefinitely. As each program is implemented, the City will gain a more comprehensive understanding of the sanitary sewer infrastructure. Correspondingly, projects are discreet, one-time activities with limited scope and duration.

This Plan prioritizes projects and programs into the following three categories:

- <u>High Priority</u>: If these projects and programs are not completed, risk of service disruption to customers is significant and more immediate. High priority projects and programs should begin in the next 1 to 2 years.

- Medium Priority: If these projects and programs are not completed, risk of service disruption to customers may be possible in the future. Medium priority projects and programs should begin in the next 3 to 5 years.

- Long-Range: These projects and programs should be considered for implementation after 5 years.

Based on a comprehensive analysis of the sewer system as previously described, thirteen programs were recommended for the sewer collection system. In addition, the City's portion of the SPWRP Capital Plan expenditures is included as a program. Several policy recommendations were also identified based on discussions with the City's Utilities staff and review of the City's existing policies.

The following lists the High Priority Programs recommended for Englewood's sewer system:

- SPWRP Capital Plan: This is the amount of the WRRF's Capital Plan expenditures that is paid from the City's sewer enterprise fund. Similar to the sewer collection CIP, the WRRF CIP has high priority, medium priority, and long-range projects. Englewood's portion of the WRRF CIP budget expenses is shown in Table ES-1 on page ES-5 within the three program categories based on project timing.

- GIS System Updates: The City has an excellent sewer GIS database but there are data gaps that need to be addressed. This program is a one-time update of the existing GIS data to fill in these gaps followed by additional regular updates of the GIS as new information becomes available or the physical system changes.

- CCTV Inspections/Cleaning: This program will collect condition assessment data on the City's 80 miles of sewer mains and provide the City with a far better understanding of the system's deficiencies and needs.

- Manhole Inspections: In conjunction with the CCTV inspections, all 1,558 manholes should be inspected to evaluate their condition and identify deficiencies/needs.

- Emergency Repair Projects: Funding should be allocated to an annual emergency repair program to address critical defects in the sewer system as they occur and/or are identified through the inspection programs.

- Enterprise Asset Management (EAM): EAM systems facilitate work planning, execution, reporting, and system analysis. The City's Infor EAM system should be assessed, and work processes updated to leverage the full capabilities of the system.

- Comprehensive Asset Management Program: This program will enable the City to pro-actively manage the sewer system assets based on the condition/criticality of each asset. The results are an evolving prioritized plan for asset renewal, system upgrades and O&M activities to minimize risk.

The following lists the Medium Priority Programs recommended for Englewood's sewer system:

- Sewer Main Rehabilitation/Replacement: The City typically repairs sewer mains only as critical defects occur. A program is recommended to systematically rehabilitate aging and deteriorating sewer mains to improve system reliability.
- Manhole Rehabilitation/Replacement: In conjunction with the sewer rehabilitation program, the City should systematically rehabilitate the system's manholes.
- Program Management: The recommended programs will require dedicated resources to manage scope, budget and schedule of implementation.
- Construction Management: The recommended programs will require dedicated resources to manage schedule, cost, quality and safety of the construction contracts.

The following lists the Long-Range Programs recommended for Englewood's sewer system:

- Flow and Rainfall Monitoring: The purpose of this program is to collect data for characterization of dry-weather and wet-weather flow conditions in the system. This data is important for calibrating the existing sewer model and assessing the system's capacity under a range of conditions.
- Model Expansion, Re-Calibration and Updates: The model developed under this Master Plan should be expanded to include smaller diameter sewers and re-calibrated based on additional flow and rainfall monitoring data. This will provide better confidence in the capacity assessments performed with the model and identify any local capacity restrictions in the smaller diameter pipes.
- Sewer Master Plan and Model Updates: Models and Master Plans are intended to be adaptive and evolving tools for long-term planning. They should be updated periodically based on system changes and evolving needs/priorities.

Capital Improvement Plan Budget Estimate

The projected cost of the programs for the sewer system, including sewer collection and treatment, is estimated to be approximately $61 million over the next 15 years, based on 2020 dollars. Table ES-1 summarizes the budgeted costs for all recommended programs.

Table ES-1: Budget Summary of Recommended CIP Programs

Category	15-Year Budget Cost[1,2]
Programs – High Priority	$10,800,000
Programs – Medium Priority	$26,700,000
Programs – Long-Range	$23,600,000
Total	**$61,100,000**

[1]Program costs include a Class 5 contingency of 30 percent.
[2]SPWRP WRRF Capital Plan budget costs are included in all three categories based on project timing.

The CIP schedule is based on beginning implementation in 2020 but is dependent on available funding followed by other critical path factors including, but not limited to: study, design, permitting, construction, and program management activities and durations. A detailed, one-page sheet has been developed for each program describing the recommendations, costs, schedule, and assumptions. Program sheets are provided in Appendix G.

1. Introduction

The City of Englewood, Colorado (City or Englewood) is a community of approximately 30,000 residents located south of Denver. The City is generally bounded by Denver to the north, Cherry Hills Village to the east, Littleton to the south, and Sheridan to the west. The City spans just under seven square miles.

Some portions of the sewer system located within the City boundary are owned jointly or solely by other municipalities, as shown in Figure 1-1 on page 1-3. The sewer collection system owned by the City contains 80.4 miles of pipe ranging from 8 to 54 inches in diameter and 1,558 manholes. There are no sewage pumping stations within the collection system. Nearly all wastewater from the City's collection system is treated at the South Platte Water Renewal Partners (SPWRP) Water Resource Recovery Facility (WRRF), which currently receives flows from the Cities of Englewood and Littleton, as well as 19 other sanitation districts. A small portion of the City's collection system, containing 1.2 miles of sewer mains, discharges to the Metro Wastewater Reclamation District (Metro) sewer system for treatment at Metro's wastewater treatment facilities.

1.1 Scope and Purpose

The City of Englewood has chosen to initiate a comprehensive Sewer Master Plan for the sewer collection system owned and maintained by the City. In September 2019, the City selected Hazen and Sawyer (Hazen) and our teammate Bai Engineers (Bai) to develop the Sewer Master Plan (Plan). This report establishes an initial Master Plan for the City's sewer collection system, providing an overall evaluation of the system and an understanding of existing and future needs. The scope of this study includes the following tasks:

- Review and leverage existing data sources in the development of the Plan (see Appendix A)
- Develop a hydraulic model for sewers 15-inches in diameter or larger
- Collect level and rainfall monitoring data to support calibration of the model
- Calibrate the hydraulic model with respect to baseline (existing) dry and wet weather conditions
- Input future flow projections into the model assuming a uniform three percent increase in flows across the sewer system by year 2030
- Conduct capacity evaluations using the sewer model under baseline and future flow conditions
- Develop deficiency criteria and identify system deficiencies for baseline and future flow conditions
- Develop an asset register for sewers 15-inches in diameter or larger
- Develop criteria for assigning risk scores to all assets in the register
- Identify sewer programs to address capital, asset management, operations and maintenance (O&M) needs

- Determine capital projects necessary to address system deficiencies
- Prioritize recommended programs and projects through workshops with City staff
- Develop a Class 5 cost estimate for prioritized programs and projects
- Recommend a 15-year Capital Improvement Plan (CIP)

The purpose of this Plan is to serve as a guiding document for the City to:

- Increase sewer system reliability
- Apply business risk exposure to effectively allocate sewer system funds for needed programs and capital projects
- Effectively allocate City resources to implement programs

The utility master planning process must be continual and comprehensive so that the Sewer Collection System Master Plan remains updated. The Master Plan is kept up to date by incorporating supplemental studies that are adopted between updates of the Master Plan. The Master Plan itself should be updated every five years.

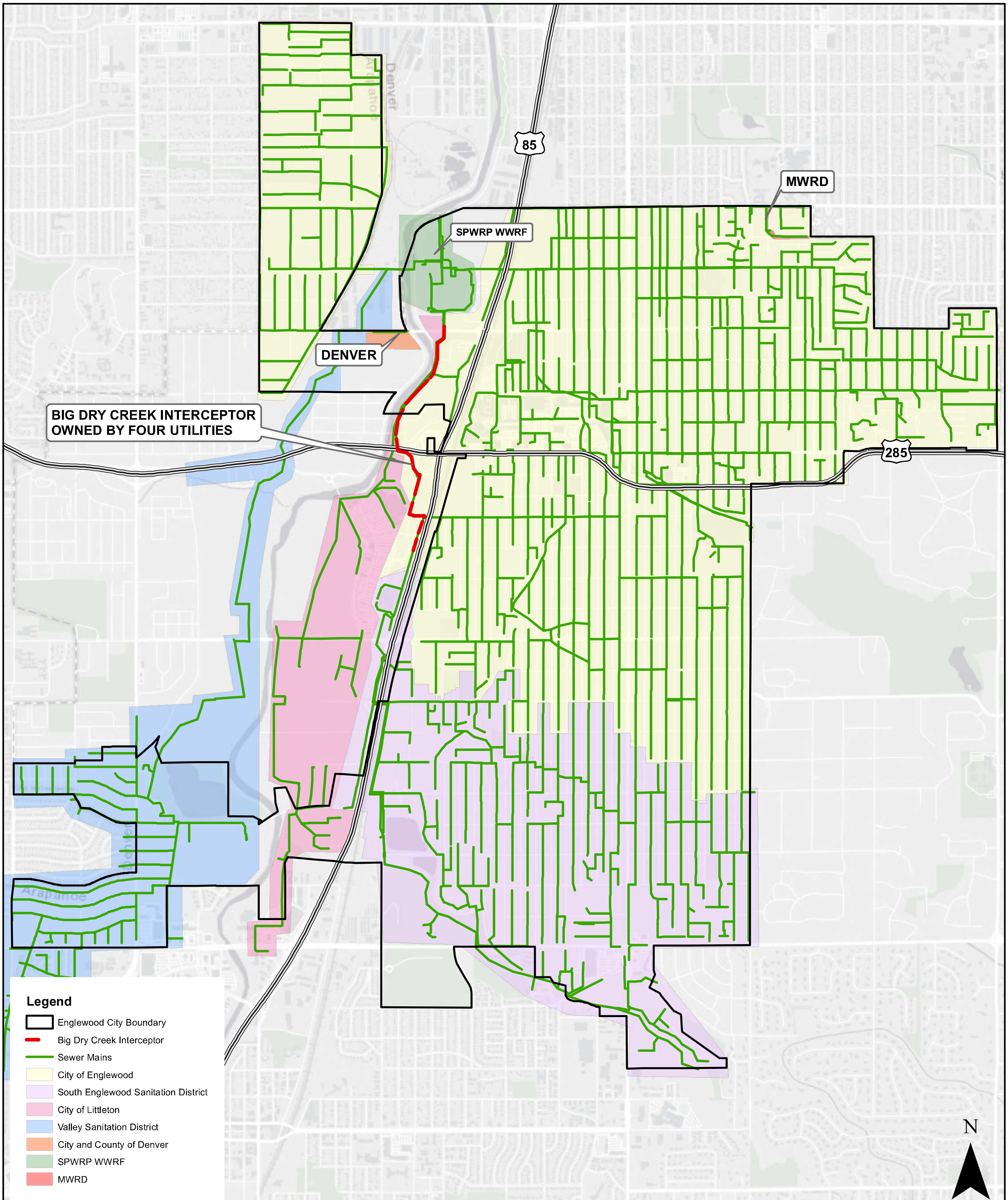

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FIGURE 1-1: SEWER SYSTEM OWNERSHIP WITHIN ENGLEWOOD CITY LIMITS

2,600 1,300 0

1 Inch = 2,584 Feet

DATE: MAY 2020

2. Existing Sewer Collection System

2.1 Sewer Utility Owners within City of Englewood

Seven utilities own sanitary sewer mains within Englewood's City limits. These utility providers are:

- City of Englewood
- South Englewood Sanitation District No. 1 (South Englewood)
- City of Littleton (Littleton)
- Valley Sanitation District (Valley)
- City and County of Denver (Denver)
- Metro Water Reclamation District (Metro)
- SPWRP WRRF

Figure 2-1 shows a map of all sanitary sewer mains within the City's Geographic Information System (GIS) dataset along with the utility owner.

Table 2-1 provides a breakdown of the sanitary sewer assets within the City's GIS dataset by utility owner.

Table 2-1: Sanitary Sewer Assets by Utility Owner

Utility Owner	Length of Sewer Mains (Miles)	Number of Sewer Manholes
Englewood	80.4	1,558
South Englewood	30.4	640
Valley	14.2	283
Littleton	5.8	128
SPWRP WRRF	1.7	66
Metro	0.5	10
City and County of Denver	0.1	3
TOTAL	**133.1**	**2,688**

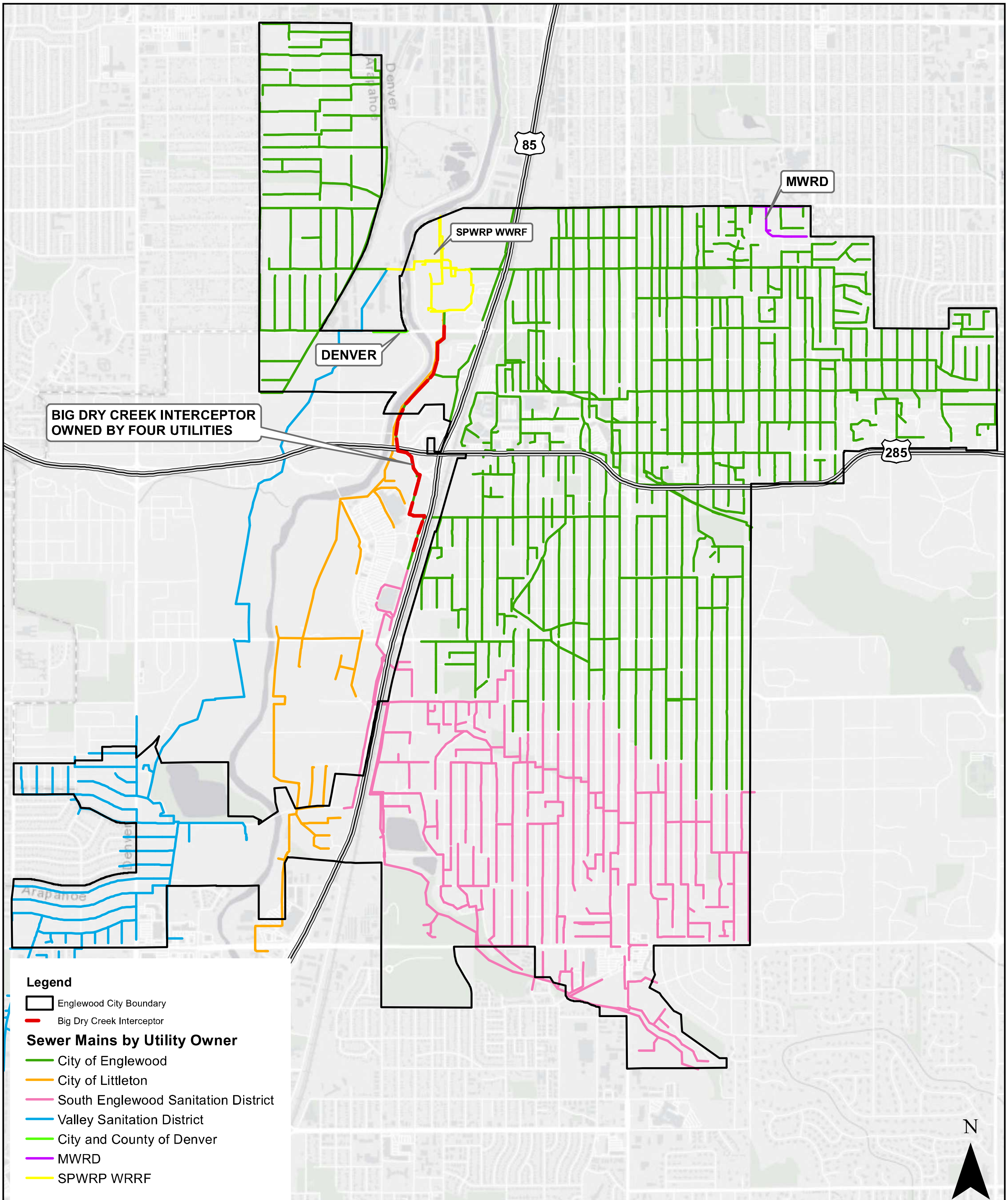

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FIGURE 2-1: SANITARY SEWER MAINS BY UTILITY OWNER

2,600 1,300 0

1 Inch = 2,584 Feet

DATE: MAY 2020

Englewood's Utilities Department operates and maintains the sewer collection assets owned by the City of Englewood. The City of Englewood also entered into an agreement with South Englewood in 2019 whereby Englewood's Utilities Department performs operations and maintenance activities for South Englewood's sewer system within Englewood's City limits. The City of Englewood receives an annual flat fee in quarterly increments from South Englewood for completing all locate requests, annually cleaning and inspecting their 30.4 miles of sewer mains, responding to emergency calls and performing appropriate remedial action/cleanup, answering inquiries on sewer service within the City limits, and performing routine repairs. South Englewood is responsible for capital improvements such as cured-in-place pipe (CIPP) lining, sliplining and manhole upgrades. The sewer assets owned by Valley, Littleton, SPWRP, Metro and City and County of Denver are operated and maintained by their respective utility owners.

There are 10,090 sewer customer accounts within the City's GIS dataset. Table 2-2 provides a breakdown of customer accounts by utility owner.

Table 2-2: Sewer Customer Accounts by Utility Owner

Utility Owner	Number of Sewer Accounts
Englewood	6,576
South Englewood	2,424
Valley	935
Littleton	36
Metro	116
City and County of Denver	3
TOTAL	**10,090**

2.2 Englewood Sewer System

The overall purpose of this Master Plan is to identify and prioritize programs and projects for the City's sewer system. These programs and projects will be limited to the sewer system that is owned and maintained by the City. Table 2-3 on the following page summarizes the City's sewer mains by pipe diameter.

Table 2-3: City Sewer Mains by Pipe Diameter

Pipe Diameter (in)	Length of Sewer Mains (Miles)	Number of Sewer Mains
Unknown	0.9	25
8	61.5	1,207
10	5.7	115
12	3.8	96
15	4.0	76
16	0.2	4
18	1.3	27
21	0.8	23
24	1.0	21
27	0.1	4
42	0.4	8
54	0.7	15
TOTAL	**80.4**	**1,621**

Figure 2-2 on the following page shows the percentages of different gravity sewer pipe materials present in the City's sewer system.

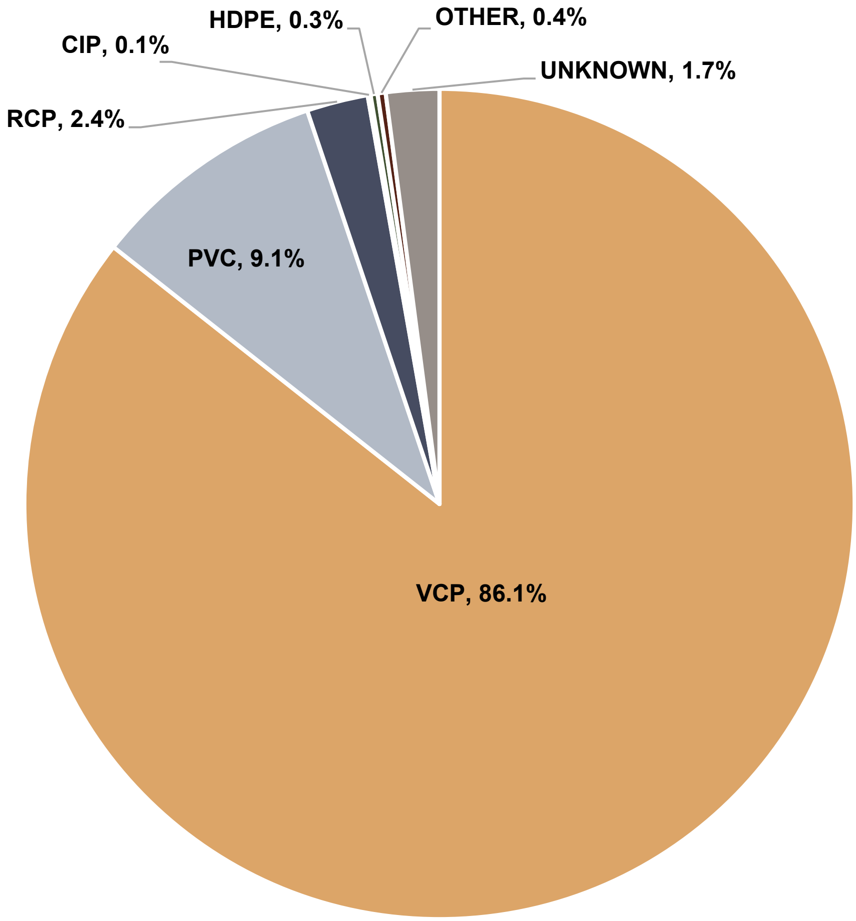

Figure 2-2: Sewer Pipe Material Distribution

As shown in Figure 2-2, over 86 percent of the system is vitrified clay pipe (VCP). VCP is a brittle pipe material that is prone to cracking if it is disturbed. Based on discussions with the City's operations and maintenance staff, the main issues recorded for VCP sewer pipes in the system are offset joints, root intrusion and cracks.

Figure 2-3 provides an overview of the City's sewer system and illustrates the pipe diameters throughout the system.

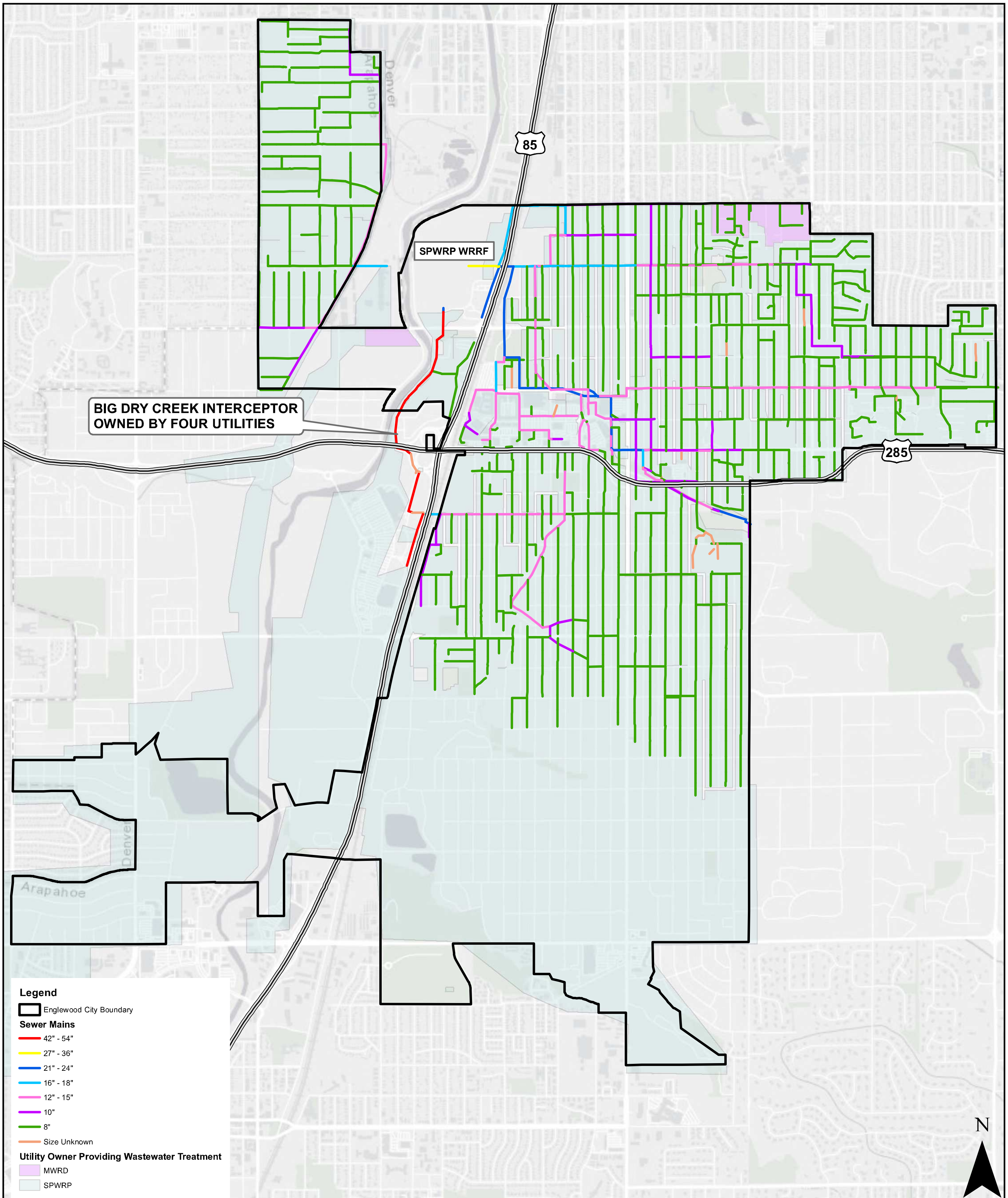

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FIGURE 2-3: ENGLEWOOD SEWER SYSTEM MAP

2,600 1,300 0

1 Inch = 2,584 Feet

DATE: MAY 2020

2.3 Major Interceptor Sewers

In general, the City's sewer system flows from south to north, and from east to west, via gravity to the SPWRP WRRF. There is only one major interceptor within Englewood's sewer collection system, the Big Dry Creek Interceptor (BDCI). This interceptor conveys flow from the southern portion of Englewood's collection system to the SPWRP WRRF. The interceptor also conveys flows from South Englewood, Southgate Water and Sanitation District, and Littleton to SPWRP WRRF. The pipe segments range in diameter from 42 to 54 inches.

The 42-inch diameter BDCI was originally constructed in the early 1980s. The interceptor runs parallel to the South Platte River to the west and Highway 85 to the east. It originates at Mansfield Avenue, where flows from South Englewood and Englewood discharge to the interceptor, and terminates at the SPWRP WRRF. According to the Connector District Study dated August 1985, a portion of the BDCI at the intersection of Highway 285 (Hampden Avenue) and Highway 85 (Sante Fe Drive) was identified as having insufficient capacity. The BDCI was re-routed west of the intersection in the early 1990s as part of the Dartmouth Avenue Realignment project. The re-routed portion of the BDCI, from MH 4-1-2-4 to the SPWRP WRRF, is 54-inch RCP and HDPE pipe.

2.4 Collector Sewers

For the purposes of this Master Plan, five major collector sewers are identified to define the conveyance of flow from Englewood's system to the SPWRP WRRF. These five collector sewers are named according to the roads on which they are located:

- Kenyon Avenue Collector Sewer (Kenyon)
- Little Dry Creek and Hampden Avenue Collector Sewer (LDC & Hampden)
- Floyd Avenue Collector Sewer (Floyd)
- Bates Avenue Collector Sewer (Bates)
- Pecos Street Collector Sewer (Pecos)

Figure 2-4 on the following page identifies the extents and locations of these collector sewers, along with the BDCI.

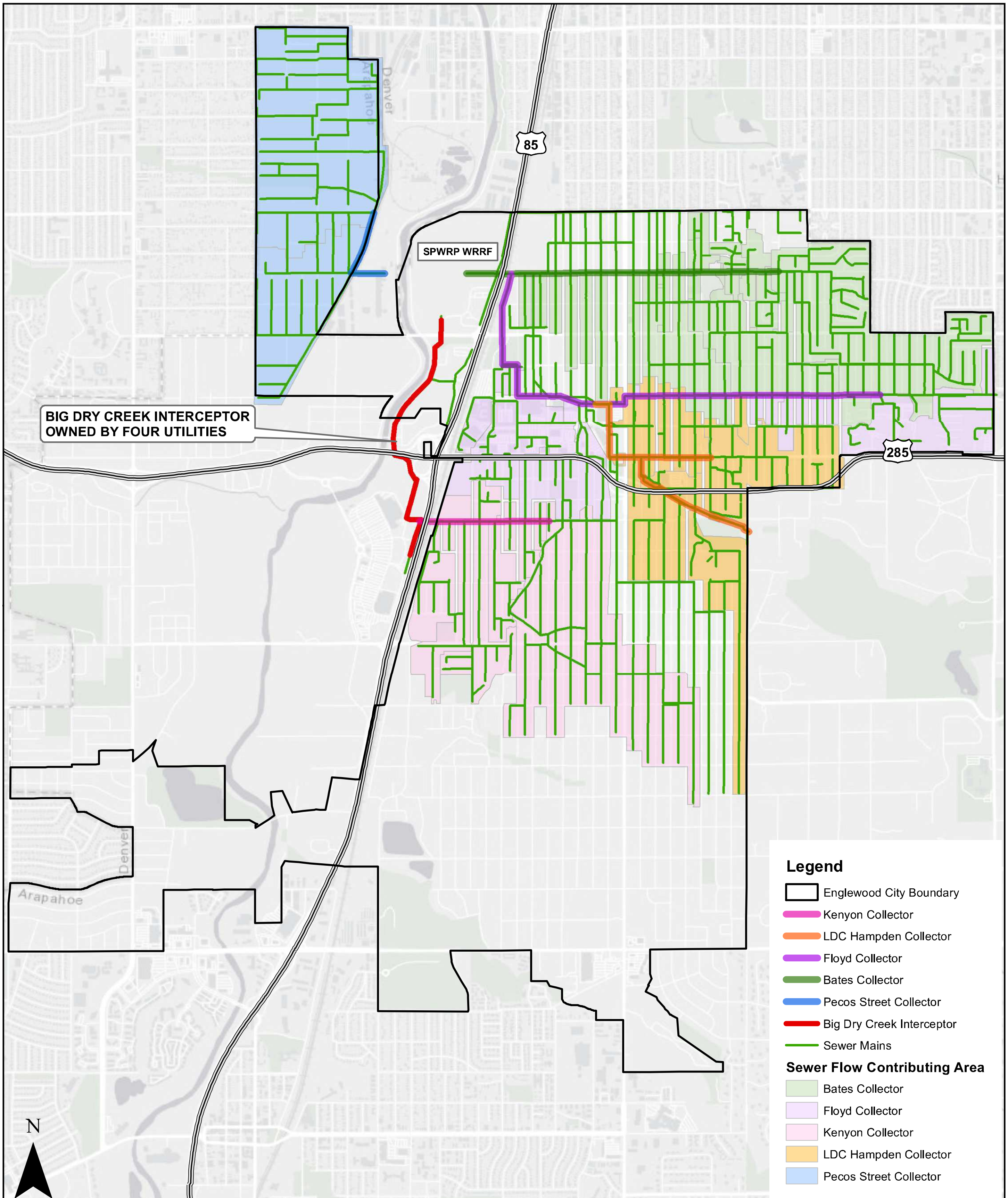

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FIGURE 2-4: ENGLEWOOD MAJOR INTERCEPTORS AND COLLECTOR SEWERS

DATE: MAY 2020

2.4.1 Kenyon Collector Sewer

The Kenyon Collector Sewer conveys sewer flows from the area west of Highway 85 between Little Dry Creek and the northern service boundary of South Englewood Sanitation District. The pipe segments range in diameter from 15 to 16 inches. The pipe materials are vitrified clay pipe (VCP) and cast-iron pipe (CIP).

2.4.2 LDC & Hampden Collector Sewer

The LDC & Hampden Collector Sewer conveys sewer flows from the area east of Broadway between Little Dry Creek and Hampden Avenue. Flows from the Cities of Cherry Hills Village and Greenwood Village also discharge to the LDC & Hampden Collector Sewer at MH 3-1-4-21. Based on the information provided by the City during preparation of this Master Plan, Cherry Hills Village and Greenwood Village do not pay sewer conveyance fees to Englewood.

The LDC & Hampden Collector Sewer pipe segments range in diameter from 15 to 21 inches. The pipe materials are VCP and polyvinyl chloride (PVC).

2.4.3 Floyd Collector Sewer

The Floyd Collector Sewer conveys sewer flows from the area east of SPWRP WRRF between Floyd Avenue and Hampden Avenue. The pipe segments range in diameter from 15 to 24 inches and the pipe material is PVC and reinforced concrete pipe (RCP).

2.4.4 Bates Collector Sewer

The Bates Collector Sewer conveys sewer flows from the area east of SPWRP WRRF between Floyd Avenue and Bates Avenue. The pipe segments range in diameter from 8 to 27 inches and the pipe material is VCP, RCP and PVC.

2.4.5 Pecos Street Collector Sewer

The Pecos Street Collector Sewer conveys sewer flows from the area northwest of SPWRP WRRF. The pipe segments range in diameter from 15 to 18 inches and the pipe material is VCP.

2.5 Treatment Facilities

Ninety-nine percent of the sewer system owned by the City conveys flow via gravity to the SPWRP WRRF, formerly the Littleton/Englewood WWTP. The remaining one percent of the system, or 1.2 miles, conveys flow to Metro’s sewer system at manhole IDs 34-1-1-27, 34-1-1-35, 34-1-1-39, and 35-2-2-17. The previous Figure 2-4 shows the portion of the system in the northeast corner of the City that discharges to Metro’s system.

3. Level and Rainfall Monitoring

The purpose of the level and rainfall monitoring program was to obtain measurements at key locations in the sewer system to calibrate the sewer model and characterize system operation during dry and wet weather conditions. Temporary level and rainfall data were collected in the sewer system from October 18, 2019 through December 11, 2019. A total of five (5) SmartCover level meters were installed, and raw depth data was collected and reported on a five-minute time interval. Velocity was calculated, rather than directly measured, based on Manning's equation for partially full pipes. Since only level sensors were installed in the system, the velocity calculation was performed to approximately represent system flows. Direct measurement of velocity and depth using area-velocity flow monitors is recommended as a future effort to refine the sewer model. The area-velocity method was then used to calculate flow through the pipe based on the measured depths and calculated velocities. One (1) tipping bucket rain gauge was used to correlate rainfall event characteristics with the calculated flow data.

3.1 Level Meter and Rain Gauge Site Selection

The five level meter locations were selected to measure the levels in the sewer system owned and maintained by the City of Englewood. A site investigation was performed for each meter location to assess the flow characteristics within the manhole and verify that adequate hydraulic conditions existed for data collection. The rain gauge was located in the southwest corner of the City at Centennial Park. The locations of the five (5) level meters and one (1) rain gauge are shown in Figure 3-1 along with the meter basin boundaries. Table 3-1 summarizes the meter basin characteristics.

Table 3-1: Meter Basin Characteristics

Meter ID	Sewered Area (acres)	Length of Sewer Mains (LF)	No. of Residential Sewer Taps[1]	No. of Commercial Sewer Taps[1]
L1	503	80,375	1,518	7
L2	405	57,500	607	7
L3	303	57,403	715	33
L4	129	18,800	332	7
L5	542	107,352	2,031	9

[1] Residential taps defined as taps with 4-inch diameter. Commercial taps are greater than 4-inch diameter.

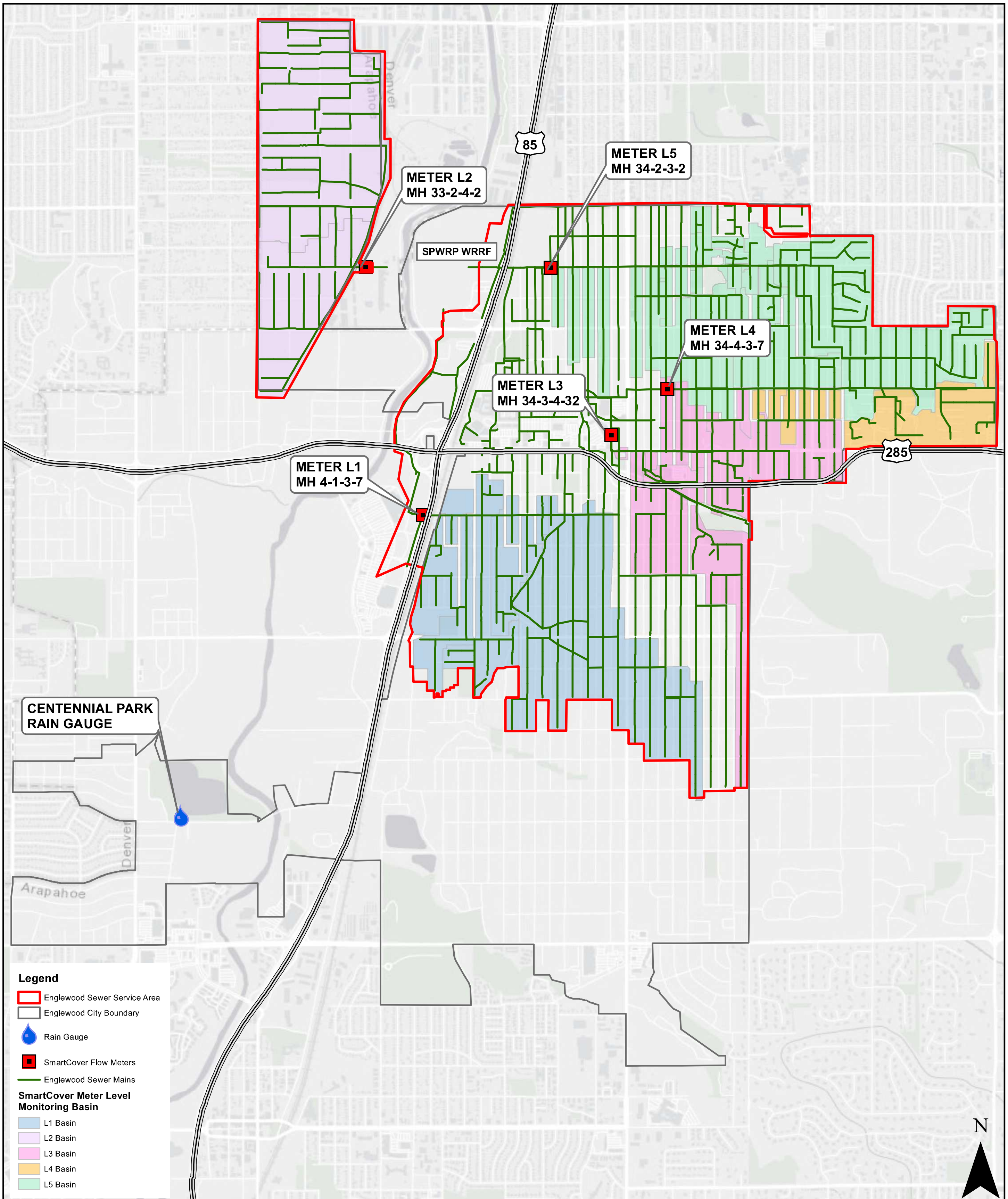

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FIGURE 3-1: LEVEL METER AND RAIN GAUGE LOCATION MAP

2,600 1,300 0

1 Inch = 2,584 Feet

DATE: MAY 2020

3.2 Level Monitoring Data Review and Analysis

The level data collected from the SmartCover meters was reviewed regularly throughout the monitoring period, as part of the quality control (QC) process. All level data was deemed suitable for use in model development and calibration except for the following time periods:

- Meter L1 on November 26, 2019: partial data loss, possibly due to snow cover on the satellite antenna
- Meter L2 from November 20, 2019 – December 11, 2019: From November 20th to December 3rd, the meter signal was lost due to a battery malfunction. The battery issue was resolved on December 3rd and the meter was re-calibrated. However, the level monitoring data from December 3rd to December 11th was not used because it showed a continuous rise in monitored sewer level that was deemed potentially erroneous.
- Meter L3 from December 5, 2019 – December 9, 2019: partial data loss, due to an antenna issue
- Meter L5 from December 5, 2019 – December 8, 2019: partial data loss, due to a battery malfunction

As discussed above, velocity and flow were calculated based on the measured level data by utilizing Manning's equation for flow in a partially full pipe. These calculations are described further in the Sewer Loading Development Technical Memorandum in Appendix B. The calculated flow rates for each meter site are based on the assumption that velocities in gravity sewers behave according to Manning's equation. The flows used in the model development and calibration (Section 4) are estimated rather than directly measured.

The calculated flows for each meter site were then compared to the City's water billing records and previous flow monitoring data, where available. The water billing data was obtained for the most recent billing cycle, August 1, 2019 through October 31, 2019. The results of this flow comparison are summarized in Table 3-2.

Table 3-2: Flow Comparison for Meter Sites

Meter ID	Average Weekday Dry Weather Flow (GPM)	Average Weekend Dry Weather Flow (GPM)	Average Flow from Water Billing Records (GPM)[1]	Average Flow from Previous Flow Monitoring[2]
L1	221.5	224.2	366	195
L2	164.0	115.7	201	n/a
L3	172.3	142.7	402	n/a
L4	67.1	71.8	245	n/a
L5	372.7	375.2	660	n/a

[1] Significant differences between flows from sewer monitoring and flows from water billing records are not uncommon. These billing records cover a time period when water usage for irrigation (landscape watering) occurs. The average weekday/weekend dry weather sewer flows do not include such usage. Not all water billed is returned to the sewer, due to irrigation and other factors.

[2] From 2011 Littleton/Englewood WWTP Sewer Inflow/Infiltration (I/I) Study

3.3 Rainfall Monitoring Data Review and Analysis

During the 2-month monitoring period, no rainfall events were observed at the Centennial Park Rain Gauge. However, several snow melting events occurred during the monitoring period. The wet weather response to these snow melting events at the five meter locations was determined using the Environmental Protection Agency's (EPA's) Sanitary Sewer Overflow Analysis and Planning (SSOAP) toolbox Version 2.0 as described in Section 4.4. Figure 3-3 illustrates the snow melting data recorded at the Centennial Park Rain Gauge during the level monitoring period.

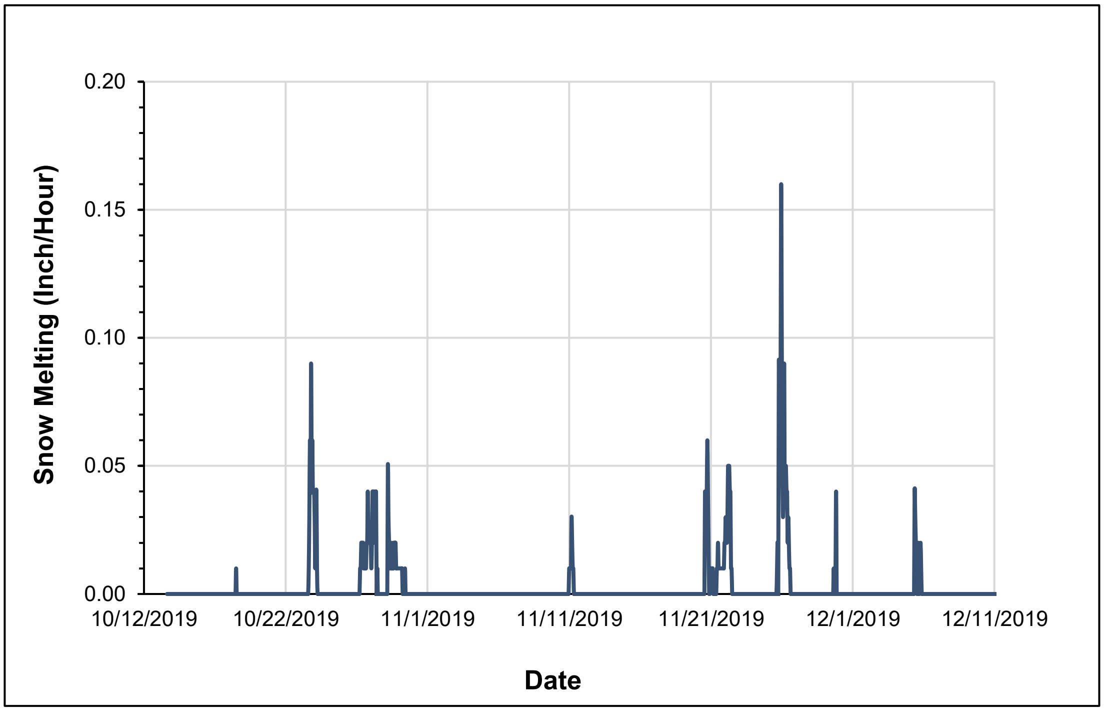

Figure 3-2: Snow Melting Events during the Monitoring Period

4. Model Development and Calibration

4.1 Model Overview

A hydrologic/hydraulic model of a sewer system is a mathematical representation of an actual physical collection system. Data describing the physical characteristics of the system as well as input data and boundary information are supplied to the modeling program, which simulates the response of the collection system to dry and wet weather flows. Physical data describing the collection system infrastructure includes pipe diameter, invert elevation, length, roughness, manhole rim elevation, connectivity and geometry, etc. Other model input data includes precipitation, dry weather flow characteristics, and boundary information.

An essential step in ensuring accuracy is model calibration, which is the process of adjusting data describing the mathematical model of the system until model predictions are in reasonable agreement with observed data.

4.1.1 Model Extents

The model developed for this Master Plan includes sewers with diameters 15 inches and larger, with some smaller sewers included for connectivity, as required by the scope for this Plan. The model includes gravity lines and manholes as appropriate to represent the collection system. There are no pump stations or diversion structures in the system. The model is a subset of the actual collection system, and as such contains nine (9) miles of gravity sewer.

4.1.2 Software

InfoSWMM® was selected for use in modeling the Englewood sewer system. InfoSWMM utilizes a user-friendly, GIS-based, graphical object-oriented interface from which to develop and execute the model's functions. InfoSWMM is a wastewater and stormwater modeling and management software application that performs fast, accurate, reliable simulations to represent the hydraulic behavior of sewer systems. InfoSWMM uses a system of integrated relational databases to store and apply data describing the collection system and can handle non-uniform, non-steady flow behavior, including surcharged pipes, looped networks, bidirectional flow, bifurcations, and backwater impacts. InfoSWMM also contains self-diagnosis and debugging features, as well as an array of options for simulating the hydrologic cycle, such that rainfall is converted into inflow into the modeled sewer system. InfoSWMM version 14.7 was used for all simulations conducted during this study.

4.2 Model Input Data Sources

Physical data describing the modeled system include horizontal and vertical data for manholes and sewer pipes, such as x-y coordinates, manhole rim and invert elevation, pipe invert elevation, pipe diameter, and pipe length. The model database was populated with the sewer network data from the GIS database.

Where GIS data were missing or contained obvious errors (e.g., negative pipe slopes, etc.), the model was updated based on available record drawings and the City's manhole inventory spreadsheet.

After these data sources were exhausted, field surveys were conducted for any remaining data gaps in the model. Interpolation was used to fill in data gaps where field surveys identified inaccessible manholes. The updates to the City's GIS data are described further in the Model-Ready GIS Dataset for Sewer Network Technical Memorandum in Appendix C.

The most pertinent and sensitive parameters that were populated in the model are discussed in detail in the following subsections. Other data entered in the model database include hydrologic parameters that are calibrated and verified using flow and rainfall monitoring data. In lieu of explicitly applying hydrologic methods, peaking factors can also be established and entered into the model to analyze wet weather response in the system.

4.2.1 Model Network

The InfoSWMM model includes a network that is subdivided into three primary features: sub-catchments, conduits (sewer mains), and junctions (includes manholes and any other point along a piped network where physical characteristics change), as described further below. The model network for any modeling project typically consists of a subset of the actual sewer system, and this subset is often determined by a variety of factors including project needs, computer hardware or software limitations and availability/reliability of data. The model developed as part of this Master Plan generally includes sewers 15 inches in diameter and larger in the model network, with some exceptions for situations where smaller sewers (8-12 inches in diameter) are required for connectivity. Figure 4-1 on the following page illustrates the model network.

In addition to flows generated within the City of Englewood service area, flows from the City of Cherry Hills Village and the City of Greenwood Village also enter the sewer model network. Thus, the model network incorporates flows from these outside jurisdictions.

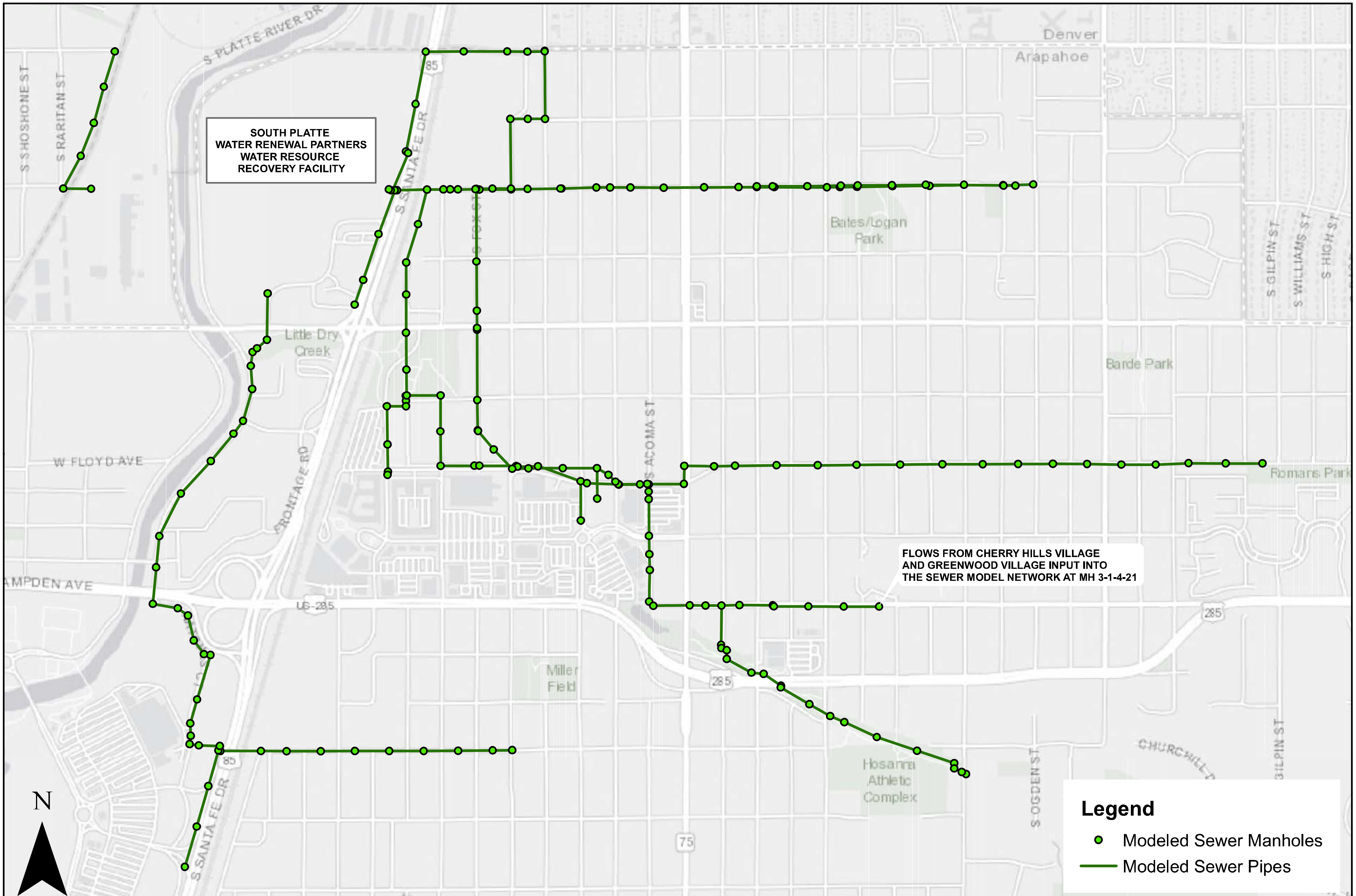

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FIGURE 4-1: SEWER MODEL NETWORK

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

4.2.2 Model Subcatchments

Model subcatchments represent the hydrologic units where runoff is generated from rainfall and are tributary to (and consequently introduced into) the piping network. Subcatchments were delineated based on the existing sewer system GIS data, particularly the flow of wastewater throughout the modeled system. A subcatchment was developed for each manhole in the model network, based on the parcels connected to the sewer pipe immediately upstream of the manhole. Sewer tap records were used to distribute dry weather flow for each subcatchment.

4.2.3 Manhole (Junction) Data

The pertinent manhole data in the model is the spatial location and connectivity to sewers as well as rim elevations. Horizontal locations (x, y coordinates) and rim elevations were obtained from GIS data. Missing rim elevations were populated using the City's Digital Elevation Model (DEM). Where errors were identified for the horizontal locations of manholes, field surveys were conducted using a handheld GPS unit to obtain the x, y coordinates.

4.2.4 Pipe (Conduit) Data

Pertinent sewer pipe data includes invert elevations, pipe size/diameter, roughness, length and connectivity with manholes. Connectivity, pipe diameters and lengths were based largely on GIS data, and were refined through a review of record drawings where discrepancies or data gaps existed. Invert elevations were obtained from GIS data but were superseded by record drawings or field measurements where erroneous data were observed. Pipe roughness was based on the material data available in the GIS database. Table 4-1 summarizes the initial roughness values used for each material type. Table 4-2 summarizes the modeled pipe inventory.

Table 4-1: Initial Pipe Roughness Values[1]

Manning's n	Pipe Material
0.015	VCP
0.013	PVC
0.015	RCP
0.015	CIP

[1] Final roughness values in individual model segments were based on engineering judgment and/or calibration efforts.

Table 4-2: Modeled Pipe Inventory[1]

Diameter (in)	Length (ft)
8	2,099
12	1,123
15	21,195
16	1,056
18	6,414
21	4,430
24	4,988
27	59
42	2,417
54	4,059
Total	**47,840**

[1]As discussed in Section 4.1.1, the modeled pipe inventory generally includes sewer mains 15 inches in diameter and larger, with some smaller mains included for connectivity, as required by the scope for the Plan.

4.2.5 Boundary Conditions

Outfalls allow flow to discharge out of the model network at the terminal points in the system. There are a total of three outfalls in the model, at the three locations where flow discharges to the SPWRP WRRF. The boundary conditions at these outfalls were specified as free discharges for purposes of this Master Plan, since the objective was to evaluate piping capacity and the ability of the sewer system to convey flows on its own merit.

4.3 Dry Weather Flows

Dry weather flows were developed from an analysis of the calculated flow data (to differentiate between dry and wet weather days) at each of the meter locations for the two-month monitoring period. The dry weather flow development is summarized in this section and additional details are provided in the Sewer Loading Development Technical Memorandum in Appendix B.

4.3.1 Diurnal Patterns

Dry weather flow was allowed to fluctuate according to a diurnal pattern. Dry weather days were selected throughout the monitoring period and were grouped into two categories: weekdays and weekends. The

24-hour diurnal dry weather flow patterns were averaged together for each category to create a set of two diurnal profiles for each meter basin. These profiles were then normalized based on the average daily flow (see Table 4-3) to create dimensionless diurnal peaking factor patterns, which were then automatically applied in the model according to the days of the week of the particular simulation. This process allows for the dry weather flow to fluctuate according to its actual diurnal pattern, versus using a constant average value. Figure 4-2 shows the weekday and weekend diurnal patterns for meter basin L4.

Table 4-3: Average Daily Dry Weather Flows

Meter Basin	Weekday Average Dry Weather Flow (MGD)	Weekend Average Dry Weather Flow (MGD)
L1	0.319	0.323
L2	0.236	0.167
L3	0.248	0.205
L4	0.097	0.103
L5	0.537	0.540

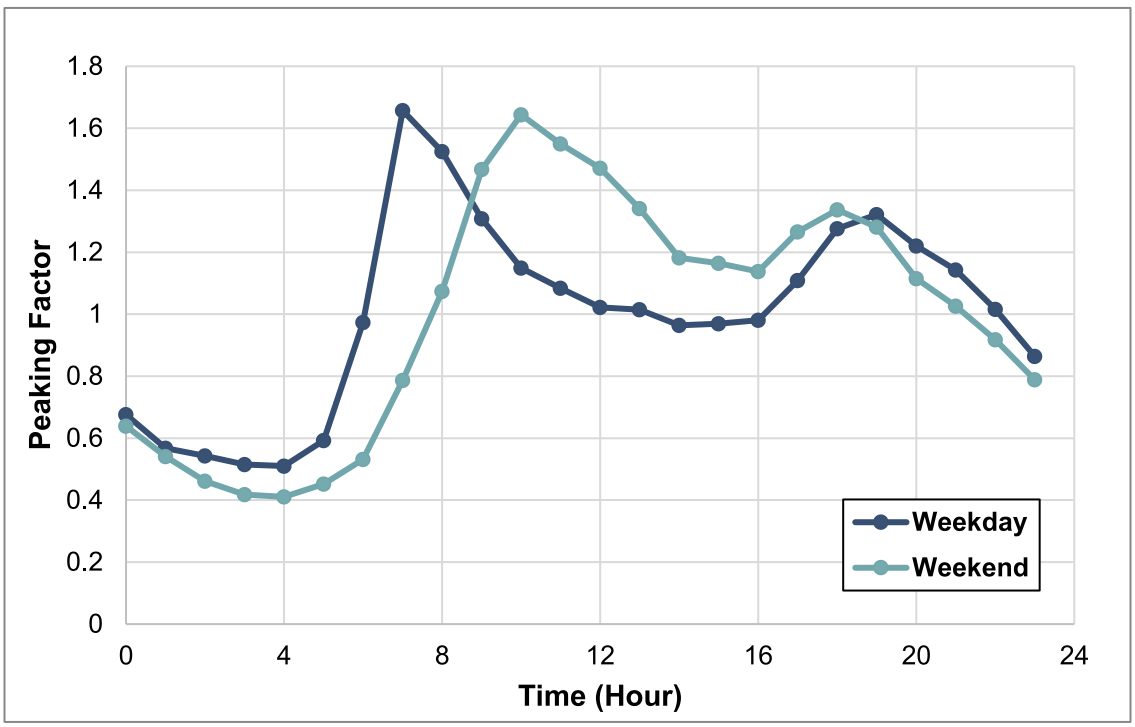


Figure 4-2: Meter Basin L4 Dry Weather Diurnal Curves

4.3.2 Distribution of Dry Weather Flow

Distribution of dry weather flow from the meter data to the individual model subcatchments was based on the number of residential and commercial sewer taps. A total number of sewer taps was assigned to each model subcatchment and dry weather flow was then distributed to each model subcatchment based on the relative quantity (i.e., proportion) of sewer taps. Table 4-4 provides the dry weather flow distribution for each meter basin.

Table 4-4: Dry Weather Flow Distribution

Meter Basin	Weekday Dry Weather Flow Distribution (GPD/sewer tap)	Weekend Dry Weather Flow Distribution (GPD/sewer tap)
L1	206	208
L2	370	260
L3	287	238
L4	265	284
L5	259	261

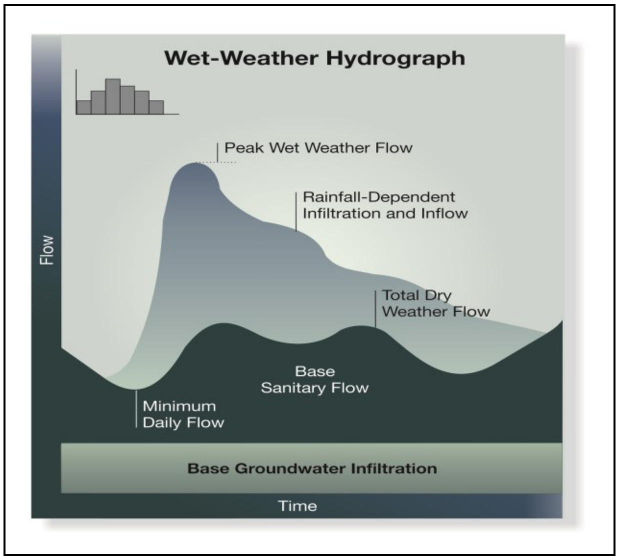
Unmetered areas (typically areas outside of Englewood's sewer service area) were assigned the same dry weather parameters (diurnal patterns and flow distribution) as meter basin L3.

4.4 Wet Weather Flows

Wet weather flows were developed from an analysis of flow and rainfall monitoring data. Since this sewer system is a separated sanitary system, wet weather flow enters the sewers via rainfall dependent infiltration and inflow (RDII). The wet weather flow development is summarized below, and additional details are provided in the Sewer Loading Development Technical Memorandum in Appendix B.

The RTK unit hydrograph method was used as the hydrologic routine for representing the wet weather response in the sewer system model due to RDII. This method uses three triangular-shaped unit hydrographs to represent the RDII flow. Three parameters define each triangular unit hydrograph: R (ratio of RDII volume to rainfall volume), T (time to peak), and K (ratio of "time to recession" to "time to peak"). The R-Value, or capture co-efficient, represents the relative fraction of rainfall that ends up in the sewer system. Higher R-values indicate a greater number or severity of sewer system defects that allow greater entry of wet weather flows into the sewer system.

The first set of parameters (R1, T1, K1) represents the fast response of the sewer system to inflow, the second set (R2, T2, K2) represents the delayed response of the system to infiltration, while the third set (R3, T3, K3) represents the much longer and slower response of the sewer system to infiltration that could last days and weeks. Figure 4-3 illustrates this methodology as it relates to the wet weather RDII sewer system response.



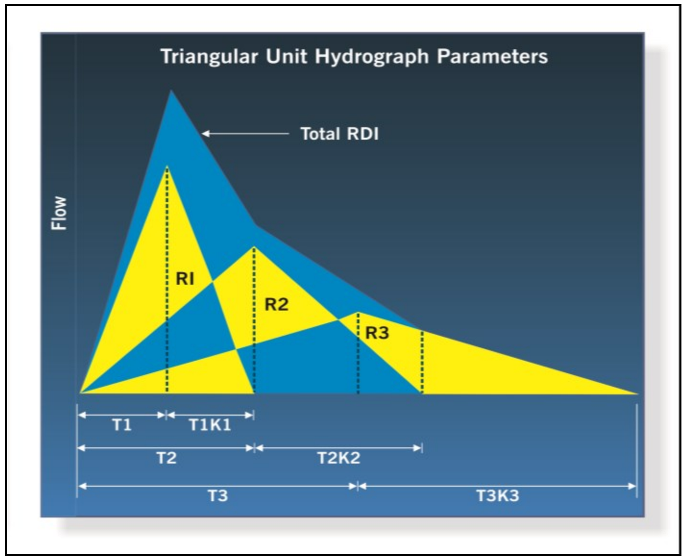


Figure 4-3: Wet Weather Hydrograph and Triangular Hydrograph Parameters

The EPA SSOAP software was used to identify RDII response events for each meter basin based on the calculated flow data and rainfall monitoring data. Due to the short duration of the monitoring period and the time of year, no rainfall events were captured during the monitoring period. However, several snow melting events were recorded. The RDII response events for each meter basin are listed in Table 4-5. The wet weather event start times, durations, and number of events vary between meter basins. Wet weather events were defined based on the observed response in the sanitary sewer system, due to the limited system response recorded. Not all meter basins responded to the snow melting events over the same time period, and not every meter basin responded to every snow melting event. As shown in Table 4-5, no wet weather events were recorded at meter basin L2.

Table 4-5: Wet Weather Events based on RDII Response

Meter Basin	Wet Weather Event Start Time (Snow Melting)	Wet Weather Event End Time (Snow Melting)
L1	10/23/2019 18:00	10/24/2019 1:00
	10/27/2019 11:00	10/27/2019 19:00
	10/29/2019 12:00	10/29/2019 20:00
	11/21/2019 20:00	11/22/2019 8:00
L2	n/a	n/a
L3	10/27/2019 18:00	10/28/2019 2:00
	11/20/2019 12:00	11/21/2019 9:00
	11/21/2019 16:00	11/22/2019 7:00
	12/5/2019 8:00	12/6/2019 5:00
L4	11/21/2019 17:00	11/22/2019 3:00
	11/26/2019 9:00	11/26/2019 20:00
L5	10/29/2019 10:00	10/29/2019 19:00
	11/26/2019 9:00	11/27/2019 6:00

Because there was only a minor flow response to the wet weather events during the monitoring period, and all events were snow melting events rather than rain events, the hydraulic model will be limited in its capability to predict how the system will respond to rainfall events. RTK values were determined based on the largest RDII response event for each meter basin. Additional flow monitoring should be performed during the Spring season to capture rainfall events. This data can be used to update the wet weather parameters and re-calibrate the model.

A previous infiltration/inflow (I/I) analysis study was performed for the Littleton/Englewood Wastewater Treatment Plant (now known as SPWRP WRRF) tributary area by CDM in 2011. The I/I analysis was based on flow monitoring performed for a three-month period from April 2010 through June 2010. As part of this study, peaking factors were developed for five design storm events for the tributary area. These peaking factors were determined by extrapolation of a linear regression equation based on significant I/I events recorded during the monitoring period. The largest rainfall event during the 2010 monitoring period was approximately a 1-year recurrence interval event. Due to the lack of rainfall events during the monitoring period for this Master Plan, the peaking factors from this previous study were used to determine the model-predicted peak instantaneous flow for each design storm event. These peaking factors are provided in Table 4-6.

Table 4-6: Peaking Factors for Design Storm Events

Storm Event	Rainfall Volume[1] (in)	Peaking Factor[2]
2-Year, 6-Hour	1.4	2.1
5-Year, 6-Hour	1.9	2.4
10-Year, 6-Hour	2.5	2.8
25-Year, 6-Hour	2.8	3.1
50-Year, 6-Hour	3.0	3.2

[1]Rainfall volume based on Table RA-1 in the Urban Storm Drainage Criteria Manual
[2]Wet weather peak flow divided by dry weather average flow

4.5 Model Calibration

Model calibration is a crucial step in determining that the model accurately simulates the collection system response to dry and wet weather flow. The hydraulic model was calibrated to represent dry weather flow and wet weather flow based on the two-month monitoring period. Level and rainfall data were collected in the sewer system from October 18, 2019 through December 11, 2019. Additional details on the model calibration are provided in the Sewer Hydraulic Model Calibration Technical Memorandum in Appendix D.

4.5.1 Dry Weather Calibration

Dry weather flow calibration was accomplished by simulating a dry weather weekday (November 2, 2019) and a dry weather weekend day (November 4, 2019) and comparing the modeled versus calculated peak flows and volumes at each metering location.

Each model subcatchment was assigned to a meter basin based on its location. The modeled and metered dry weather peak flows and volumes matched reasonably well for meter basins L2, L3 and L4. Manning's roughness coefficient "n" was increased to 0.018 for meter basins L1 and L5 during the dry weather calibration.

4.5.2 Wet Weather Calibration

Wet weather calibration is typically accomplished by simulating observed wet weather events and adjusting model parameters in an iterative fashion until modeled hydrograph shape and timing, as well as values for flow, volume and depth matched with measured values, within specified tolerances/criteria.

Due to the lack of rainfall events during the monitoring period, wet weather calibration was not performed. The RTK parameters developed from the largest RDII response event in each meter basin were input into the model and no additional changes to the wet weather parameters were made. Unmetered areas were assigned the same wet weather parameters as meter basin L3. Additional flow monitoring is recommended throughout the modeled network during the Spring season to capture rainfall events.

4.5.3 Calibration Criteria

Based on generally accepted practice, model accuracy and robustness are achieved by setting the model calibration parameters (within an acceptable range) such that the model's predicted response matches that of an observed or measured response (e.g., monitored field conditions). The following paragraphs summarize the model calibration criteria as described in the industry standard guideline document, "Wastewater Planning Users Group (WaPUG) Code of Practice for the Hydraulic Modelling of Wastewater Systems, November 2002."

Generally, the comparison of predicted and observed responses were quantified in a statistical framework and visually depicted through observed versus model-predicted plots for each location in the model (i.e., meter locations) where the respective data is compared.

The following calibration criteria were used in this study as a guideline:

<u>Dry Weather Flow Calibration:</u>

- Modeled peak flows should be within 10 percent of the observed peak flows
- Modeled 24-hour volumes should be within 10 percent of the observed volumes

<u>Wet Weather Flow Calibration (not performed):</u>

- Modeled peak flows should be within +25 percent and -15 percent of the observed peak flows
- Modeled storm event volumes should be within +20 percent and -10 percent of the observed volumes
- Modeled depths of flow in surcharged sewers should be within +1.6 feet and -0.33 feet of the observed depths

<u>General:</u>

- Matching as closely as possible the ratio of the time to peak for the modeled and observed events indicating that the shapes of the modeled and observed hydrographs are similar

4.5.4 Calibration Results

Figure 4-4 compares model-predicted volumes relative to observed values for a dry weather weekday and weekend day. Calibration criteria ranges (pink dashed lines) are also shown on this plot. The model is calibrated well to dry weather conditions observed during the monitoring period at all five sites. Figure 4-4 indicates that the total volume is slightly outside the guideline ranges for meter location L2.

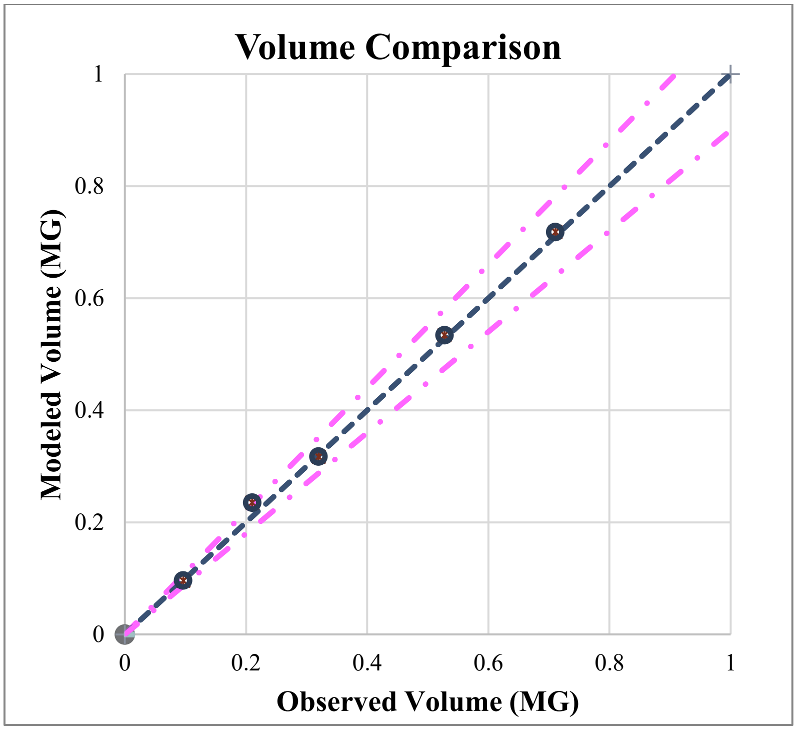


Figure 4-4: Dry Weather Flow Calibration - Volume

Figure 4-5 compares model-predicted peak flows relative to observed values for a dry weather weekday and weekend day. Calibration criteria ranges (pink dashed lines) are also shown on this plot. The model is calibrated well to peak flow dry weather conditions observed during the monitoring period at all five sites. Figure 4-5 does indicate that the peak flow is slightly outside the guideline ranges for meter location L2.

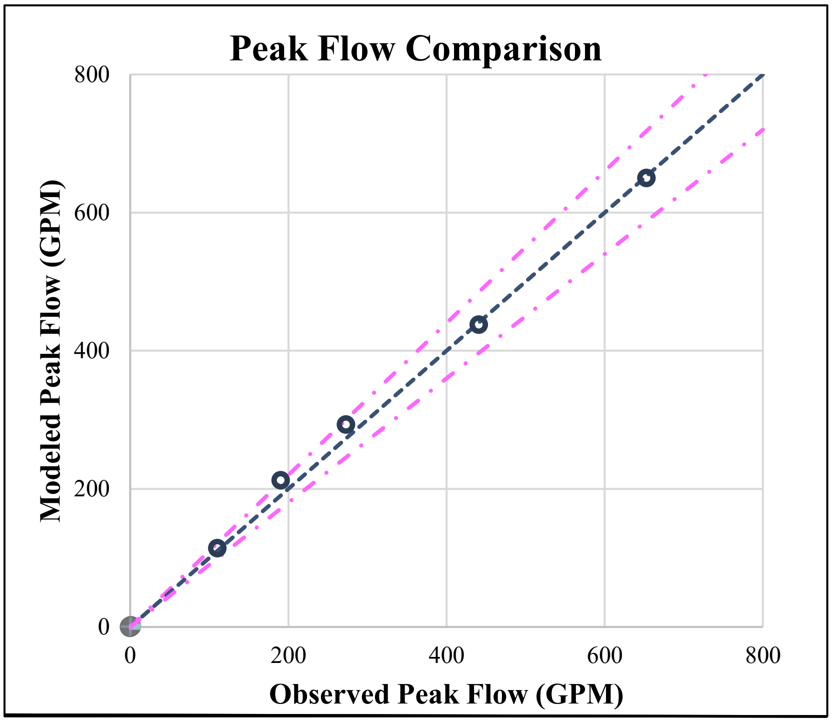


Figure 4-5: Dry Weather Flow Calibration – Peak Flow

Model calibration and verification for wet weather conditions must be completed following an additional flow monitoring period. Model calibration is achieved by adjusting wet weather parameters based on an evaluation of modeled versus metered peak flows and volumes for several rainfall events. Verification of the model is then performed by simulating additional rainfall events (ones not used for calibration) and comparing modeled results to observed data, without changing model parameters. This additional step provides confidence in the model's ability to make robust predictions after all parameters have been finalized.

5. Capacity Evaluation

The assessment of the existing and future capacity of the collection system and its ability to convey predicted peak flows is summarized in the following section. The overall capacity evaluation approach was to simulate dry and wet weather conditions in the collection system using the hydrologic/hydraulic model and evaluate the system based on established performance criteria. The capacity evaluation approach and results are summarized in this section. Additional details are provided in the Existing and Future Sewer Collection System Analysis Technical Memorandum in Appendix E.

5.1 Flow Projections

As required by the scope for this Master Plan, the future flow projections for the capacity evaluation are based on assumed uniform three percent increase in flows across the sewer system by year 2030.

5.2 Design Storms

Five design storms were included in this assessment, with the following return frequencies:

- 2-year, 6-hour
- 5-year, 6-hour
- 10-year, 6-hour
- 25-year, 6-hour
- 50-year, 6-hour

The model-predicted peak flow for each design storm event was determined by applying established peaking factors to the average dry weather flow as described in Section 4.4.

5.3 Performance Criteria

The following criteria were selected for evaluation of system performance under dry weather conditions:

- Maximum percent full (depth/Diameter, or d/D): 70 percent
- Minimum velocity: 2 feet per second (2 ft/sec)
- Maximum velocity: 10 ft/sec

The following criteria were selected for evaluation of system performance under wet weather conditions:

- Maximum percent full (d/D): 100 percent, i.e., hydraulic grade line at the pipe crown

5.4 Baseline and Future Capacity Evaluations

Model simulation results for baseline and future (year 2030) conditions are presented in graphical format herein. Figures 5-1 through 5-14 illustrate the performance (percent full) of the sewer system during dry weather and wet weather for all five design storms. The figures illustrate the percent full of all modeled pipe segments as well as locations of model-predicted sanitary sewer overflows (SSOs).

It should be noted that SSOs shown do not necessarily correlate to actual observed occurrences; rather, they represent the model-predicted potential for significant surcharging under the estimated design storm conditions. Tables 5-1 and 5-2 summarize the capacity limitations in gravity sewers due to model-predicted surcharging for baseline and future conditions.

Table 5-1: Model-Predicted Surcharging, Baseline

Design Storm	No. of Surcharged Pipes
2-Year, 6-Hour	0
5-Year, 6-Hour	0
10-Year, 6-Hour	2
25-Year, 6-Hour	4
50-Year, 6-Hour	6

Table 5-2: Model-Predicted Surcharging, Year 2030

Design Storm	No. of Surcharged Pipes
2-Year, 6-Hour	0
5-Year, 6-Hour	0
10-Year, 6-Hour	2
25-Year, 6-Hour	6
50-Year, 6-Hour	9

There was one model-predicted SSO location under the 50-year, 6-hour storm event for future (Year 2030) conditions at manhole ID 3-1-2-42.

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FIGURE 5-1: SEWER CAPACITY EVALUATION - DRY WEATHER WEEKDAY (BASELINE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

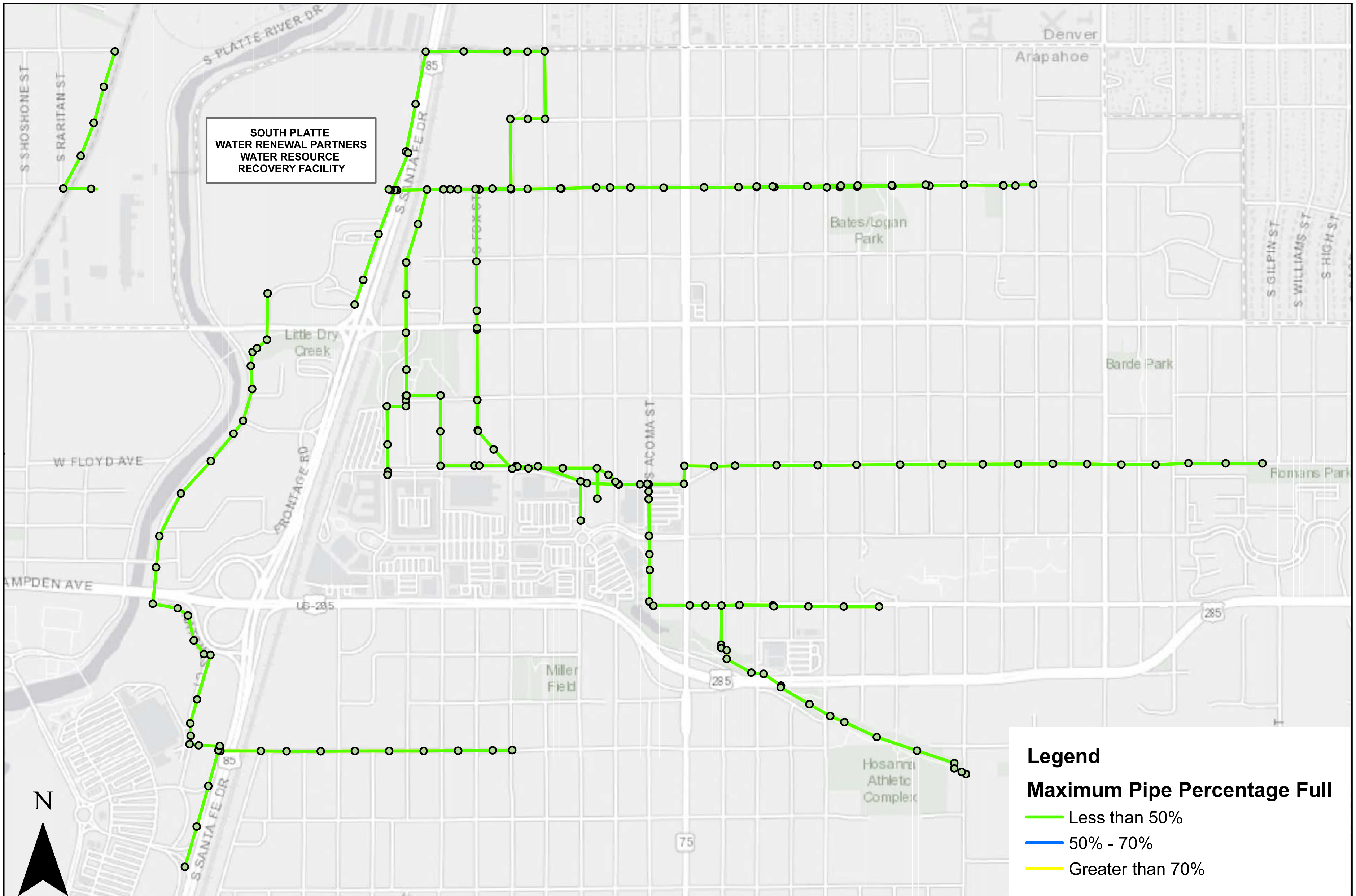

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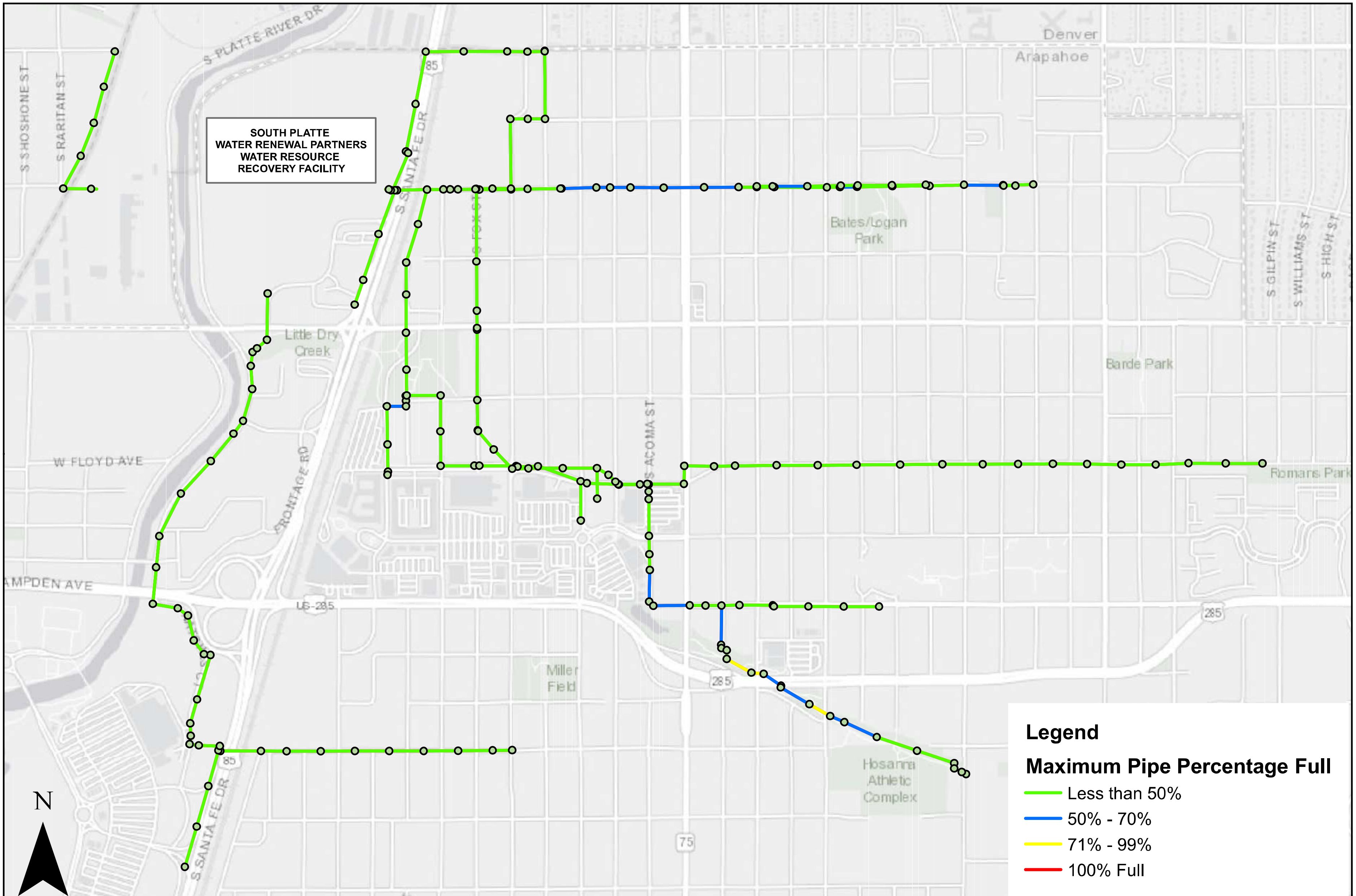
FIGURE 5-2: SEWER CAPACITY EVALUATION- DRY WEATHER WEEKEND (BASELINE)

DATE: FEBRUARY 2020



Hazen

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FIGURE 5-3: SEWER CAPACITY EVALUATION - 2-YEAR, 6-HOUR STORM EVENT (BASELINE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

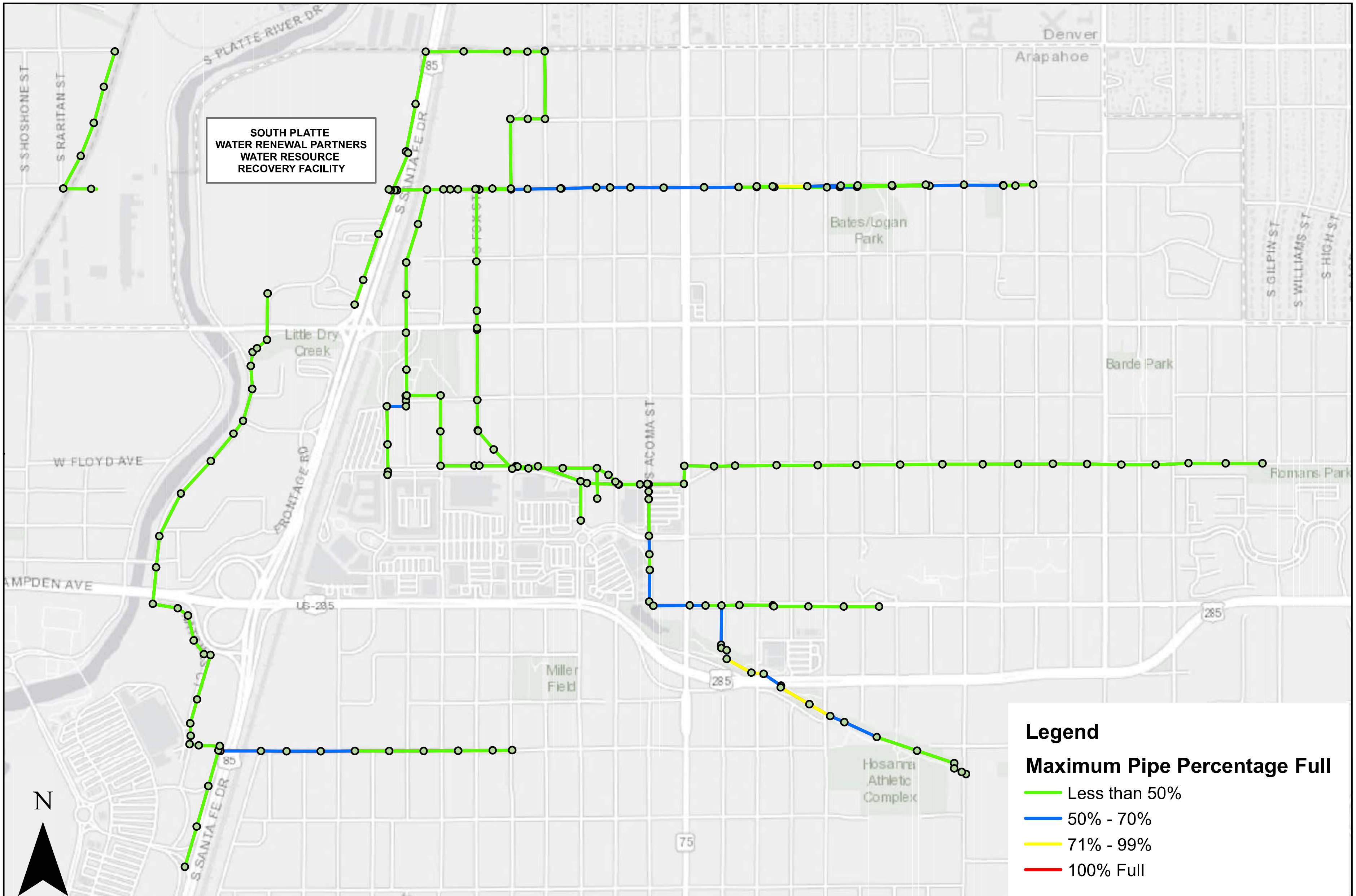

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FIGURE 5-4: SEWER CAPACITY EVALUATION - 5-YEAR, 6-HOUR STORM EVENT (BASELINE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

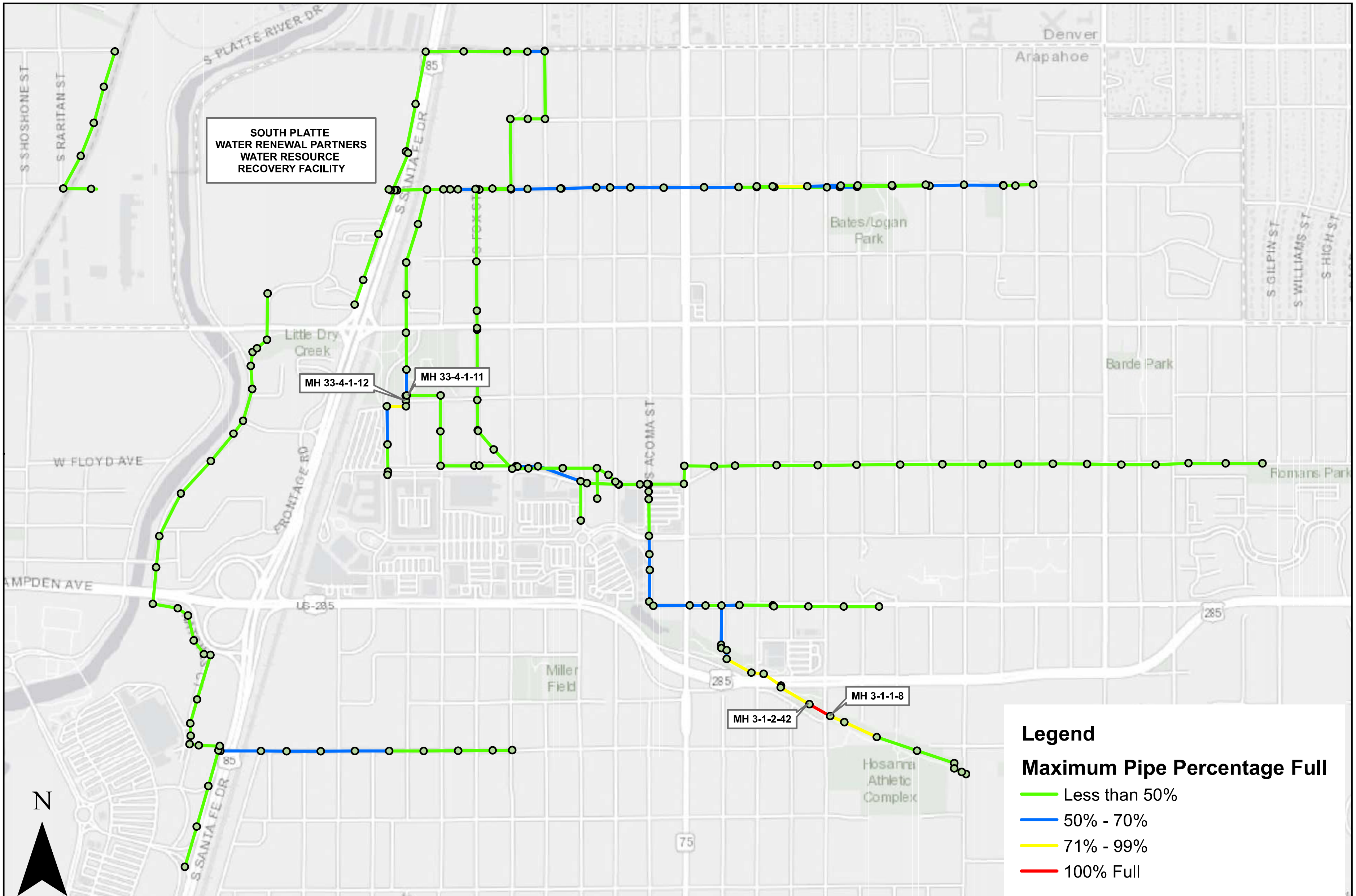

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FIGURE 5-5: SEWER CAPACITY EVALUATION - 10-YEAR, 6-HOUR STORM EVENT (BASELINE)

DATE: FEBRUARY 2020

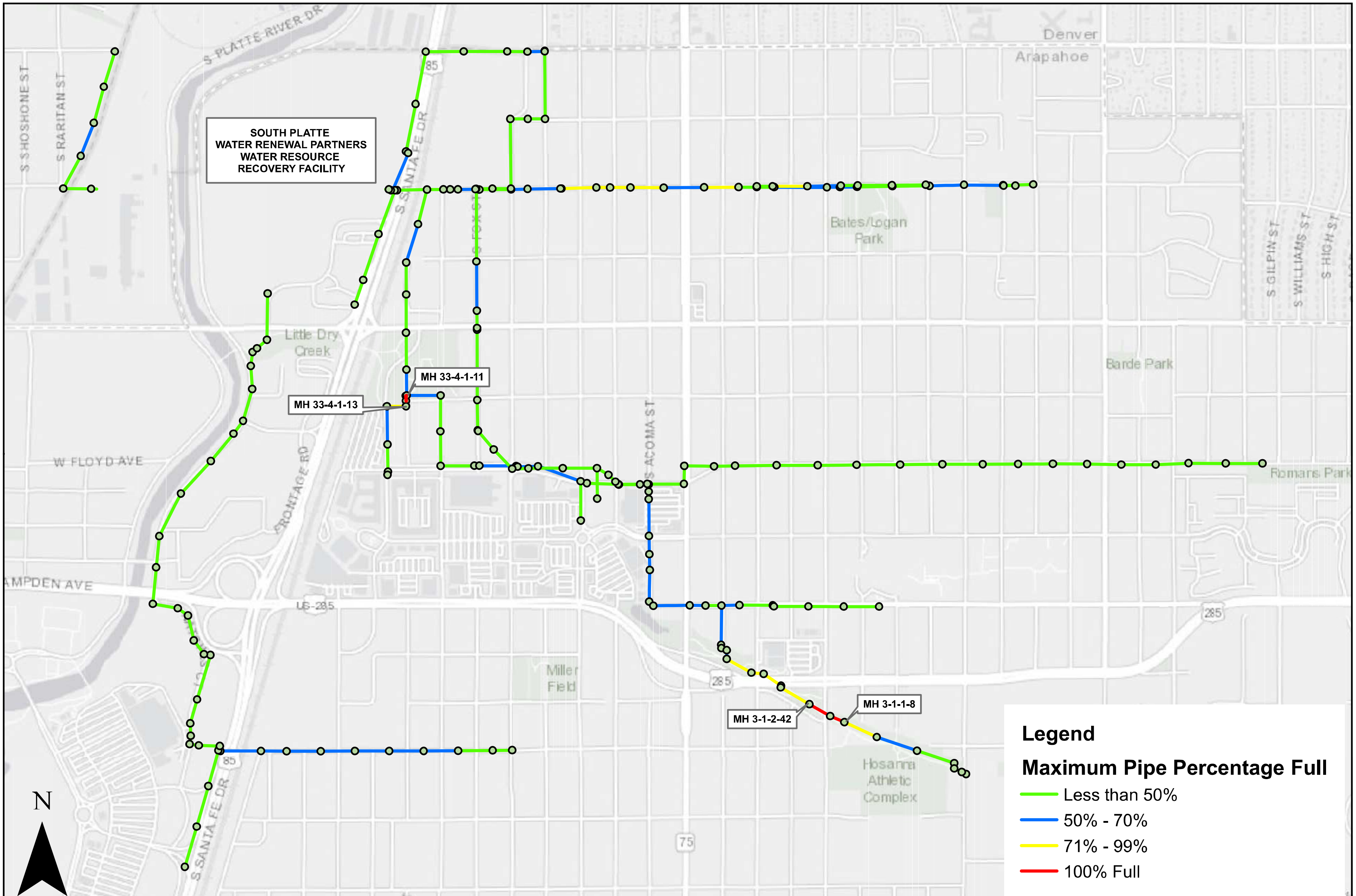

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FIGURE 5-6: SEWER CAPACITY EVALUATION - 25-YEAR, 6-HOUR STORM EVENT (BASELINE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

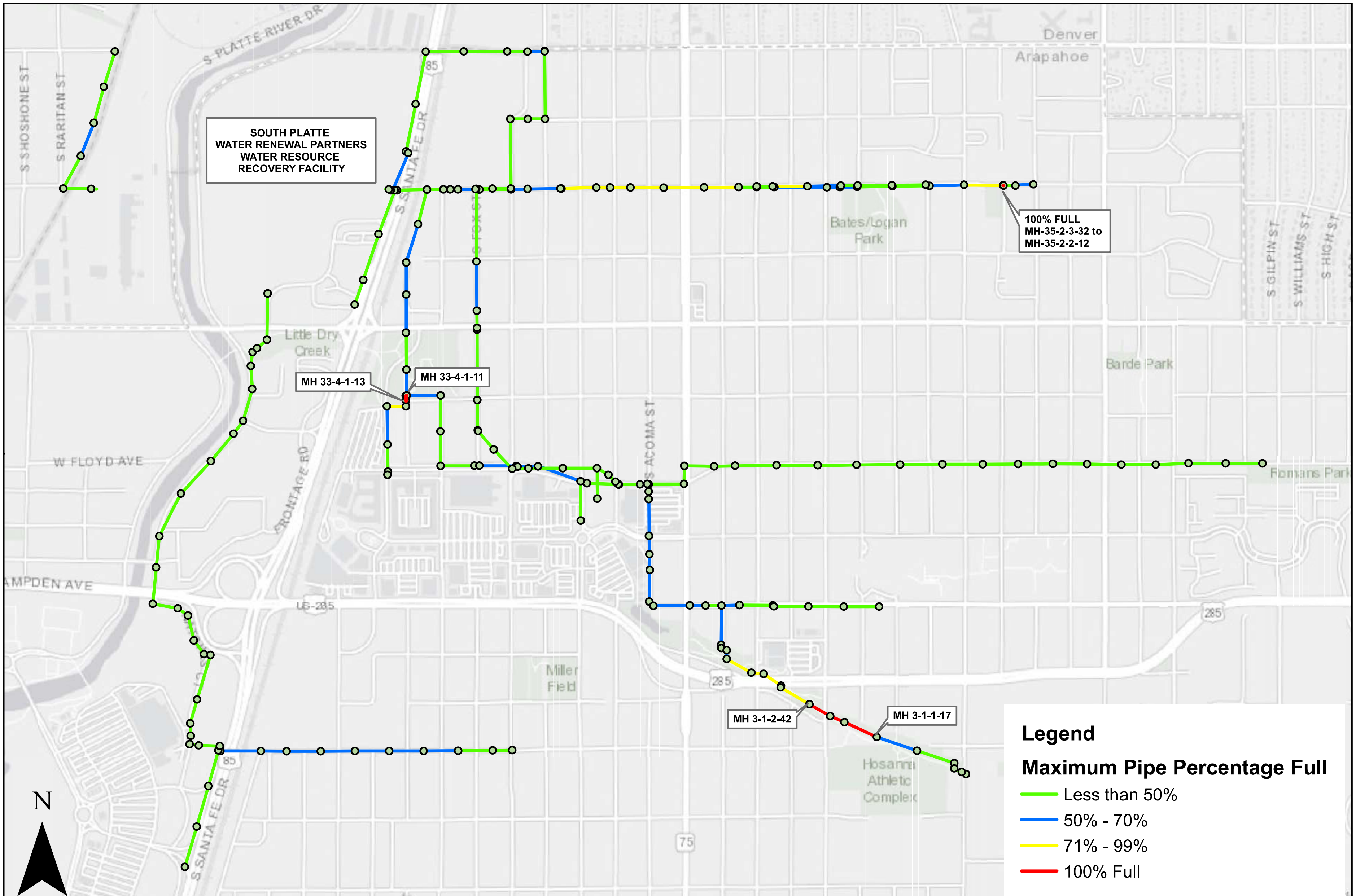

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FIGURE 5-7: SEWER CAPACITY EVALUATION - 50-YEAR, 6-HOUR STORM EVENT (BASELINE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

Hazen

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FIGURE 5-8: SEWER CAPACITY EVALUATION - DRY WEATHER WEEKDAY (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

Hazen

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FIGURE 5-9: SEWER CAPACITY EVALUATION - DRY WEATHER WEEKEND (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

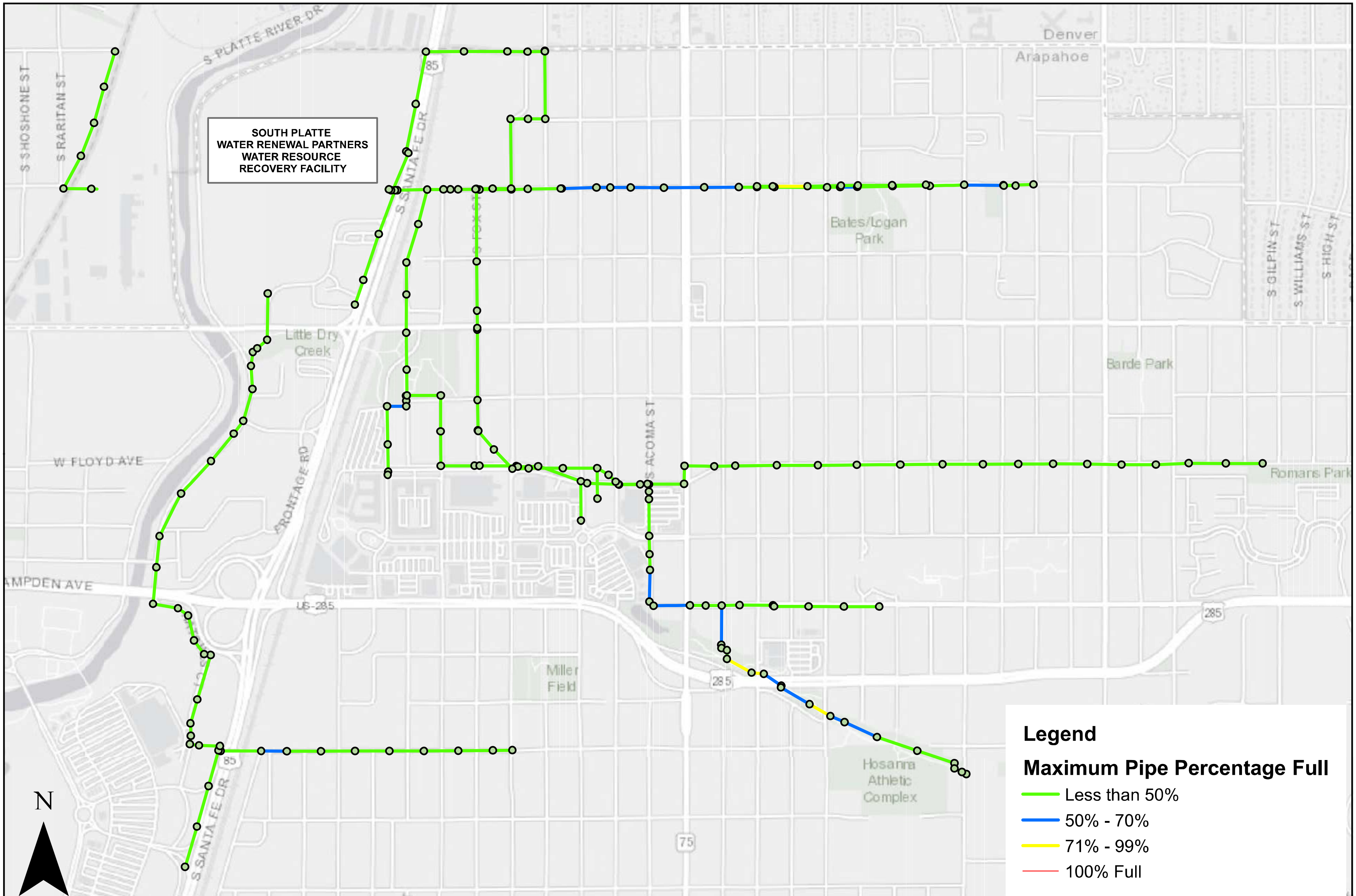

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FIGURE 5-10: SEWER CAPACITY EVALUATION - 2-YEAR, 6-HOUR STORM EVENT (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

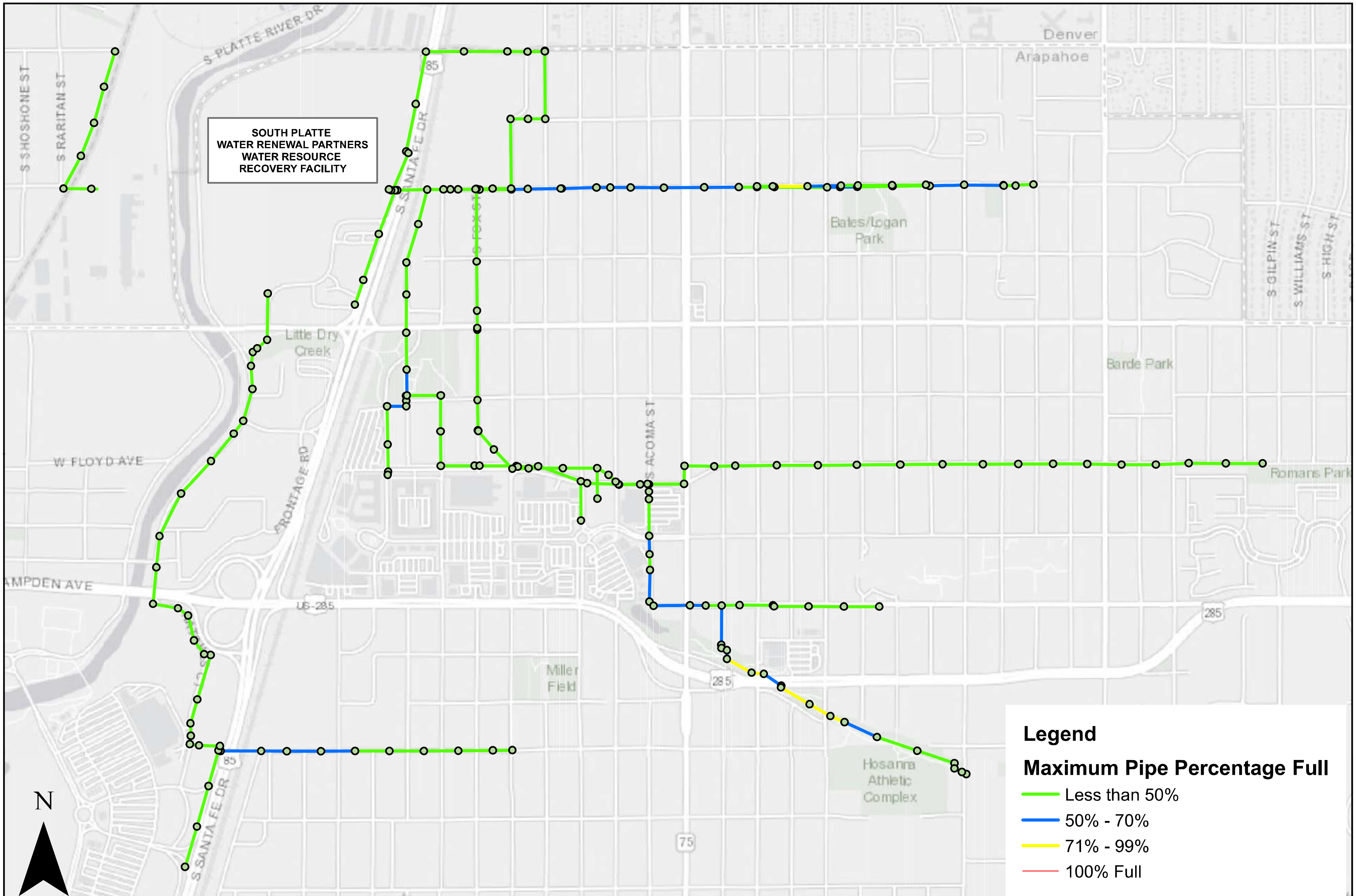

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FIGURE 5-11: SEWER CAPACITY EVALUATION - 5-YEAR, 6-HOUR STORM EVENT (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

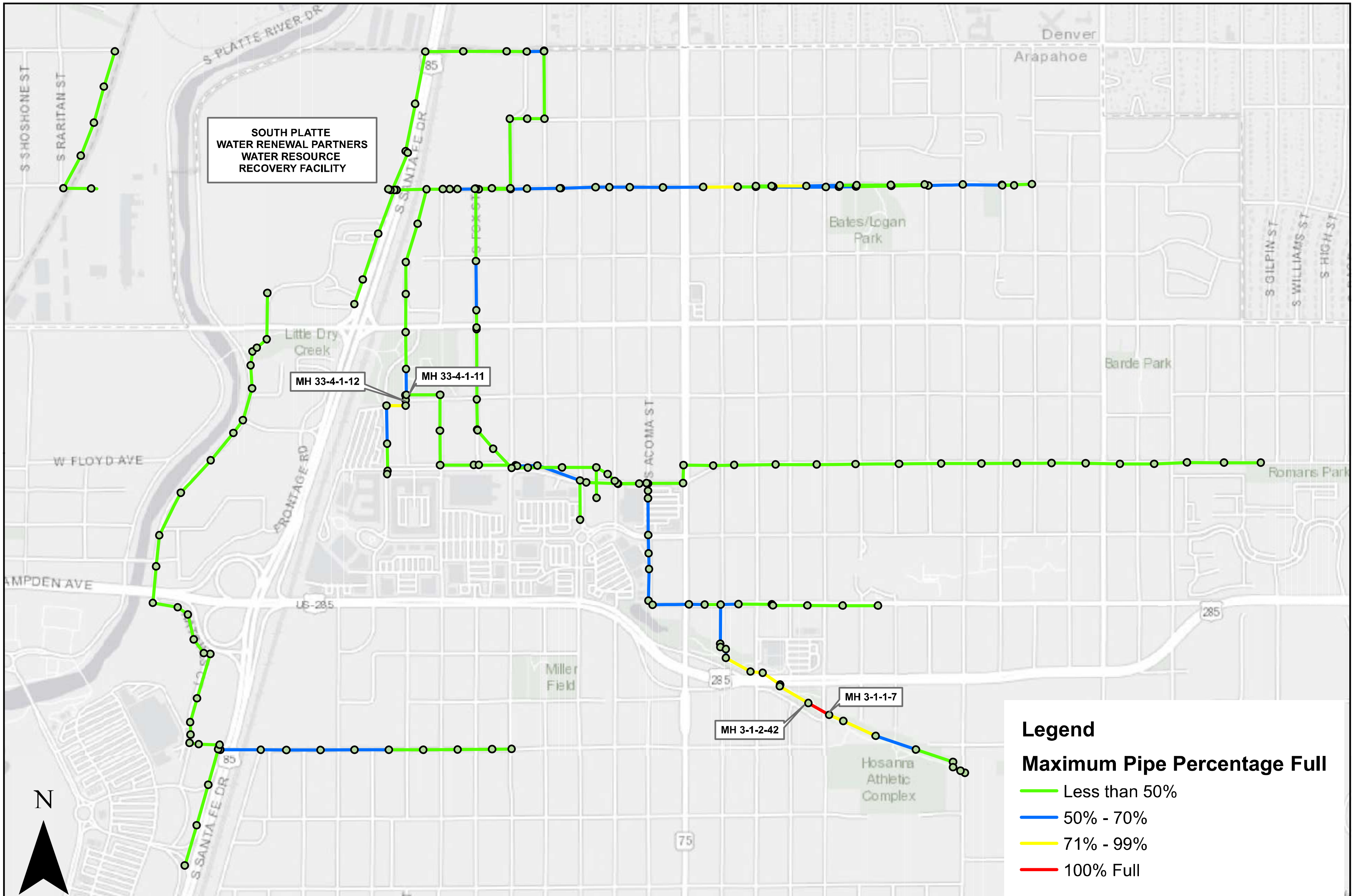

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FIGURE 5-12: SEWER CAPACITY EVALUATION -10-YEAR, 6-HOUR STORM EVENT (FUTURE)

DATE: FEBRUARY 2020

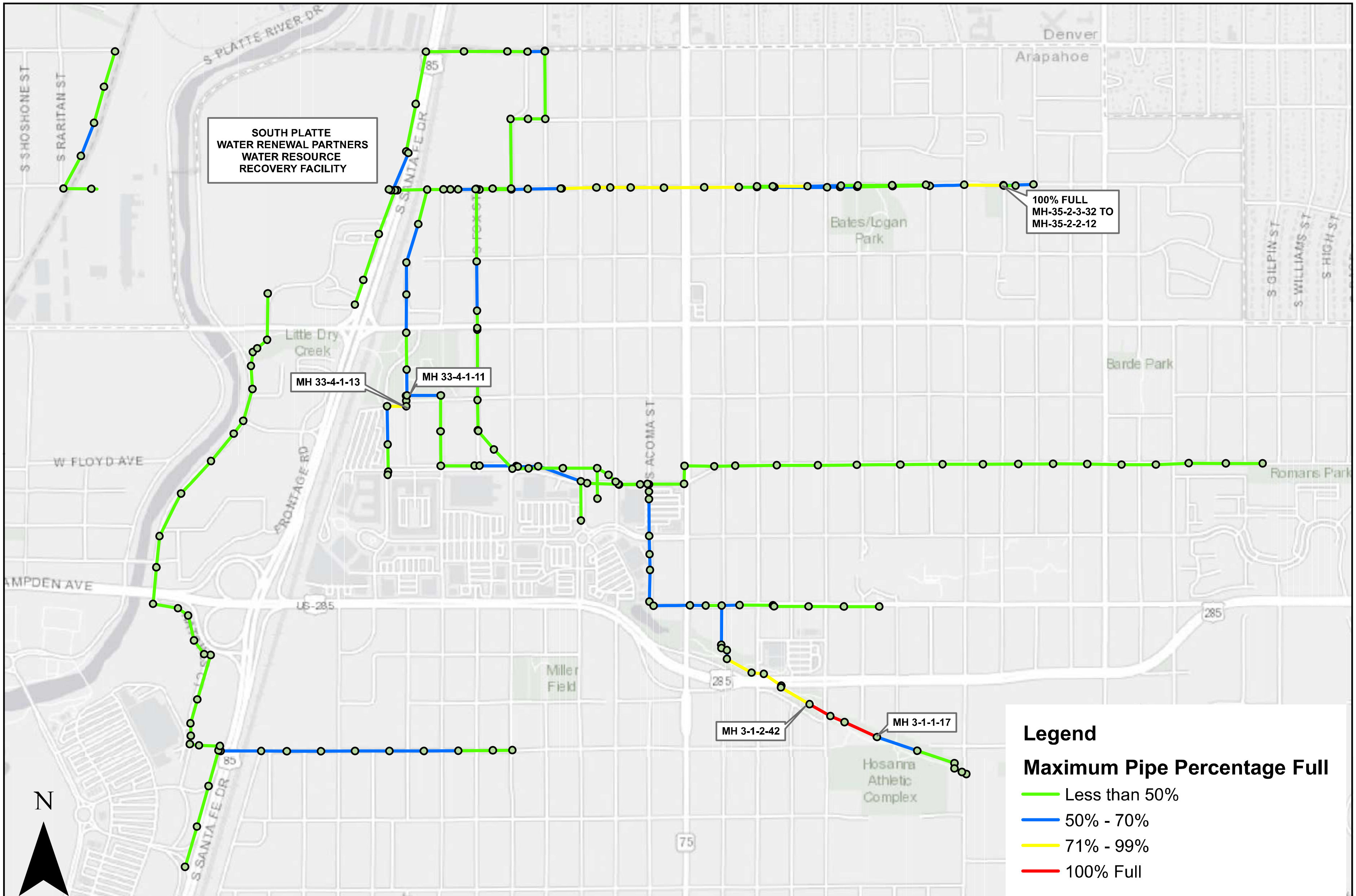

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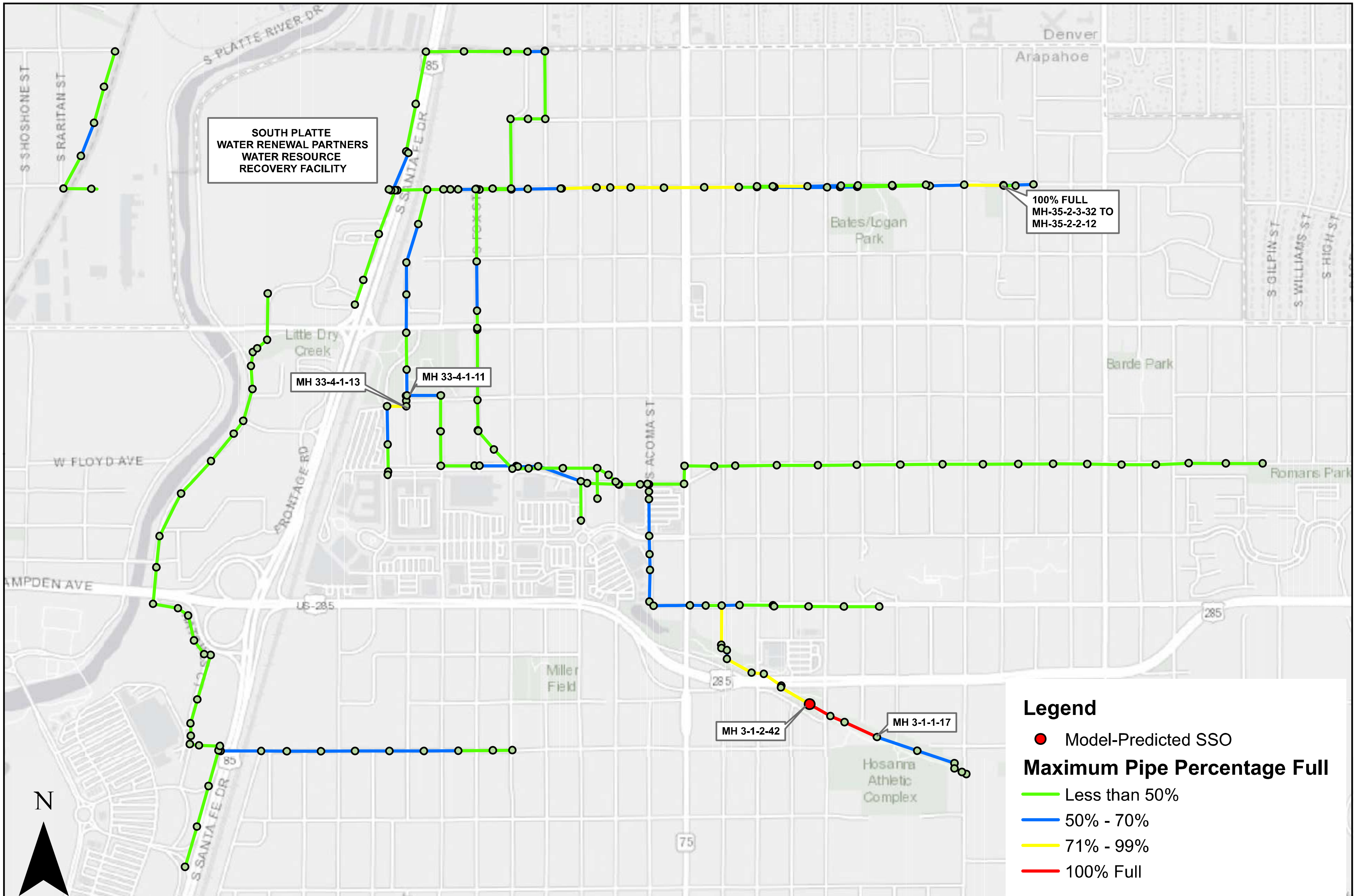
FIGURE 5-13: SEWER CAPACITY EVALUATION - 25-YEAR, 6-HOUR STORM EVENT (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020



Hazen

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FIGURE 5-14: SEWER CAPACITY EVALUATION - 50-YEAR, 6-HOUR STORM EVENT (FUTURE)

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

5.4.1 Dry Weather Evaluation

5.4.1.1 Baseline Conditions

There are no model-predicted SSOs or capacity shortages during dry weather. No sewer mains are predicted to be more than 70 percent full during dry weather peak hour flow.

No sewer mains are predicted to have a maximum velocity over 10 ft/s during peak hour flow. However, 49 percent of sewer mains (weekday flows) and 54 percent of sewer mains (weekend flows) are predicted to have a maximum velocity under 2 ft/s during peak hour flow. Sewer mains with lower velocities are more susceptible to debris accumulation. These areas should be monitored more frequently for potential debris buildup, and any pipes confirmed to have recurring debris accumulation should be scheduled for more frequent cleaning as part of the City's CCTV inspection and cleaning activities.

5.4.1.2 Future Conditions

Similar to the baseline conditions, there are no model-predicted SSOs or capacity shortages during dry weather. No sewer mains are predicted to be more than 70 percent full during dry weather peak hour flow.

No sewer mains are predicted to have a maximum velocity over 10 ft/s during peak hour flow. However, 49 percent of sewer mains (weekday flows) and 53 percent of sewer mains (weekend flows) are predicted to have a maximum velocity under 2 ft/s during peak hour flow.

5.4.2 Wet Weather Evaluation

5.4.2.1 Baseline Conditions

No model-predicted SSOs were observed for any of the five design storm events. No model-predicted surcharging was observed for the 2-year, 6-hour and 5-year, 6-hour storm events. Surcharging is defined as the hydraulic grade line (HGL) above the pipe crown. Pipe surcharging was predicted for a few sewer pipes under the 10-year, 25-year and 50-year, 6-hour storm events.

5.4.2.2 Future Conditions

No model-predicted SSOs were observed until the 50-year, 6-hour storm event. Similar to the baseline conditions, no surcharging was observed for the 2-year, 6-hour and 5-year, 6-hour storm events. In general, the magnitude of model-predicted surcharging increased under future conditions for the 10-year, 25-year and 50-year, 6-hour storm events. However, the model-predicted surcharging is limited to a few sewer pipes within the modeled network.

5.4.2.3 Key Findings

Overall, most of the modeled system is able to convey current and future dry and wet weather flows without pipe surcharging. There are no model-predicted capacity limitations during dry weather, under baseline or future conditions. However, a future flow projections analysis is recommended to define future flows more accurately throughout the system based on development projections, both greenfield and infill.

Confidence in wet weather capacity results is limited due to the lack of rainfall events and associated system response captured during the monitoring period. Additional flow and rainfall monitoring is recommended during the Spring season to record the system's response to several significant rain events. This data would be used to update the peaking factors (static) for the five design storm events and/or to update the calculated RTK values for dynamically simulating the system's response to design storms in the model.

In addition, local capacity restrictions are possible in the smaller diameter sewers that were not modeled. In areas where localized capacity is a concern, particularly in areas of planned or on-going re-development, it is recommended that the model be expanded to include the collection system serving these areas.

5.4.3 Model Refinement Recommendations

The following recommendations will enhance the collection system model developed as part of this Master Plan:

- Expand the hydraulic model to include all sewers 10-inches in diameter and larger, and smaller-diameter sewers as needed, particularly in areas with significant development
- Perform dry and wet weather re-calibration based on additional flow and rainfall monitoring data
- Update future flow projections for two planning horizons based on current and projected development trends. For the purposes of this Master Plan, the future flow projections are based on an assumed uniform three percent increase in flows across the sewer system by year 2030 as required by the Plan's scope. Englewood's population has remained relatively flat over the last 40 years; however, more recent vertical development has resulted in increased population density and potential for population growth. Therefore, the hydraulic model should be updated following a more in-depth projection of future flows.
- Perform an updated dry and wet weather capacity assessment for existing and future conditions for the expanded, re-calibrated model utilizing refined future flow projections

6. Risk Assessment

6.1 Risk Assessment Methodology

6.1.1 Overview

A desktop risk assessment was conducted for the City's major sewer interceptors. Per the scope for this Plan, only sewers 15-inches in diameter and larger were included (45,103 total LF of sewers). The purpose of the risk assessment was to establish the existing condition of critical assets and to identify and prioritize repair and replacement (R/R) projects to be included in the Capital Improvement Plan (CIP). This section describes the methodology used and summarizes the results of the risk assessment. A detailed description of the approach is included in the Sewer System Risk Assessment Technical Memorandum in Appendix F.

The risk assessment was performed by first creating an asset register of all City-owned interceptors 15-inches in diameter and larger. Then, pipe-specific characteristics such as size and material were evaluated, along with surrounding environment characteristics such as depth and proximity to critical facilities, to infer risk of failure.

An asset register is a record of physical assets within a system which includes pertinent asset data characteristics, asset status and condition, which should be continuously updated as part of an asset management program. The asset register for this Master Plan is provide in an Excel spreadsheet in Appendix F. However, the asset register should be expanded to include additional assets (e.g., manholes, smaller diameter sewer mains) and transitioned to the City's Enterprise Asset Management software as part of the programs discussed in Sections 7.4 and 7.5.

6.1.2 Likelihood of Failure

The likelihood of failure (LoF) measures an asset's likelihood of, or timing to, failure. LoF is directly correlated to the asset's condition. Typically, LoF scores incorporate available condition assessment field data, such as CCTV inspection data and maintenance records. Since this data was unavailable for pipes 15-inches and greater, LoF scores were determined based on the available GIS data for sewer interceptor pipes: pipe age (where available) and pipe material.

Scoring criteria were developed for each LoF category. Pipe assets were given a score on a scale of 1 to 5 (best to worst) for each of the categories and then an overall weighted LoF score was calculated for each interceptor pipe.

6.1.3 Consequence of Failure

Consequence of failure (CoF), or criticality of an asset, measures the direct and indirect impacts and costs associated with asset failure. Criticality assessment is often performed on linear pipe networks using GIS tools for determining impacts from failures on surrounding infrastructure, critical users such as hospitals, and the environment.

Consequence of failure can vary from a minor inconvenience to a major disruption of service. For example, failure of a large interceptor in front of a hospital has significant consequences while failure of a small diameter main collecting sewage from a small number of users has far less consequence of failure.

Criticality scores were determined based on three main categories: location, pipe depth and pipe diameter, as described in Table 6-1. Scoring criteria were developed for each CoF category. Pipe assets were given a score on a scale of 1 to 5 (best to worst) for each of the categories and then an overall weighted score was calculated for each interceptor pipe.

Table 6-1: Consequence of Failure Categories

Category	Description
Location	• Proximity to critical facilities (schools, hospitals, fire stations, police stations, light rail stations and city hall) • Proximity to water bodies (streams, rivers and reservoirs) • Proximity to railroads and major highways
Pipe Depth	Depth to pipe invert. Impact of pipe repair is directly correlated to the pipe depth.
Pipe Diameter	Diameter of pipe is often correlated to the overall number of customers affected by failure, as well as the cost and time required to repair the failure

6.1.4 Risk-Based Assessment

Risk scores are used as the basis for prioritizing asset repair and replacement. Replacement of assets with a higher risk score should be funded prior to the replacement of assets with a lower risk score. The equation to compute risk is presented below:

$$\text{Risk Score} = \text{LoF Score} \times \text{CoF Score}$$

As the equation shows, the risk score is equally weighted between the LoF and CoF scores. Assets in poor condition (i.e., high LoF score) with a high CoF pose the greatest risk. Likewise, assets in excellent condition (i.e., low LoF score) with a low CoF pose the lowest risk.

6.2 Risk Assessment Results

A risk score was calculated and documented for each interceptor in the asset register (City interceptors 15-inches in diameter or larger). The risk score can provide an indication of the best management approach for each of the assets. For low CoF and low LoF assets, a run-to-failure approach may be most appropriate. For high CoF and high LOF assets, immediate action, such as replacement or repair, may be needed. For those assets with high CoF but low LoF, frequent inspection may be the best management approach to monitor any deterioration of the critical asset over time. Finally, for those assets with low CoF but high LoF, the merits of renewal versus continued maintenance should be considered, to provide the highest level of service at the lowest lifecycle cost to the City. Figure 6-1 illustrates a typical risk matrix showing the various management strategies for different risk profiles.

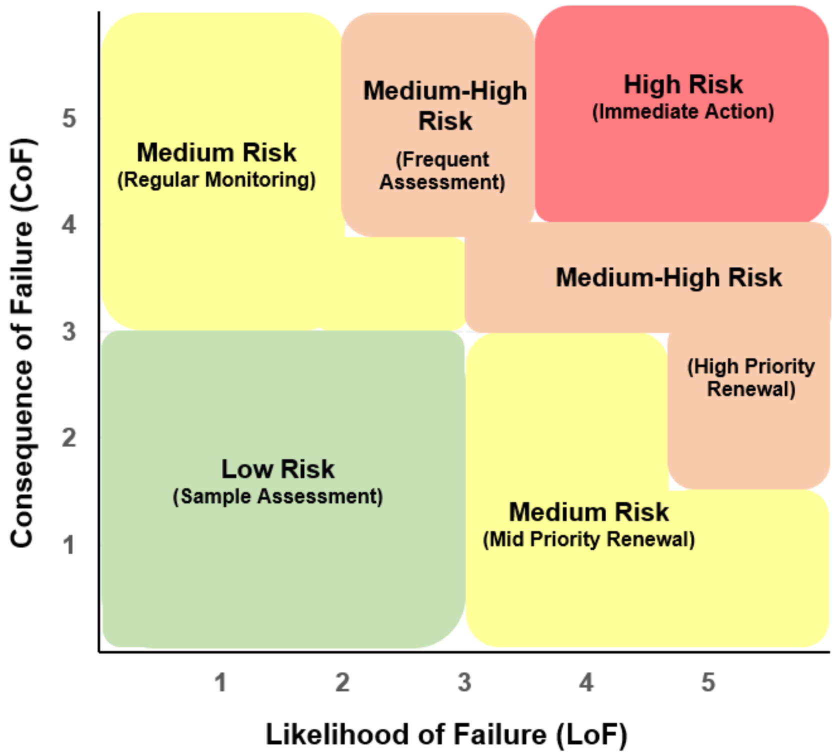

Figure 6-1: Typical Risk Matrix and Associated Management Approaches

From the calculated risk scores, a relative risk rating was assigned to each pipe segment analyzed. The results of the risk-based assessment are summarized in Table 6-2.

Figure 6-2 shows a map of all the interceptors color-coded based on their risk ratings.

Table 6-2: Summary of Interceptor Risk Ratings

Risk Rating	No. of Pipe Segments	Linear Feet	% of Total LF Assessed
High	9	2,569	5.7
Medium-High	39	9,820	21.8
Medium	116	27,868	61.8
Low	17	4,846	10.7
Total	**181**	**45,103**	**100.0**

The majority of the City's interceptors (73 percent) had either "medium" or "low" risk ratings. As shown on Figure 6-2 on page 6-5, two pipe sections received "high" risk ratings. One section is 1,176 LF along S. Huron Street between W. Cornell Avenue and W. Bates Avenue. The high score is due to its size (24-inch), material (RCP), depth (approximately 30 feet), and proximity to a railroad. The other pipe section is 1,393 LF of the BDCI that runs along Santa Fe Drive. This section received a high score due to its size

(42-inch), material (RCP), depth (approximately 17 feet) and proximity to a major road. As discussed above, CCTV inspection data were not available for any of the interceptors analyzed.

It is important to note that desktop risk assessment relies heavily on good quality data. Where data such as pipe depth, material, size and installation year were not available in the GIS database, assumptions were made. These data gaps should be closed over time so that an updated analysis will be possible in the future.

6.3 Risk Assessment Recommendations

Due to the low cost of sewer main inspection relative to the cost of rehabilitation or replacement, it is recommended that the City perform comprehensive CCTV inspections of the sewer system before identifying R/R projects. The CCTV inspections should be prioritized according to the asset risk ratings developed in this Master Plan and the City's institutional knowledge of the system. Following completion of the CCTV inspections, the LoF scores for each asset should be updated to incorporate the inspection results (i.e., number and severity of structural and operations and maintenance defects). Instead of individual R/R projects, the following Section 7 of this Master Plan identifies two programs, Sewer Main Rehabilitation and Manhole Rehabilitation, that are recommended to budget for on-going renewal of sewer system assets.

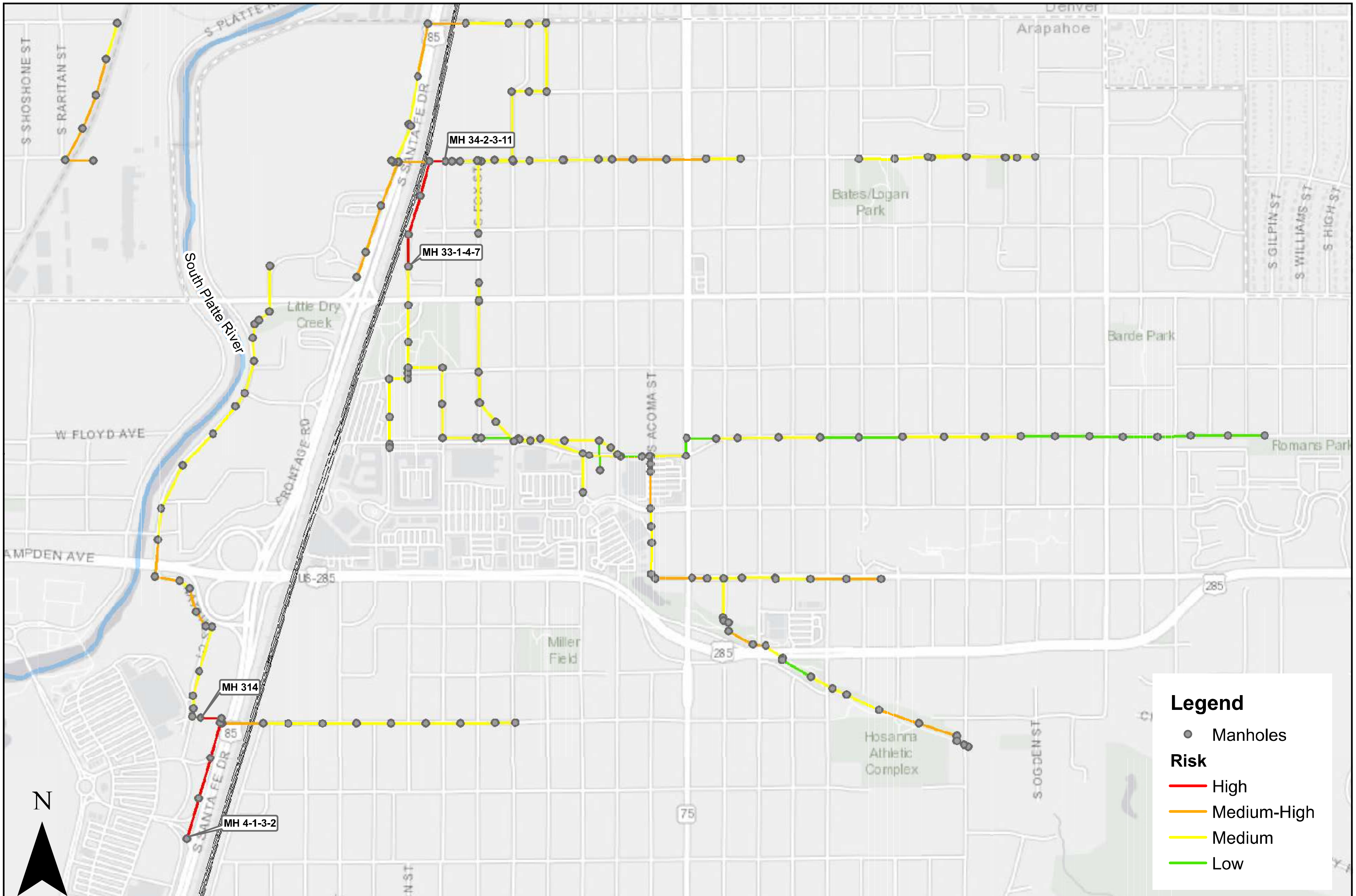

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FIGURE 6-2: SEWER INTERCEPTORS RISK RATINGS

1,600 800 0

1 Inch = 1,183 Feet

DATE: FEBRUARY 2020

7. Sewer System Programs

The capacity assessment and risk assessment tasks described in Sections 5 and 6 did not result in any discrete capital improvement project recommendations. This is due in part to the limited data available for this master planning effort. The City's collection system is aging and has been the subject of corrective maintenance instead of the more preferred preventative maintenance practices. Therefore, programs have been identified with the goal of obtaining additional data on the existing collection system and improving the City's sewer system management approach.

Programs are defined as on-going activities intended to proactively assess, maintain and upgrade aging infrastructure. They vary in size and cost with several continuing indefinitely. As each program is implemented, the City will gain a more comprehensive understanding of their sanitary sewer infrastructure. As a result of discussions with the City's Utilities staff and analysis of the City's existing data and activities, thirteen programs are recommended to assist the City in transitioning from a reactive to a proactive sewer system management approach. The programs listed in Table 7-1 are based on sanitary sewer best management practices.

Each program has been assigned a unique identifier (i.e., PRG-SEW-C-XXX). Some of the programs in Table 7-1 have been implemented previously, but due to limited City resources many of the program activities have been deferred.

The sewer system program costs and prioritization are provided in Section 9: Capital Improvement Plan. Individual program sheets detailing recommendations, costs, schedule and assumptions are provided in Appendix G.

Table 7-1: Sewer System Programs

Program ID	Program Name
PRG-SEW-C-001	Geographic Information System (GIS) Update
PRG-SEW-C-002	Program Management
PRG-SEW-C-003	CCTV Inspections/Cleaning
PRG-SEW-C-004	Enterprise Asset Management
PRG-SEW-C-005	Comprehensive Asset Management Program
PRG-SEW-C-006	Manhole Inspections
PRG-SEW-C-007	Sewer Main Rehabilitation/Replacement
PRG-SEW-C-008	Manhole Rehabilitation/Replacement
PRG-SEW-C-009	Construction Management
PRG-SEW-C-010	Flow and Rainfall Monitoring
PRG-SEW-C-011	Model Expansion, Re-calibration and Updates
PRG-SEW-C-012	Emergency Repair Projects
PRG-SEW-C-013	Sewer Master Plan and Model Update

7.1 Geographic Information System (GIS) Update

The City has an excellent GIS database for the sewer collection system. However, there are remaining data gaps within the pipe and manhole attribute tables that should be addressed. These include manhole rim elevations, manhole installation year, pipe invert elevations, pipe slope, pipe material and pipe installation year. This program is a one-time update of the City's existing GIS data to fill in any missing data and populate any additional data fields for the sewer assets followed by additional regular updates of the GIS as new information becomes available or the physical system changes.

7.2 Program Management

Program management is the process of holistically managing several projects. The Capital Improvement Plan (CIP) includes several programs, varying in scope, budget and schedule that will need dedicated staff to manage. Program management can be led by City staff or outsourced to a consulting firm. Utilizing a consulting firm provides greater flexibility of resources and allows City staff to remain focused on key initiatives. It is recommended that the City develop resources to perform program management for the various sewer system programs. If the City decides to perform the program management internally, the City should review available staff resources and determine additional staff needs.

7.3 CCTV Inspections and Cleaning

It is industry-standard practice to perform periodic CCTV inspection of sanitary sewer mains to assess structural and O&M condition of the assets and identify system deficiencies and needs. These periodic assessments provide the data needed to maintain a robust asset management program, plan for rehabilitation and renewal of the assets, and schedule O&M activities. Sewer main cleaning reduces debris build-up that, if left unchecked, can reduce system capacity and can lead to sewer blockages and backups.

The City owns sewer jetting (cleaning) and CCTV inspection equipment and their current goal is to annually jet clean all sewer mains 15-inches in diameter and smaller. However, CCTV inspections are performed infrequently as issues are identified in the system due to limited staffing. Limited CCTV inspection data for the sewer system is available, and the existing condition of most pipe assets is unknown. It is recommended that the City perform CCTV inspections and cleaning for all of their sewer mains (approximately 80 miles) within the next year. Cleaning will include manhole channels and other manhole components where needed. Inspections should be performed in accordance with the National Association of Sewer Service Companies (NASSCO) Pipeline Assessment Certification Program (PACP) standards.

The City should also establish an on-going CCTV inspection and cleaning program. The frequency of re-inspections should be determined by analysis of the baseline inspection data obtained over the next year. Depending on the defects identified and their corresponding PACP grades, the re-inspection frequency may range from every five to every twenty years. The re-inspection schedule should be accelerated for defects that warrant being monitored more closely. For the purposes of allocating funding for this program, an average re-inspection cycle of ten years is assumed. According to the American Water Works Association's (AWWA) *Benchmarking Performance Indicators for Water and Wastewater*

Utilities Survey Data and Analyses Report (2016 Edition), reporting utilities inspected an average of eleven percent of their sewer pipe network per year.

The existing cleaning cycle for each sewer main should also be re-evaluated after the baseline inspections are complete. The required cleaning frequency for each pipe can vary widely from less than one year up to five years or more. Cleaning frequency should be optimized based on Utilities staff knowledge of problem areas, work order cleaning history recorded as part of the Enterprise Asset Management Program, and PACP O&M defect codes from the CCTV Inspection Program.

7.4 Enterprise Asset Management

Enterprise Asset Management (EAM) Systems, also referred to as Computerized Maintenance Management Systems (CMMS), are utilized to facilitate work planning, inventory management, work execution, reporting and system analysis. Presently, the City owns Infor EAM software licenses; however, the software is not being used to its full capabilities by the majority of staff as related to sanitary sewer system management. It is recommended that the City develop optimized sanitary sewer work management processes and workflows, then determine the type of management reporting needed. Once defined, these work processes should be implemented in Infor or another appropriate CMMS/EAM software.

7.5 Comprehensive Asset Management Program

A Comprehensive Asset Management Program (CAMP) provides for effective, pro-active management of sewer assets based on the condition and criticality of each asset (i.e., business risk exposure). It is recommended that the City implement a CAMP including all sewer system infrastructure to create a prioritized plan for asset renewal, capacity upgrades and O&M activities to minimize risk. The Environmental Protection Agency (EPA) identifies the following benefits of asset management[1].

- Prolonging asset life and improving decisions about asset rehabilitation, repair and replacement
- Meeting consumer demands with a focus on system sustainability
- Setting rates based on sound operational and financial planning
- Budgeting focused on critical activities for sustained performance
- Meeting service expectations and regulatory requirements
- Improving responses to emergencies and the security and safety of assets

[1] *Asset Management for Water and Wastewater Utilities.* Environmental Protection Agency. Sustainable Water Infrastructure.

7.6 Manhole Inspections

Manholes are the primary point of access to sewer mains and are critical to the operation and maintenance of the sewer collection system. It is industry-standard practice to perform periodic inspection of manholes to assess structural and O&M condition of the assets and identify the system's deficiencies and needs.

Limited manhole inspection data for the sewer system is available and the existing condition of most manhole assets is unknown. It is recommended that the City inspect all 1,558 manholes within the next year. Inspections should be performed in accordance with the NASSCO Manhole Assessment Certification Program (MACP) standards or similar inspection form template.

The City should also establish an on-going manhole inspection program. The frequency of re-inspections should be determined by analysis of the baseline inspection data obtained over the next year. Depending on the defects identified and their corresponding MACP grades, the re-inspection frequency may range from every five to every twenty years. The re-inspection schedule should be accelerated for defects that warrant being monitored more closely. For the purposes of allocating funding for this program, an average re-inspection cycle of ten years is assumed.

7.7 Sewer Main Rehabilitation/Replacement

The City typically repairs sewer mains only as critical defects occur. A program is recommended to systematically rehabilitate aging and deteriorating sewer mains to improve system reliability.

Sewer rehabilitation is used to address structural and O&M defects in sewer mains. The most common trenchless rehabilitation technology, cured-in-place pipe (CIPP) lining, has an estimated design life of 50 years or more. One of the main benefits of trenchless sewer rehabilitation is that it renews existing pipes without costly and disruptive excavation. Sewer rehabilitation can repair many common defects in pipes, but severe defects such as pipe collapses and significant deformations still require excavation. Therefore, it is critical to identify defects through inspections before they deteriorate to the point where CIPP lining is not feasible. It is recommended that all CIPP lining be designed for the fully deteriorated existing pipe condition. With this design requirement, the cured liner does not require any support from the original host pipe.

A typical rule of thumb for many utilities is one percent renewal per year, based on an estimated life span of 100 years for collection system pipelines. However, since a formal rehabilitation program has not been established previously, it is assumed that higher renewal rates may be required at first. According to AWWA's *Benchmarking Performance Indicators for Water and Wastewater Utilities Survey Data and Analyses Report* (2016 Edition), reporting utilities perform system renewal and replacement for an average of 1.6 percent of their sewer collection system per year. This AWWA report presents the performance results for water/wastewater utilities across the nation for the fiscal year 2015. The numbers reported can provide basic comparison data for peer utilities, although the reporting methods and approach do vary across utilities. Based on this benchmark data, it is recommended that the City establish a sewer main rehabilitation program to rehabilitate two percent of their sewer mains per year. This program also includes an allowance for open cut repair/replacement that may be required based on the defects in the pipes selected for rehabilitation each year.

The rehabilitation areas will be selected based on the results of the Comprehensive Asset Management Program and the CCTV Inspection Program. The percent of the system to be rehabilitated per year will be reviewed and updated once inspection data is available for all sewer mains. The data collected during the initial comprehensive CCTV inspection of the system will indicate whether the renewal rates should be lower or higher than two percent per year.

7.8 Manhole Rehabilitation/Replacement

Manhole rehabilitation is used to address structural and O&M defects in manholes. In conjunction with the sewer rehabilitation program, the City should establish a formal manhole rehabilitation program to rehabilitate two percent of their sewer manholes per year. This program includes an allowance for other repairs/replacement that may be required based on the defects in the manholes selected for rehabilitation each year.

The rehabilitation areas will be selected based on the results of the Comprehensive Asset Management Program and the Manhole Inspection Program. The percent of the system to be rehabilitated per year will be reviewed and updated once inspection data is available for all manholes. The data collected during the initial comprehensive manhole inspections of the system will indicate whether the renewal rates should be lower or higher than two percent per year.

7.9 Construction Management

Construction management provides effective management of schedule, cost, quality, safety, scope and function of construction projects. The CIP includes two programs, sewer and manhole rehabilitation, that will need dedicated staff for construction management. Construction management can be led by City staff or outsourced to a consulting firm. As with Program Management, utilizing a consulting firm provides greater flexibility for resource planning. It is recommended that the City develop resources to perform construction management for the sewer system programs.

7.10 Flow and Rainfall Monitoring

Flow and rainfall monitoring programs are used to collect data for characterization and evaluation of dry-weather and wet-weather flow conditions in the sanitary sewer collection system. This data is especially important for calibrating sewer hydraulic models to adequately predict system capacity under a range of conditions. Flow and rainfall monitoring involves installing a network of flow meters and rain gauges at strategic locations to characterize each area of the sewer system. As part of this master planning effort, only five level sensors were installed to assist in the development of the sewer hydraulic model. In order to properly calibrate and refine the model, it is recommended that up to 22 area-velocity flow meters (which directly measure both depth and velocity) be installed throughout the City during the Spring season to capture the system's response to several significant rainfall events. Flow and rainfall monitoring should also be performed prior to each Master Plan update as part of the associated hydraulic modeling updates.

7.11 Model Expansion, Re-Calibration and Updates

The model developed as part of this Master Plan includes all sewer interceptors 15-inches in diameter and larger. In order to advance the understanding of the sewer system's capacity, the following model refinements are recommended:

- Expand the hydraulic model to include smaller diameter sewers.
    - The City has indicated that their goal is to include all sewers 8-inches and larger in the expanded model. Therefore, this program will expand the existing model to include over 375,000 LF of additional 8-inch to 12-inch diameter sewers.
- Perform dry and wet weather re-calibration based on additional flow and rainfall monitoring data.
- Update future flow projections for two planning horizons as described in Section 5.4.3.
- Perform an updated dry and wet weather capacity assessment for existing and future conditions.

These model refinements will provide better confidence in the capacity assessments performed with the model and identify any local capacity restrictions in the smaller diameter pipes. The results of these efforts will be captured in an update to the Master Plan provided herein. Following the initial model expansion and re-calibration, this program will include regular updates to the model as new information becomes available or the physical system changes.

7.12 Emergency Repair Projects

As the City embarks on a more robust sewer and manhole inspection program, critical defects may be identified within the system that were previously unknown. To be financially prepared, funding should be allocated to an annual emergency repair program to address critical defects as they occur and/or are identified through the inspection programs. The types of emergency repairs may vary in size and scope but may include the following: emergency bypass pumping, excavation, pipe replacement, backfill, and surface restoration. The City will need to evaluate whether internal resources are adequate to perform these emergency repairs or if the City should engage with an emergency/on-call contractor for this work.

7.13 Sewer Master Plan and Model Update

Models and Master Plans are intended to be adaptive and evolving tools for long-term planning. They should be updated periodically based on system changes and evolving needs/priorities. At five-year intervals, it is recommended that the City perform flow and rainfall monitoring (see Section 7.10) and perform a verification of the model calibration. Flow projections should also be updated at this time. The results of these activities will be captured in a complete Master Plan update and revised Capital Improvement Plan.

8. Policy Recommendations

In addition to the program recommendations presented in Section 7, several policy recommendations have been identified based on discussions with the City's Utilities staff and review of the City's existing policies.

8.1 Design and Construction Standards

The purpose of design and construction standards is to identify minimum design standards and specifications, submittal requirements and approval or acceptance procedures to be used for sewer systems that will be maintained by the City. These standards typically apply to private development projects containing utilities that will be turned over to the City as well as all capital improvement projects. The City currently has a set of design and construction standards that are not publicly available. It is recommended that the City invest in updating them to the latest industry standards. The update should include a design manual, standard detail drawings, technical specifications, list of approved products, and detailed as-built submittal requirements including GIS layers so that the City's GIS database can be kept up to date after the completion of CIP projects or new developments.

8.2 City Building/Redevelopment Standards

Existing policies do not adequately address the type of redevelopment that the City is experiencing. The City should consider implementing policies relative to the impact of development on the sewer conveyance system. The City currently has a detailed application process for new developers. However, it would be beneficial for the City to establish a policy and develop requirements specific to the Utilities Department.

Requirements may include:

- Plan review checklists based on the City's design/construction standards
- Hydraulic analysis requirements (including necessary field work, e.g., field survey or flow monitoring, as required and as directed by the City)
- Record submittal requirements – require a complete set of signed and sealed as-builts for records prior to releasing the final Certificate of Occupancy (CO)
- Utility testing and inspection requirements
- Allocation of responsibility for sewer upgrade needs

8.3 Sewer Infrastructure Ownership

The City should develop a policy that clearly delineates the ownership of sewer service laterals. Across the nation, a variety of lateral ownership models exist. These include municipality ownership within the street only, ownership extending to the back of the sidewalk, ownership extending to the property line, and ownership of the main line only.

8.4 Coordination Between Utilities

As described in Section 2, there are several connections between the City of Englewood sanitary sewer system and other utility providers. In addition, a portion of the Big Dry Creek Interceptor is owned by four different utilities. Regular coordination meetings between the various sewer utilities that convey flows to the City's sewer system or provide sewer service within the City limits should be considered to enhance system operations.

8.5 Compensation Plan Model

The City has recently published a solicitation seeking a consultant to prepare a new compensation plan and create a sustainable model that can be updated annually. This policy update will include the following tasks:

- Determine the City's philosophy on compensation
- Utilize the most current surveys (external equity)
- Identify matches for current jobs
- Identify job grades (internal equity)
- Build a compensation model
- Calculate a market average
- Address inconsistencies and make adjustment decisions
- Create an implementation plan
- Develop a communication plan

The goal of this policy update is to attract, motivate and retain employees and mitigate risk.

9. Capital Improvement Plan

9.1 Cost Basis

Estimated program costs are considered Class 5 as defined by the Association for the Advancement of Cost Engineering International (AACEi). The class designation is determined based upon the information available for estimation and the maturity of the design. Class 5 estimates can range in accuracy from –20% to –50% on the low side to +30% to +100% on the high side, depending on the complexity of the project.

Program costs were developed using planning level costs based upon experience with similar types of programs. For internal staff costs, salary rates were obtained from the City's online financial portal and a 1.35 loaded multiplier was used to account for overhead expenses (insurance, retirement plans, paid time off, etc.). Assumptions were made regarding whether resources needed for each program would be internal or external (e.g., consulting engineer or contractor), or a combination thereof. Program costs include planning, engineering and construction costs where applicable. All costs are shown in 2020 dollars.

It is important to note that construction costs are currently increasing due to industry demands and our experience in recent years is that bid prices are often higher than projected. The costs developed for this Master Plan are meant to be conservative for budgeting purposes. As the CIP progresses and uncertainties reduce, costs estimates should be revised to reflect actual conditions.

9.2 Prioritization of Programs

Prioritization is necessary to focus the City's financial resources on the most critical programs first. As programs are completed, new initiatives and projects may require re-prioritization. This Plan prioritized programs into the following three categories:

- High Priority: If these projects and programs are not completed, risk of service disruption to customers is significant and more immediate. High priority projects and programs should begin in the next 1 to 2 years.
- Medium Priority: If these projects and programs are not completed, risk of service disruption to customers may be possible in the future. Medium priority projects and programs should begin in the next 3 to 5 years.
- Long-Range: These projects and programs should be considered for implementation after 5 years.

Based on a comprehensive analysis of the sewer system as previously described, thirteen programs were recommended for the sewer collection system. As shown in Table 9-1, these programs have been classified as High Priority, Medium Priority or Long-Range according to the descriptions above. In addition, the City's portion of the SPWRP Capital Plan expenditures is included as a program. This is the amount of the WRRF's Capital Plan expenditures that is paid from the City's sewer enterprise fund.

Similar to the sewer collection CIP, the WRRF CIP has High Priority, Medium Priority and Long-Range projects.

The projected cost of the sewer collection system programs is estimated to be approximately $30 million over the next 15 years. The projected cost of the wastewater treatment programs/projects is estimated to be approximately $31 million over the next 15 years. The program costs and prioritization are provided in Table 9-1.

Table 9-1: Budget Summary of CIP Programs

CIP ID	Program Name	Prioritization	Timeframe to Start Implementation[1]	Total Budget Cost over 15-Year CIP[2]
PRG-SEW-C-001	Geographic Information System (GIS) Update	High Priority	1-2 Years	$330,000
PRG-SEW-C-002	Program Management	Medium Priority	3-5 Years	$840,000
PRG-SEW-C-003	CCTV Inspections/Cleaning	High Priority	1-2 Years	$2,320,000
PRG-SEW-C-004	Enterprise Asset Management	High Priority	1-2 Years	$600,000
PRG-SEW-C-005	Comprehensive Asset Management Program	High Priority	1-2 Years	$620,000
PRG-SEW-C-006	Manhole Inspections	High Priority	1-2 Years	$1,000,000
PRG-SEW-C-007	Sewer Main Rehab/Replacement	Medium Priority	3-5 Years	$16,510,000
PRG-SEW-C-008	Manhole Rehab/Replacement	Medium Priority	3-5 Years	$2,990,000
PRG-SEW-C-009	Construction Management	Medium Priority	3-5 Years	$1,170,000
PRG-SEW-C-010	Flow and Rainfall Monitoring	Long-Range	6-15 Years	$1,000,000
PRG-SEW-C-011	Model Expansion, Re-Calibration and Updates	Long-Range	6-15 Years	$440,000
PRG-SEW-C-012	Emergency Repair Projects	High Priority	1-2 Years	$2,210,000
PRG-SEW-C-013	Sewer Master Plan and Model Update	Long-Range	6-15 Years	$400,000
	SPWRP Capital Plan[3]	High Priority	1-2 Years	$3,670,000
	SPWRP Capital Plan[3]	Medium Priority	3-5 Years	$5,240,000
	SPWRP Capital Plan[3]	Long-Range	6-15 Years	$21,760,000
			TOTAL	**$61,100,000**

[1]Timing of implementing each program is dependent on funding.

[2]Collection system program costs include a Class 5 contingency of 30 percent.

[3]SPWRP WRRF Capital Plan budget costs are included in all three prioritization categories based on project timing.

The City's first priority should be to fill in any gaps in the existing sewer GIS dataset (PRG-SEW-C-001) and assess the condition of all sanitary sewer assets via CCTV inspections (PRG-SEW-C-003) and manhole inspections (PRG-SEW-C-006). At the same time, it is recommended that the City create an Enterprise Asset Management Program (PRG-SEW-C-004) to efficiently manage and report on work processes (such as system inspection and cleaning) and a Comprehensive Asset Management Program (PRG-SEW-C-005) to assess the risk ratings of existing assets and prioritize rehabilitation and renewal of the system. Recognizing that additional inspection efforts may identify critical system defects, it is recommended that funding be established for emergency projects (PRG-SEW-C-012).

The results of the CCTV inspections, manhole inspections, and Comprehensive Asset Management Program will inform the prioritization of annual sewer rehabilitation (PRG-SEW-C-007) and manhole rehabilitation programs (PRG-SEW-C-008). Construction Management (PRG-SEW-C-009) is necessary for the successful implementation of the rehabilitation programs.

The flow monitoring (PRG-SEW-C-010) and model expansion/update (PRG-SEW-C-011) programs will facilitate capacity evaluation in the smaller diameter sewer mains, evaluate impacts of current development trends on capacity, and increase confidence in wet weather assessment results. Periodic Master Plan updates (PRG-SEW-C-013) should be performed including review and update of the programs and prioritized CIP discussed herein.

Program Management (PRG-SEW-C-002) is necessary to guide these various programs with overlapping schedules and ensure that program objectives are met. A flow chart illustrating the relationships between the various programs is provided in Figure 9-1.

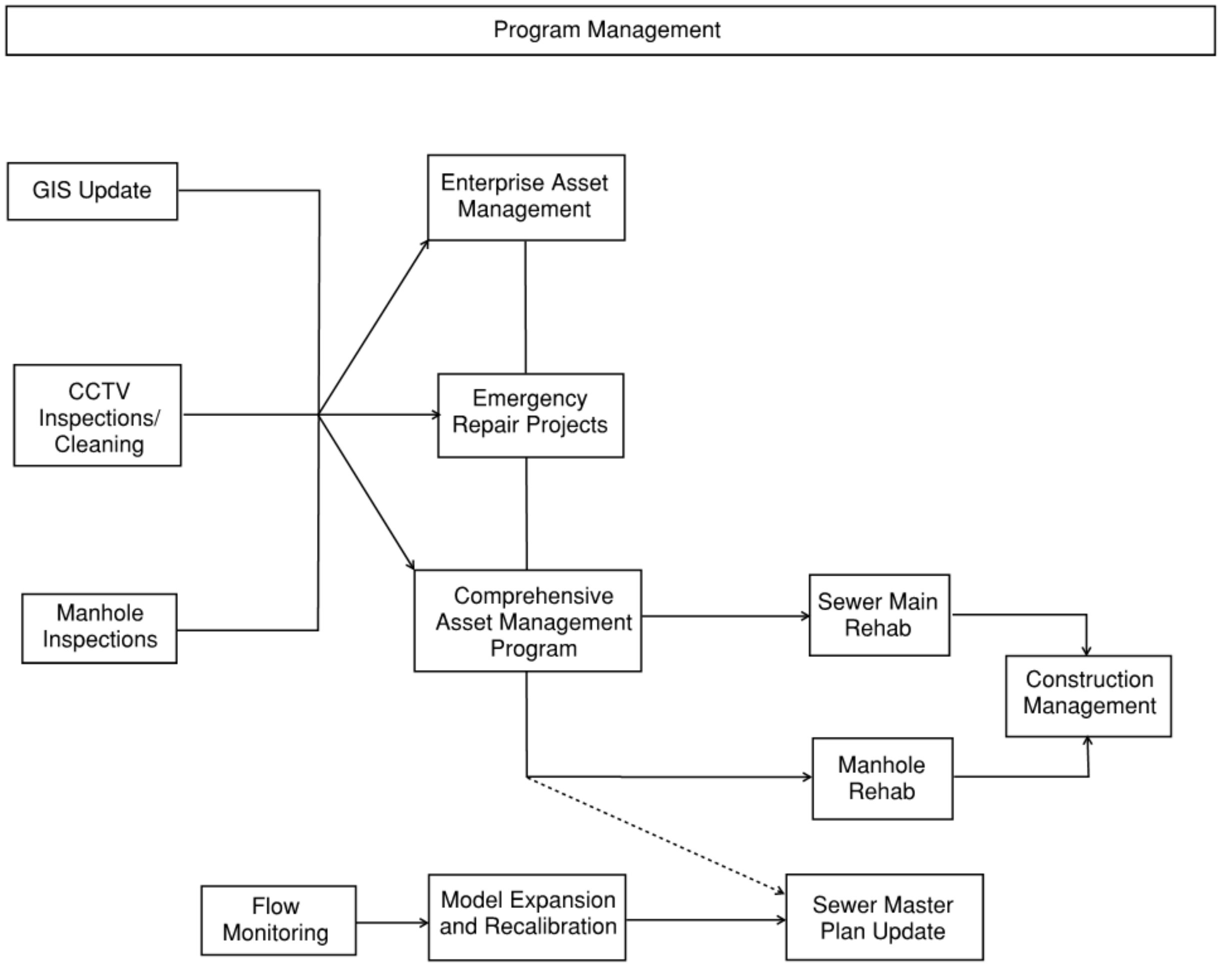

Figure 9-1: Sewer System Program Implementation

9.3 City Resources

The City's Utilities Department is responsible for the day-to-day operation and maintenance of the Allen Water Treatment Plant, the water distribution system, and the sanitary sewer collection system. The water distribution/sewer collection group consists of twelve full-time field staff and five full-time office staff. This group is responsible for the City's 80 miles of sewer system piping and manholes that collect and convey sewage from more than 6,500 customer accounts. This group also handles the operation and maintenance of the water distribution system.

With the proposed CIP, there are opportunities to increase the Utilities field and office staff allowing the City to manage some aspects of the programs internally. An initial estimate of the additional full-time equivalents (FTEs) needed to implement the CIP programs is provided in Table 9-2.

Table 9-2: Summary of Additional FTE Requirements

Program Name	FTE 2020-2024[1]	FTE 2025-2029[1]	FTE 2030-2034[1]	Staff Description
Geographic Information System (GIS) Update	1.32	1.0	1.0	1 GIS analyst
CCTV Inspections and Cleaning	3.81	1.47	1.47	1-2 PACP-certified field crews (2 people)
Enterprise Asset Management	0.67	0.83	0.83	1 Asset Management Subject Matter Expert
Comprehensive Asset Management Program	0.67	0.83	0.83	1 Asset Management Subject Matter Expert
Manhole Inspections	2.68	1.03	1.03	1 MACP-certified field crew (2 people)
TOTAL	**9.15**	**5.16**	**5.16**	

[1] Represents the total FTEs needed over a five-year period, not per year. Based on assumptions (as detailed in the Appendix G program sheets) on whether programs will be performed with internal or external resources, or a combination thereof.

Table 9-2 provides only a general indication of the of the additional staffing needs and timing for the Utilities department. It is recommended that the Utilities department leadership utilize this table as a starting point for refining the staffing needs for program implementation and developing the hiring plan for the department.

9.4 Recommendations

It is recommended that the City of Englewood implement the programs summarized in Table 9-1. The total cost of these programs is estimated at approximately $30 million over the next 15 years for the sewer collection system and $31 million over the next 15 years for wastewater treatment. The CIP schedule is based on beginning implementation in 2020 but is dependent on available funding followed by other critical path factors including, but not limited to: study, design, permitting, construction, and program management activities and durations.

A detailed breakdown by year of the proposed CIP is provided in Appendix H.

Appendix A: Reference Data

1. City of Englewood sewer collection system GIS data received on October 3, 2019 (sewer mains and sewer manholes)
2. City of Englewood Digital Elevation Model (DEM) received on October 3, 2019
3. City of Englewood sanitary sewer manhole records Excel spreadsheet titled "MH Records (Updated) 9-11-19"
4. As-built drawings for the Big Dry Creek Interceptor
5. PDF exhibit of the Big Dry Creek Interceptor Alignment from Southgate Water and Sanitation District
6. City of Englewood Sewer Quad Maps (TIFF format)
7. Littleton/Englewood Wastewater Treatment Plant Infiltration/Inflow Study. Camp Dresser & McKee Inc. (CDM). May 2011.
8. City of Englewood Zoning Map dated November 2019
9. Englewood Forward: Comprehensive Plan. December 2016. https://www.englewoodco.gov/home/showdocument?id=17175

Appendix B: Sewer Loading Development Technical Memorandum

Appendix C: Model Ready GIS Dataset for Sewer Network Technical Memorandum

GIS shapefiles updated for sewer model development are included in the USB deliverable.

Appendix D: Sewer Hydraulic Model Calibration Technical Memorandum

InfoSWMM sewer hydraulic model files are included in USB deliverable.

Appendix E: Existing and Future Sewer Collection System Analysis Tech Memo

Appendix F: Sewer System Risk Assessment Technical Memorandum

Asset Register (Excel spreadsheet and GIS shapefile) and manhole photos are included in the USB deliverable.

Appendix G: Sewer System Programs – Summary Sheets

Appendix H: CIP Projections by Year