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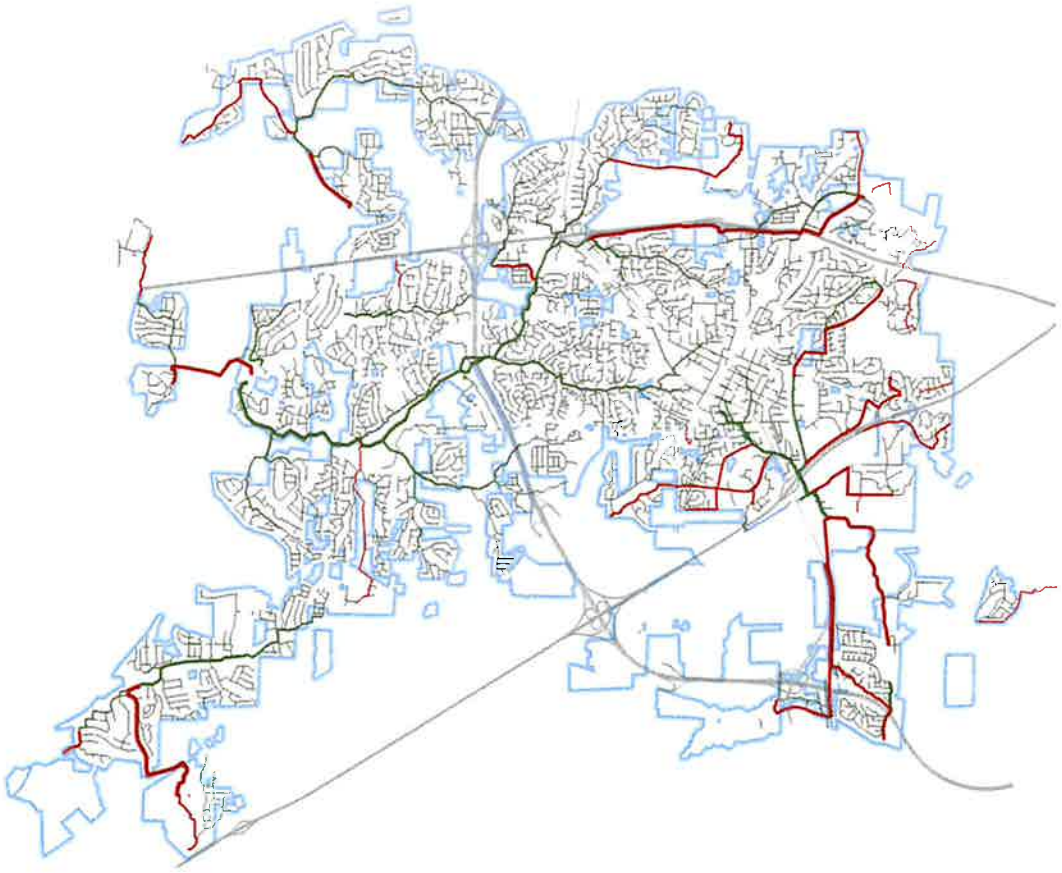

APEX
NORTH CAROLINA

Evaluation of the Current State of the Town of Apex Sanitary Sewer Collection System

Final Engineering Report
Hazen Project No. 32044-006
May 19, 2026



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List of Acronyms

Abbreviation	Definition
AC	Asbestos Cement
ADD	Annual Daily Demand
AIA	Asset and Inventory Assessment
ATT	American Tobacco Trail
CCTV	Closed-Circuit Television
CIP	Capital Improvement Plan
CoF	Consequence of Failure
COP	Copper Pipe
DEM	Digital Elevation Model
DIP	Ductile Iron Pipe
EUL	Estimated Useful Life
FEMA	Federal Emergency Management Agency
GPM	Gallons per Minute
LoF	Likelihood of Failure
NC	North Carolina
NCDOT	North Carolina Department of Transportation
PVC	Polyvinyl Chloride
RPM	Reinforced Plastic Mortar
ROW	Right-of-way
RUL	Remaining Useful Life
R&R	Rehab and Replacement
SS	Sanitary Sewer
TRS	Truss Pipe
USA	United States of America
USGS	United States Geological Survey
VCP	Vitrified Clay Pipe

Abbreviation	Definition
WR	Water Resources
WRF	Water Reclamation Facility

1. Introduction

The Town of Apex Department of Water Resources (Town) authorized Hazen and Sawyer (Hazen) to conduct an asset evaluation of the Town's sewer collection system. The Town has taken a proactive approach to asset management for its sanitary sewer infrastructure. In order to prioritize available funding for sewer collection system renewal and replacement, the Town requested that Hazen develop a risk-based asset evaluation of linear assets. The goal of this project was to develop risk modeling which could be used to recommend the right level of infrastructure investment and establish preliminary short-term renewal and replacement (R&R) needs for the Town's sewer collection system.

The Town owns, operates, and manages approximately 358 miles of sanitary sewer pipeline ranging in diameter from 1 inch to 60 inches. The sewer system is comprised of 312 miles of gravity mains and 46 miles of force mains. This report discusses the methodology used to calculate risk and forecast renewal and replacement needs for the sewer collection system linear assets. The major project deliverables described in this report include:

- Methodology and Data Summary
- Sewer Collection System Risk Assessment Framework
- Risk Assessment Results
- Asset Rehab and Replacement Cost Projections
- Capital Improvement Projects & Recommendations

1.1 Project Approach

A desktop risk assessment was performed for the collection sewer system based on the latest available GIS data. To supplement the desktop risk assessment, a field inspection program was carried out. Combining the results of the field inspections and GIS data, a risk score and level were calculated for each linear asset.

Field inspections were used to identify the condition of pipes anticipated to have a higher risk. The field inspection program included flow metering, CCTV camera inspection, and pole camera inspection. Based on the latest available GIS and input from the Town, flow metering and pole camera inspections were targeted near key junctions and larger diameter assets within the collection system. CCTV camera inspection was targeted toward gravity mains which cross roadways or railroads as well as points along the interceptor which discharges to Beaver Creek Pump Station and the collector which runs south along NC-55 toward the Apex WRF.

The risk score was calculated as the product of consequence of failure (CoF) and likelihood of failure (LoF). CoF represents the criticality of pipeline assets (cost impact, size, difficulty of repair, etc.) and LoF represents the known or anticipated condition of the pipeline assets. The calculated risk score was used to recommend the appropriate level of infrastructure investment, identify short-term R&R needs, and provide a long-term financial forecast of costs in the sewer collection system.

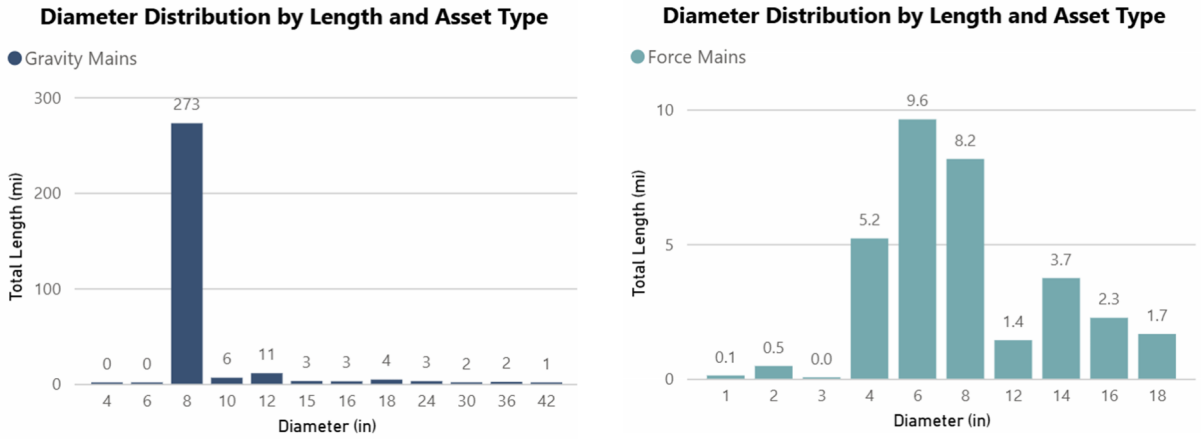
1.2 Sewer Collection System Description

The sewer collection system consists of approximately 312 miles of gravity mains and 46 miles of force mains. For the purposes of this report, assets were filtered to those that are active and owned exclusively by the Town, resulting in approximately 308 miles of gravity mains and 33 miles of force mains.

Of the approximately 4 miles of gravity sewer mains that were removed from the analysis, 2.2 miles are 42-60” DIP, co-owned by the Town, which run from north of US-64 down to the Beaver Creek Pump Station. Approximately 0.5 miles are abandoned 24-30” gravity mains originating with the James Street Outfall. Of the remaining pipes, 0.5 miles are comprised of 6-16” PVC, DIP, and unknown materials, with the majority being 8” PVC. Approximately 0.8 miles are 8-24” DIP, PVC, and CIPP owned exclusively by the Town, but categorized as not active.

Of the approximately 13 miles of force mains that were removed from the analysis, approximately 10 miles are the twin, DIP Beaver Creek Force Mains, co-owned by the Town of Apex, running from the Beaver Creek Pump Station to the Western Wake WRF. While the force main GIS feature class lists both force mains as 42” in diameter, one force main is 36” in diameter. The remaining approximately 3 miles consist of 1.5-6” PVC and DIP are either decommissioned Town-owned lift stations or private force mains, the majority being 2” PVC.

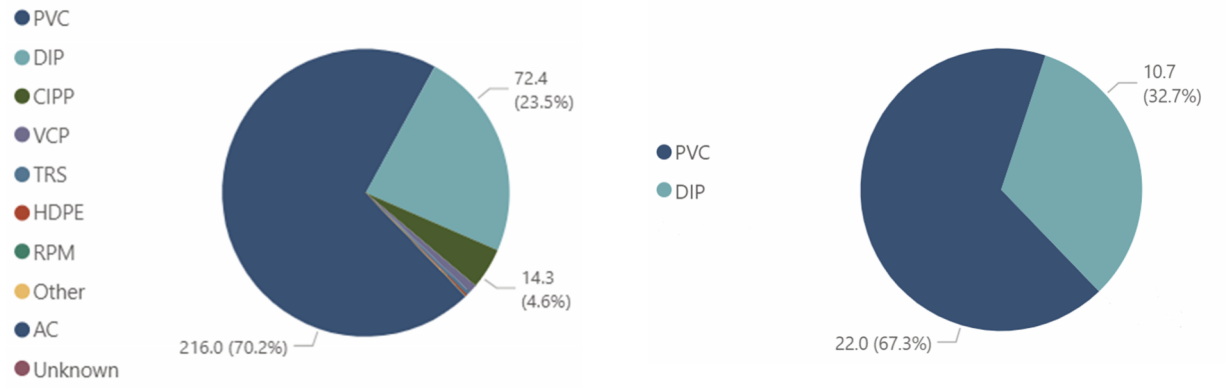
The vast majority of the gravity main system is 8-in. diameter pipe which comprises approximately 273 miles of pipe, or 89% of the gravity mains. Figure 1-1 is a stacked bar chart showing the distribution of the length of pipe by diameter in the sewer system.



(a) Gravity Mains (b) Force Mains

Figure 1-1: Distribution of Sewer Pipes by Diameter

Assets with material recorded as C900 and PVC were grouped as PVC; DIP, Ductile Iron, and RJDIP were grouped as DIP; CT and VCP were grouped as VCP; TRS and Truss grouped as TRS; all liner types were grouped as CIPP. Approximately 70 percent of the gravity mains are PVC, approximately 24 percent are DIP, and approximately 5 percent are CIPP lined, as indicated in Figure 1-2. Virtually all of the force mains are PVC or DIP, with about 2/3 PVC and 1/3 DIP.



a) Gravity Mains b) Force Mains

Figure 1-2: Length in Miles of each Sewer Pipe Material

The Apex sewer collection system pipes are, on average, approximately 18 years old. Gravity mains range from new to 75 years old and force mains range from new to 44 years old. Based on the asset age data, two large waves of sewer main installation occurred around 10 years ago and 28 years ago.

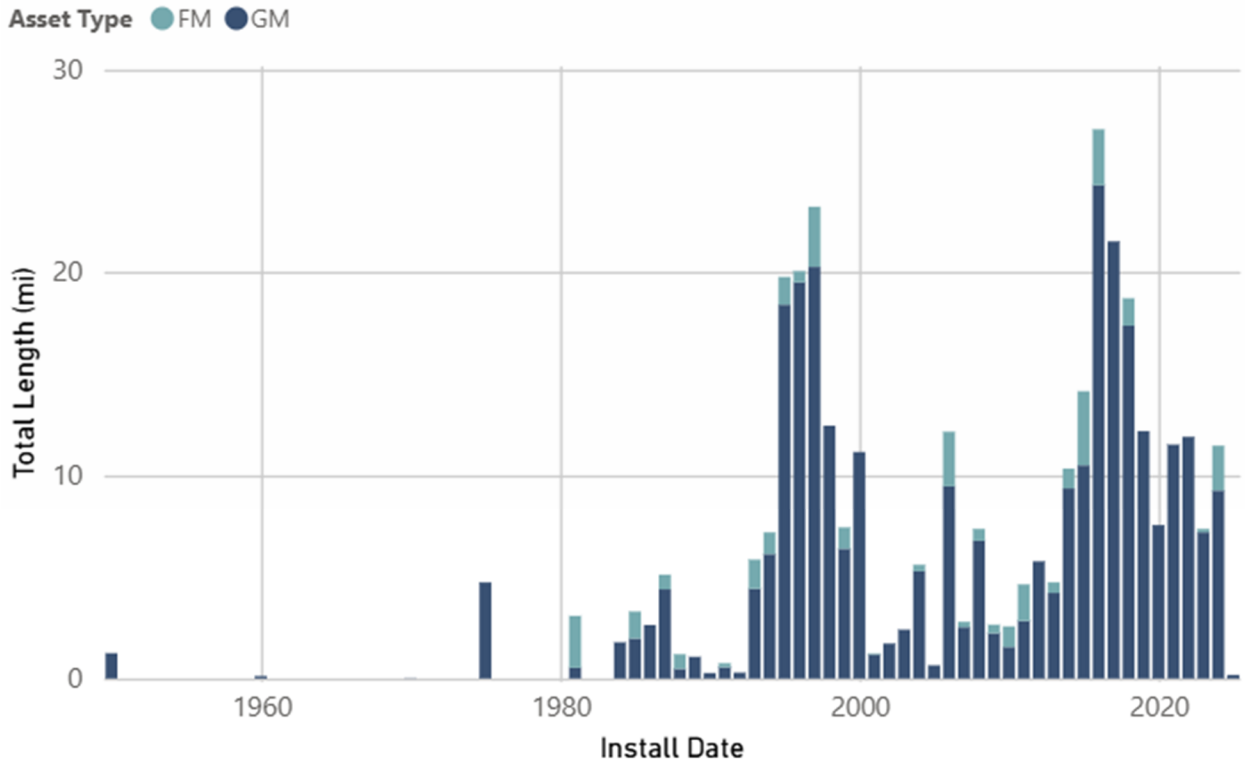


Figure 1-3: Install Date of Gravity and Force Mains

A map showing the locations of sewer collection and force mains throughout the Apex system is provided in Figure 1-4.

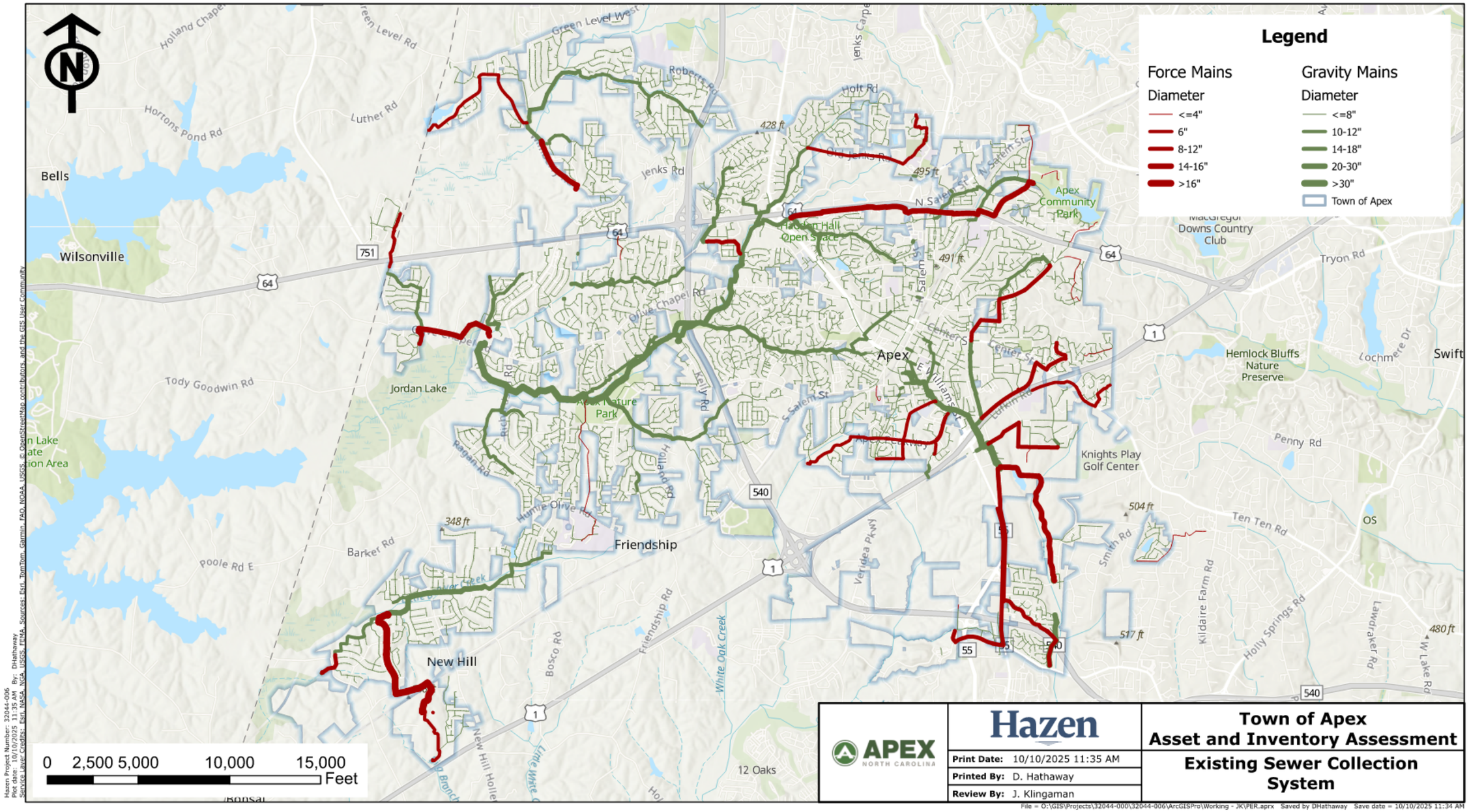


Figure 1-4: Map of Sewer Collection System

2. Methodology & Data Summary

An assessment of risk was completed for the sewer collection system to identify and prioritize the short- and long-term R&R needs. The following section describes the data sources and methodology used to estimate the risk score for each linear sewer asset. R&R projections were developed based on the estimated useful life (EUL) and remaining useful life (RUL) described in Section 2.3.

2.1 Overview

An asset risk assessment was performed to prioritize the R&R of individual assets in the sewer collection system. During the asset evaluation process, assets were scored based on the product of their individual CoF and LoF scores. CoF scores were determined based on a weighted score of financial, environmental, and social impacts of asset failure. The CoF criteria and weightings are discussed in more detail in Section 3.1. LoF scores were determined based on field data when available and a weighted combination of proxy data used to estimate the physical condition when field data was not available. The LoF scoring methodology is discussed in more detail in Section 3.2.

Following the determination of CoF and LoF scores, an overall risk score was calculated for each asset based on the product of CoF and LoF as shown in the equation below:

Risk Score = CoF Score x LoF Score

Four risk levels were defined based on the combination of LoF and CoF score: Low, Low-moderate, Moderate-high, and High. A matrix of CoF and LoF scores used to determine asset risk level is shown in Figure 2-1 below.

Low
Low-moderate
Moderate-high
High

Risk Matrix						
Risk Score = LoF * CoF		Likelihood of Failure (LoF)				
		1 Very Good	2 Good	3 Fair	4 Poor	5 Very Poor
Consequence of Failure (CoF)	1 Low Impact					
	2					
	3 Moderate Impact					
	4					
	5 High Impact					

Figure 2-1: Risk Score Matrix

2.2 Data Summary

This section summarizes the data sources used in the collection system linear asset risk evaluation, completeness, and efforts to clean and populate missing data.

2.2.1 Data Sources

The data sources used in the risk evaluation include:

- Town of Apex Open Data:
    - Gravity Mains (SS Gravity Main)
    - Sewer Manholes (Sewer Manhole)
    - Force Mains (Sewer Pressurized Main)
    - Force Main Valves (Sewer Pressurized Main Valve)
    - Historic Districts (ApexNRHD Boundary)
- Wake County iMAPS:
    - Parcels
    - Greenways (Greenways in Wake County)
    - Streams (USGS Blue Line Streams)
    - Floodplains (Flood Hazard Areas)
- NC OneMap:
    - DEM (NC Digital Elevation Model)
    - Roads (NC Routes)
    - Railroads (NCDOT North Carolina Railroads)
    - Watersheds (NC Surface Water Supply Watersheds)
    - Buildings (NC Buildings Footprints (2010))
    - Duke Energy Easements (DukeTransmissionEasements)
- Town of Apex Data Request:
    - Streets (ApexStreets_Polygon)
    - Sewer Utility Easements (WR_UtilityEasements)
    - Obstructed Easements GIS data (ObstructedEasements)

- Water Year 2022-2023 Billing Data
- Recent Work Orders (Cityworks export)

- Chatham County Open Data:
  - Gas Mains (Chatham County – Pipelines)
- Federal Emergency Management Agency (FEMA):
  - Structure Footprints (USA Structures)
- ESRI:
  - Satellite Imagery

2.2.2 Town of Apex Data Completeness

Hazen used the Town of Apex Open Data site as the basis of the risk assessment. The asset evaluation was limited to active gravity and force mains owned exclusively by the Town of Apex. Hazen used the "Active Flag" field to remove any abandoned or out of service assets from the evaluation and the "Owned By" field to limit the analysis to assets owned exclusively by the Town (fields names were ALL CAPS for the force main layer). Table 2-1 summarizes the total length of each layer.

Table 2-1: Summary of Linear Sewer Collection System Assets

GIS Layer	System Length (mi) [# of assets]	Active, Town-owned System Length (mi) [# of assets]
Sewer Gravity Mains	312 [10,051]	308 [9,958]
Sewer Force Mains	46.0 [338]	32.7 [244]

Hazen reviewed the GIS data provided by the Town for completeness of key attribute data including material, age, diameter, and utility depth. Manhole rim and invert elevation data was utilized to supplement gravity main depth. A summary of attribute completeness is provided in Table 2-2.

Table 2-2: Summary of Attribute Completeness

Attribute	Gravity Mains	Force Mains	Manholes
Diameter	100%	100%	N/A
Material	99.99%	100%	N/A
Install Year	100%	100%	N/A
Depth	0.36%	N/A	73%
No. of Segments	9,958	244	N/A

2.2.3 Data Modification

This section summarizes the data modification that took place prior to running the risk analysis. These modifications were made to fill gaps in the data and prepare the data for use in the risk modeling tool.

2.2.3.1 Gravity Mains

Gravity mains that are not exclusively owned by the Town of Apex or are not active were removed from the analysis so that results are reflective of assets owned by the Town that would affect active service. The results for assets not included in the analysis were provided to the Town of Apex separate from this report.

2.2.3.2 Force mains

Force mains that are not exclusively owned by the Town or are not active were also removed from the analysis. The results for assets not included in the analysis were provided to the Town of Apex separate from this report.

To provide additional granularity to the risk results for force mains, force main features were split up such that the length of segments was limited to less than about one mile. This was performed at valves and bends where possible.

2.2.3.3 Streets

The Town provided a polygon layer containing streets and roadways to assess proximity of sewer mains to ROW. In addition to the data provided by the Town, the NC-540 segment from NC-55 to Sunset Lake Road was added from NC OneMap data and assigned a width of 50 feet in both the northbound and southbound directions. Since NC-540 is a freeway and more similar in criticality to the other US Highways in this analysis (e.g., US-1, US-64) than to the other NC Highways (e.g., NC 55), NC-540 was grouped with the US Highways in the consequence of failure analysis.

2.2.3.4 Utility Easements

A sewer utility layer, along with supplementary easement condition data, was provided by the Town to identify easement obstructions. All obstructed easements were assigned a nonzero condition score. Duke Energy easements were limited to those adjacent to US-1. Both sewer utility and Duke Energy easements were combined into a single layer for analysis.

2.2.3.5 Top 15 Water Users

The top 15 water users were identified from 2022-23 water billing data. Large water users are typically also large sewer users. The purpose of including this data was to identify sewer mains that are locally critical and would result in a greater degree of criticality to repair. Residential and Town account types were excluded. Table 2-3 shows the top 15 water users identified for this analysis. The Apex Friendship Middle School and High School were both included as an aggregate given the large, combined water usage across the two adjacent properties. Irregular billing values were removed for these two properties, as requested by the Town.

Table 2-3: Top 15 Water Users

Customer	Address	Annual Daily Demand, ADD (gpm)
Beaver Creek PS	2916 Olive Chapel Road	14.63
SpringHill Suites Raleigh Apex	1100 Marco Drive	14.10
Lufkin Road Middle School	1002 Lufkin Road	13.53
Apex Friendship Middle School Apex Friendship High School	7701 Humie Olive Road 7801 Humie Olive Road	11.50 0.44
Everbrook Academy at the Peakway	1001 Olive Chapel Road	11.91
Spring Arbor of Apex	901 Spring Arbor Court	9.92
Apex Middle School	400 E Moore Street	9.19
Eagle Rock Concrete – Plant 2	500 Pristine Water Drive	9.01
Tidal Wave Auto Spa	1950 Lake Pine Drive	8.29
Crossroads Ford of Apex	1501 N Salem Street	7.72
Sam's Xpress Car Wash	1151 E Williams Street	7.42
Flats at 540	6001 Reedybrook Crossing	6.85
Apex Tool Group	1000 Lufkin Road	6.77
WoodSpring Suites Raleigh Apex	901 Lufkin Road	6.70

2.2.3.6 Streams

To assess difficulty of repair for pipelines in the proximity of streams, streams were classified as either minor or major. Most streams were, by default, categorized as minor. Named stream segments which intersect the 100-year flood plain were categorized as major streams. Figure 2-2 shows the classification of 'Major' and 'Minor' streams in more detail.

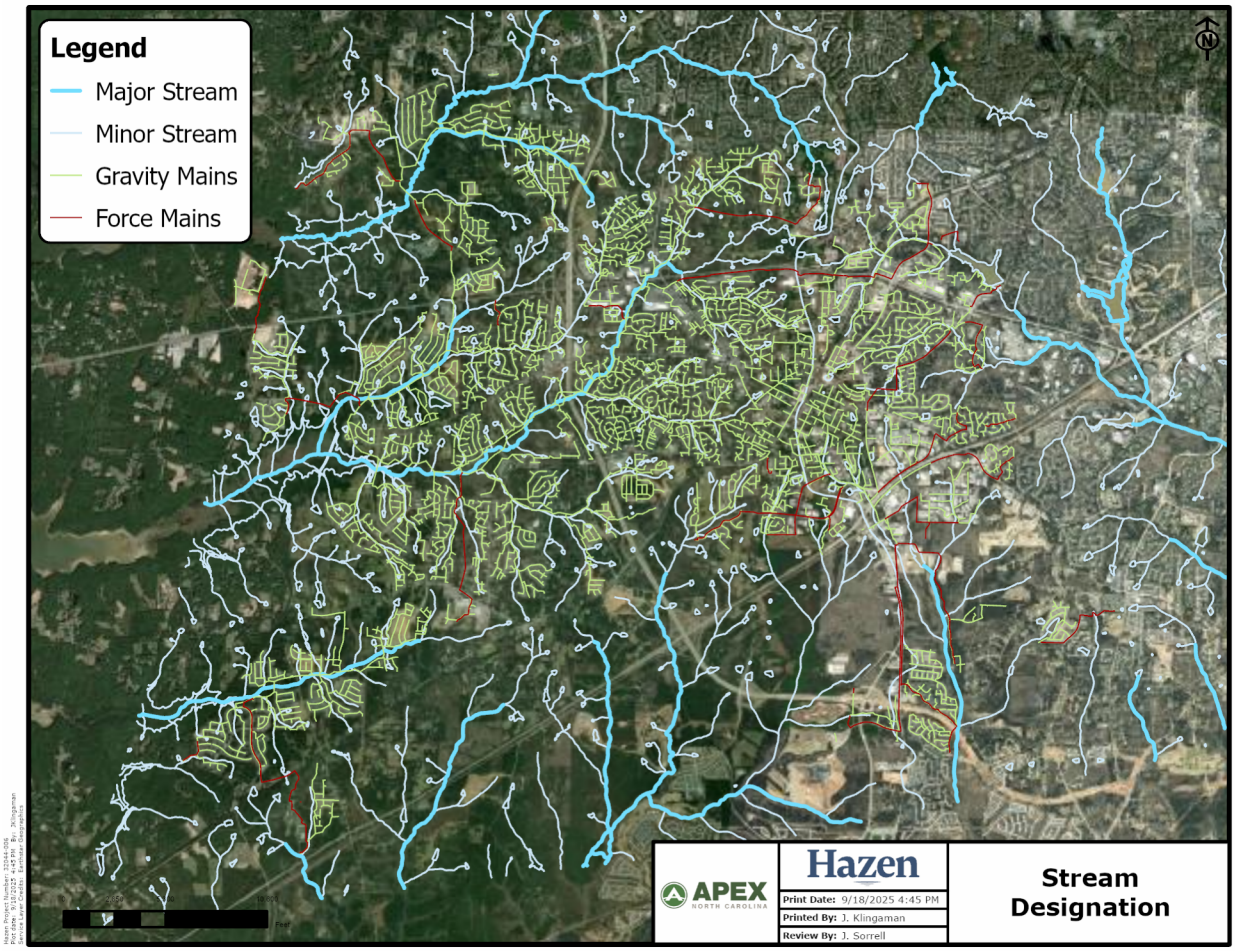
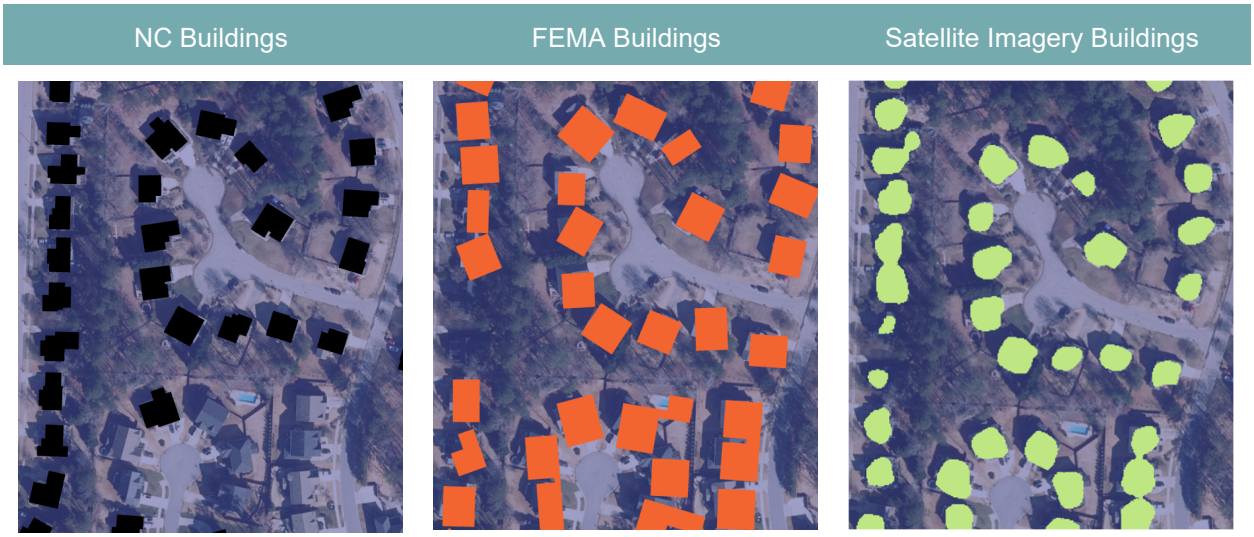


Figure 2-2: Major and Minor Streams

2.2.3.7 Buildings

Building footprint data was compiled to assess difficulty of repair for pipelines in the proximity of buildings. The primary source was the building footprints layer available through NC OneMap (Figure 2-3a). Due to rapid development in the Town of Apex since 2010, this layer misses many existing structures. A publicly available building footprints layer published by the Federal Emergency Management Agency (FEMA) was used to supplement this data. Any FEMA footprints that did not intersect an already existing NC OneMap footprint were added (Figure 2-3b). Finally, to capture even more recent developments, a deep learning model published by ESRI was used which identifies land cover classification and building footprints using aerial imagery. Any building footprints identified by this model which did not intersect an already existing NC OneMap or FEMA footprint were added (Figure 2-3c).



(a) NC OneMap (b) FEMA (c) Imagery

Figure 2-3: Building Footprint Data Sources Example

The resulting buildings layer combines all three layers to capture as many existing structures as possible and is only an approximate representation of all existing structures. As can be seen in Figure 2-4, the NC OneMap layer provided the base and was used wherever available; adding the FEMA layer increased coverage and adding the deep learning imagery model added even more structures in newer development areas. Throughout the analysis, extraneous building footprints (such as those showing up in cul-de-sacs, typically due to a temporary construction trailer) were manually removed as they were noticed.

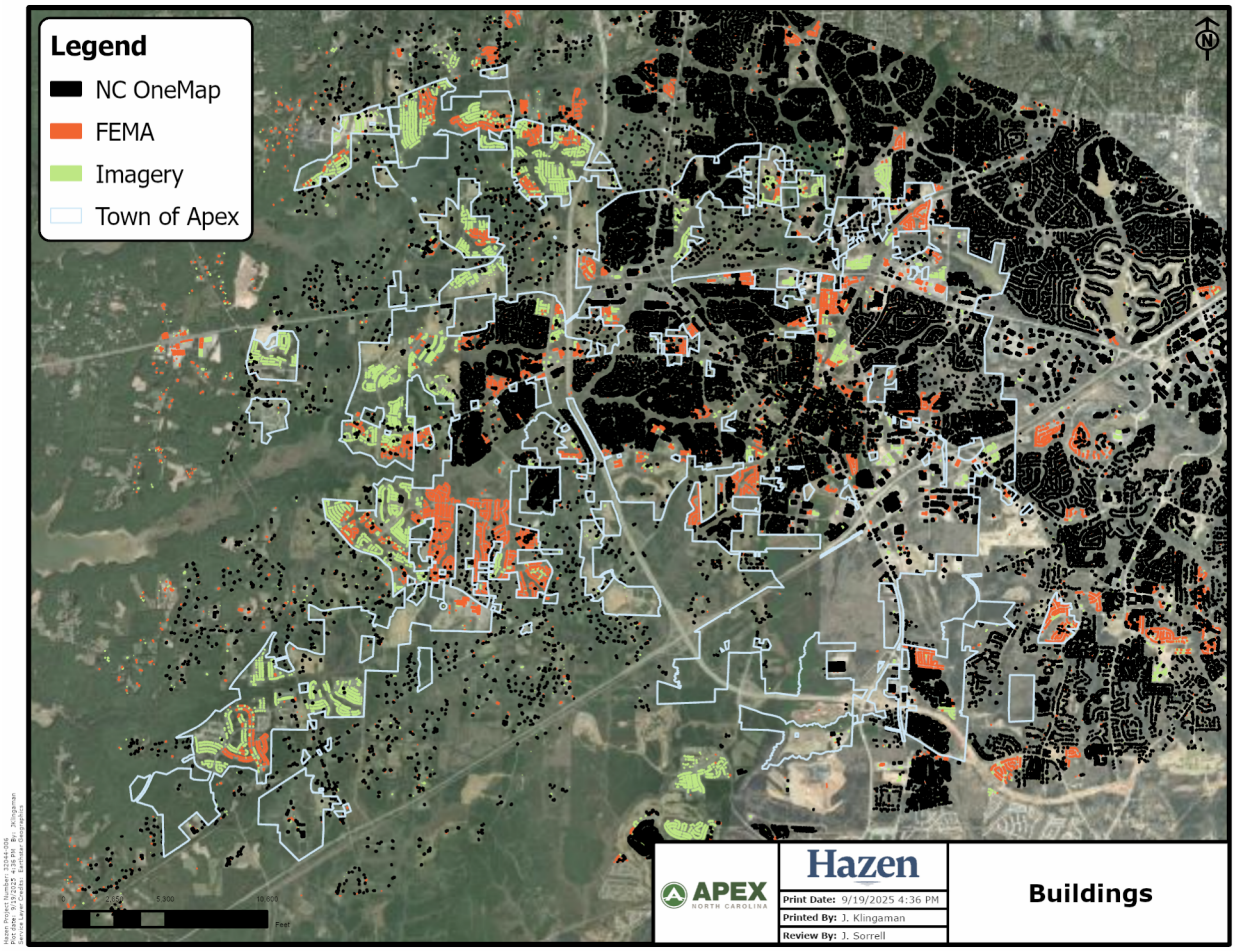


Figure 2-4: Combined Building Footprint Data

2.2.3.8 Depth

Sewer mains that are buried deeper have a greater consequence of failure. In a gravity system, the depth often exceeds 10 feet of burial depth. In a force main system, however, the depth is usually much shallower and as such, depth of force main pipes is not available in the Town of Apex GIS. This criterion was only considered for gravity mains.

The depth attribute for gravity mains in the Town of Apex system is incomplete. A combination of gravity main and sewer manhole attributes was used to assign a depth at upstream/downstream ends of each gravity main. If upstream and downstream gravity main depth data were available, those data were used. If gravity main data was not available, manhole rim and invert elevation data was used. If manhole rim elevation was not available, DEM Raster data was used. The flowchart in Figure 2-5 shows more detail of the process followed for assigning depth to upstream and downstream ends of gravity mains.

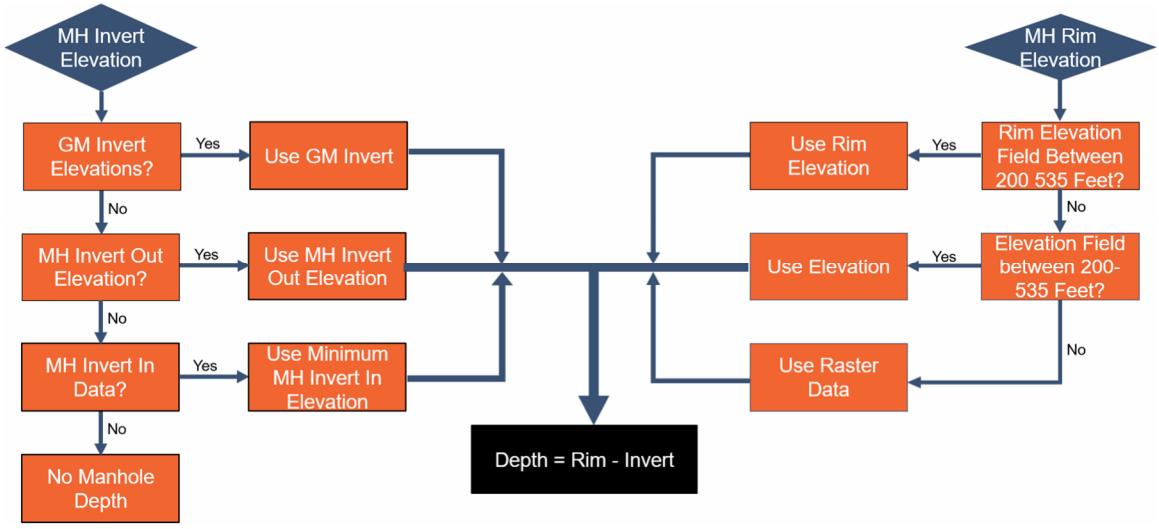


Figure 2-5: Gravity Main Upstream/Downstream Depth Assignment Process

Once depths were assigned for the upstream and downstream ends of a gravity main, a single depth was assigned for each gravity main. Depths less than 3 feet or greater than 30 feet were rejected as likely inaccurate based on Town input on typical depths in the system. The flowchart in Figure 2-6 shows more detail of the process followed for assigning depth to each gravity main asset. Approximately 75% of gravity mains were assigned a depth value.

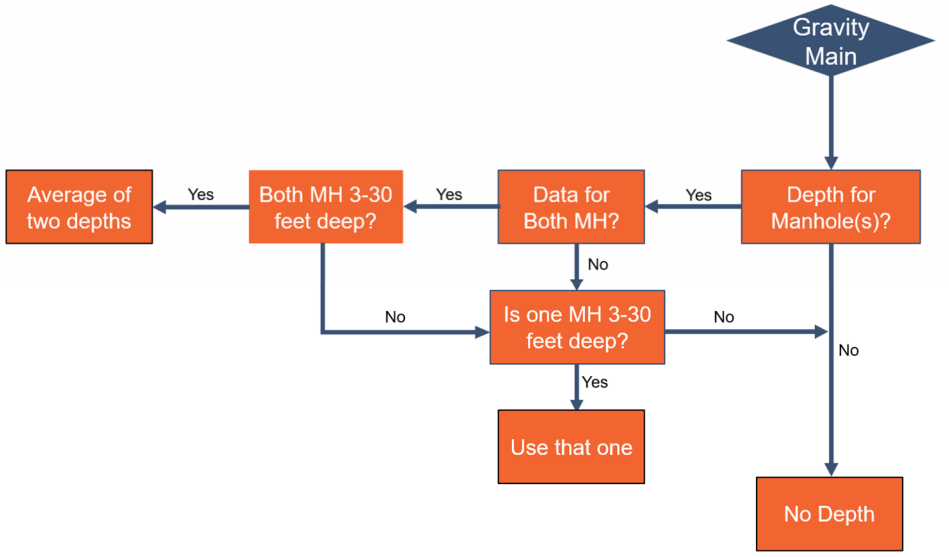


Figure 2-6: Gravity Main Average Depth Assignment Process

2.3 Remaining Useful Life

An asset's useful life is highly related to the conditions of use, maintenance requirements, operation, the original construction techniques, and the material of construction. The EUL for each pipe material is

presented in Table 2-4. The EUL assigned to each asset was based upon industry knowledge, research, engineering judgement, and input from Town staff.

Table 2-4: Estimated Useful Life (EUL) by Material

Material	Gravity Main Useful Life (years)	Force Main Useful Life (years)
Polyvinylchloride (PVC)	75	50
Clay	75	N/A
High Density Polyethylene Pipe (HDPE)	75	N/A
CP (lined pipe)	50	N/A
Ductile Iron Pipe (DIP)	50	40
Asbestos Cement (AC)	50	N/A
Cured-in-Place Pipe (CIPP)	50	N/A
Copper (COP)	N/A	40
Truss Pipe (TRS)	50	N/A
Reinforced Polymer Matrix (RPM)	50	N/A
Other	50	40

The remaining useful life (RUL) is a calculation that approximates the number of years of time the asset is expected to continue to function effectively before needing to be replaced. To project future R&R needs, the RUL was calculated for each asset. The age-based RUL estimates the replacement year for each pipe based on asset age and EUL. The RUL was calculated based on the formula below.

$$\mathbf{RUL = EUL - Asset\ Age}$$

3. Sewer Collection System Risk Assessment Framework

The following section details the criteria, scoring rubrics, weightings, and data sources used to calculate CoF and LoF scores for the sewer collection system linear assets. Additionally, the following sections summarize the LoF, CoF, and overall risk results for sewer collection system assets.

3.1 Consequence of Failure

When sewer main assets fail, the corresponding consequences depend on the diameter and accessibility of the sewer main, the criticality of the main, degree of impact to stakeholders, potential for environmental impacts, and the cost and time to repair the failure. The consequences of sewer main failure (CoF) can vary from a minor repair to a major disruption of customer service, impact to surrounding infrastructure, and possible endangerment of public health. The following sections summarize the CoF scoring methodology and results.

3.1.1 CoF Scoring Methodology

Each CoF parameter was assigned a score from 1 to 5 to describe the impact of failure, ranging from no impact to major impact. For each asset which meets the criteria for multiple scores, the larger score was used (e.g., a sewer main crossing both a public street and an NC HWY is assigned a streets score of 4). Additionally, each parameter was assigned a weighting that defines the typical relative importance of each criterion in assessing the overall consequence of failure. Table 3-1 and Table 3-2 present the guidelines for scoring each consequence parameter from 1 to 5, along with the criteria weightings used in the evaluation. Weighting criteria was established through a series of workshops with Town staff. Maps displaying geospatial results of each CoF criteria can be found in Appendix B.

While many of the CoF criteria are related to difficulty of repair, four criteria were combined into a single category, named difficulty of repair, based on the common element of being in the proximity of external items that would complicate any construction activity to renew or replace. The four criteria were streams, buildings, top 15 water users, and gas mains. The primary reason for this was to remove dilution from the resulting risk scores. Most pipelines do not intersect all four of these, resulting in many low CoF scores. Additionally, proximity to multiple of these external items does not significantly increase the consequence of failure beyond the proximity to just one of these items. Each sewer main was assigned a difficulty or repair score based on the most severe of these 4 criteria. By combining these criteria, each sewer main in the proximity of any one of these receives a difficulty of repair score greater than 1 with an associated 30% weight.

Table 3-1: Consequence of Failure Criteria for Gravity Mains

Criteria	Description	Weight (%)	Data Source	1 – No Impact	2	3	4	5 – Major Impact	Analysis Notes
GM Diameter	Score based on diameter of gravity main (measure of criticality/flow demand)	20	Town of Apex Gravity Main GIS Layer	8” or smaller diameter	8”<diameter<=12”	12”<diameter<=18”	18”<diameter<=30”	Greater than 30” diameter	Numeric analysis using ‘DIAMETER’ field
Transportation	Score based on proximity of gravity main to Roads, Railroads, and Greenways	20	Town of Apex Streets and NC Routes GIS Layers	Default	Intersects Public Street	Intersects Secondary Route	Intersects NC HWY	Intersects US-64, US-1, or NC-540	Max score of the following three categories: Roads: spatial analysis combined with categorical analysis using ‘CLASSNAME’ and ‘STNAME’ fields Railroads: spatial analysis combined with categorical analysis using ‘TRACK_STAT’ field Greenways: spatial analysis combined with categorical analysis using ‘OWNER’ field
			NC Railroad Layer	Default	N/A	Intersects Preserved Corridor	N/A	Intersects Active Railroad	
			Wake County Greenways Layer	Default	N/A	Intersects Greenway not owned by Town of Apex	N/A	N/A	
Difficulty of Repair	Score based on proximity of gravity main to Streams, Buildings, Top 15 Water Customer, and Gas Mains	30	NC Streams and FEMA Flood Plain GIS Layers	More than 30’ from any stream	10’<distance to nearest stream<=30’	distance to nearest stream<=10’	Crosses a ‘Minor Stream’	Crosses a ‘Major Stream’	Max score of the following four categories: Streams: spatial analysis combined with categorical analysis using ‘Is_Major’ field Buildings: spatial analysis Top 15 Water Customer: spatial analysis Gas Mains: spatial analysis
			Satellite Imagery, NC Buildings Layer, FEMA Buildings Layer	More than 20’ from any building	10’<distance to nearest building<=20’	5’<distance to nearest building<=10’	0’<distance to nearest building<=5’	Under a building	
			Town of Apex Water Billing Data, Wake County Parcels GIS Layer	Default	N/A	N/A	N/A	Within 50 feet of top 15 water user	
			Gas Mains GIS Layer	More than 20’ from a gas main	10’<distance to nearest gas main<=20’	5’<distance to nearest gas main<=10’	0’<distance to nearest gas main<=5’	Crosses a gas main	
GM Depth	Score based on estimated depth of gravity main below ground surface	15	Town of Apex Gravity Main and Sewer Manhole GIS Layers	3’<=depth<=5’	5’<depth<=10’	10’<depth<=15’ (default value)	15’<depth<=20’	20’<depth<=30’	Numeric analysis based on estimated gravity main depth
Watersheds	Score based on whether gravity main is within Water Supply Watershed	5	Water Supply Watersheds GIS Layer	Default	N/A	N/A	N/A	Inside water supply watershed	Spatial analysis
Easements	Score based on proximity of gravity main to Town of Apex and Duke Energy Easements	5	Town of Apex WR Utility and Duke Energy Easements GIS Layers	Default	N/A	Apex WR Utility Easement with non-zero condition score	N/A	Duke Energy Easement	Spatial analysis combined with categorical analysis using ‘EasementTy’ field
Land Class	Score based on land use(s) where gravity main is located	5	Wake County Parcels GIS Layer	Vacant; Forestry; Agriculture; Horticulture; (default value)	Acre With Improvement, No House; Acres Greater than 10 With House	Residential Less Than 10 Acres; Manufactured Home; Mobile Home Park; HOA	Condominium, Condo Complex; Apartment; Retirement Home	Golf Course; Commercial; Industrial; Cemetery; EXEMPT; Historic; State Assessed; Water/Sewer System; Part Exempt;	Max score of the following two categories: Land Class: spatial analysis combined with categorical analysis using ‘LAND_CLA_1’ field Historic District: spatial analysis
			Town of Apex Historical District	Default	N/A	N/A	N/A	Historic District	

Table 3-2: Consequence of Failure Criteria for Force Mains

Criteria	Description	Weight (%)	Data Source	1 – No Impact	2	3	4	5 – Major Impact	Analysis Notes
FM Diameter	Score based on diameter of force main (measure of criticality/flow demand)	30	Town of Apex Force Main GIS Layer	4” or smaller diameter	4”<diameter<=6”	6”<diameter<=12”	12”<diameter<=16”	Greater than 16” diameter	Numeric analysis using ‘DIAMETER’ field
Transportation	Score based on proximity of force main to Roads, Railroads, and Greenways	25	Town of Apex Streets and NC Routes GIS Layers	Default	Intersects Public Street	Intersects Secondary Route	Intersects NC HWY	Intersects US-64, US-1, NC-540	Max score of the following three categories: Roads: spatial analysis combined with categorical analysis using ‘CLASSNAME’ and ‘STNAME’ fields Railroads: spatial analysis combined with categorical analysis using ‘TRACK_STAT’ field Greenways: spatial analysis combined with categorical analysis using ‘OWNER’ field
			NC Railroad Layer	Default	N/A	Intersects Preserved Corridor	N/A	Intersects Active Railroad	
			Wake County Greenways Layer	Default	N/A	Intersects Greenway not owned by Town of Apex	N/A	N/A	
Difficulty of Repair	Score based on proximity of force main to Streams, Buildings, Top 15 Water Customer, and Gas Mains	30	NC Streams and FEMA Flood Plain GIS Layers	More than 30’ from any stream	10’<distance to nearest stream<=30’	distance to nearest stream<=10’	Crosses a ‘Minor Stream’	Crosses a ‘Major Stream’	Max score of the following four categories: Streams: spatial analysis combined with categorical analysis using ‘Is_Major’ field Buildings: spatial analysis Top 15 Water Customer: spatial analysis Gas Mains: spatial analysis
			Satellite Imagery, NC Buildings Layer, FEMA Buildings Layer	More than 20’ from any building	10’<distance to nearest building<=20’	5’<distance to nearest building<=10’	0’<distance to nearest building<=5’	Under a building	
			Town of Apex Water Billing Data, Wake County Parcels GIS Layer	Default	N/A	N/A	N/A	Within 50 feet of top 15 water user	
			Gas Mains GIS Layer	More than 20’ from a gas main	10’<distance to nearest gas main<=20’	5’<distance to nearest gas main<=10’	0’<distance to nearest gas main<=5’	Crosses a gas main	
Watersheds	Score based on whether force main is within Water Supply Watershed	5	Water Supply Watersheds GIS Layer	Default	N/A	N/A	N/A	Inside water supply watershed	Spatial analysis
Easements	Score based on proximity of force main to Town of Apex and Duke Energy Easements	5	Town of Apex WR Utility and Duke Energy Easements GIS Layers	Default	N/A	Apex WR Utility Easement with non-zero condition score	N/A	Duke Energy Easement	Spatial analysis combined with categorical analysis using ‘EasementTy’ field
Land Class	Score based on land use(s) where force main is located	5	Wake County Parcels GIS Layer	Vacant; Forestry; Agriculture; Horticulture; (default value)	Acre With Improvement, No House; Acres Greater than 10 With House	Residential Less Than 10 Acres; Manufactured Home; Mobile Home Park; HOA	Condominium, Condo Complex; Apartment; Retirement Home	Golf Course; Commercial; Industrial; Cemetery; EXEMPT; Historic; State Assessed; Water/Sewer System; Part Exempt	Max score of the following two categories: Land Class: spatial analysis combined with categorical analysis using ‘LAND_CLA_1’ field Historic District: spatial analysis
			Town of Apex Historical District	Default	N/A	N/A	N/A	Historic District	

3.1.2 Consequence of Failure Results

The criteria, scoring rubrics, and weightings were combined to determine an overall CoF score for each of the sewer collection system assets. This section provides a high-level summary of the CoF scoring results. A full list of assets and their associated CoF scores is included in the GIS deliverable. The sewer main CoF scoring results are displayed geospatially in Figure 3-1.

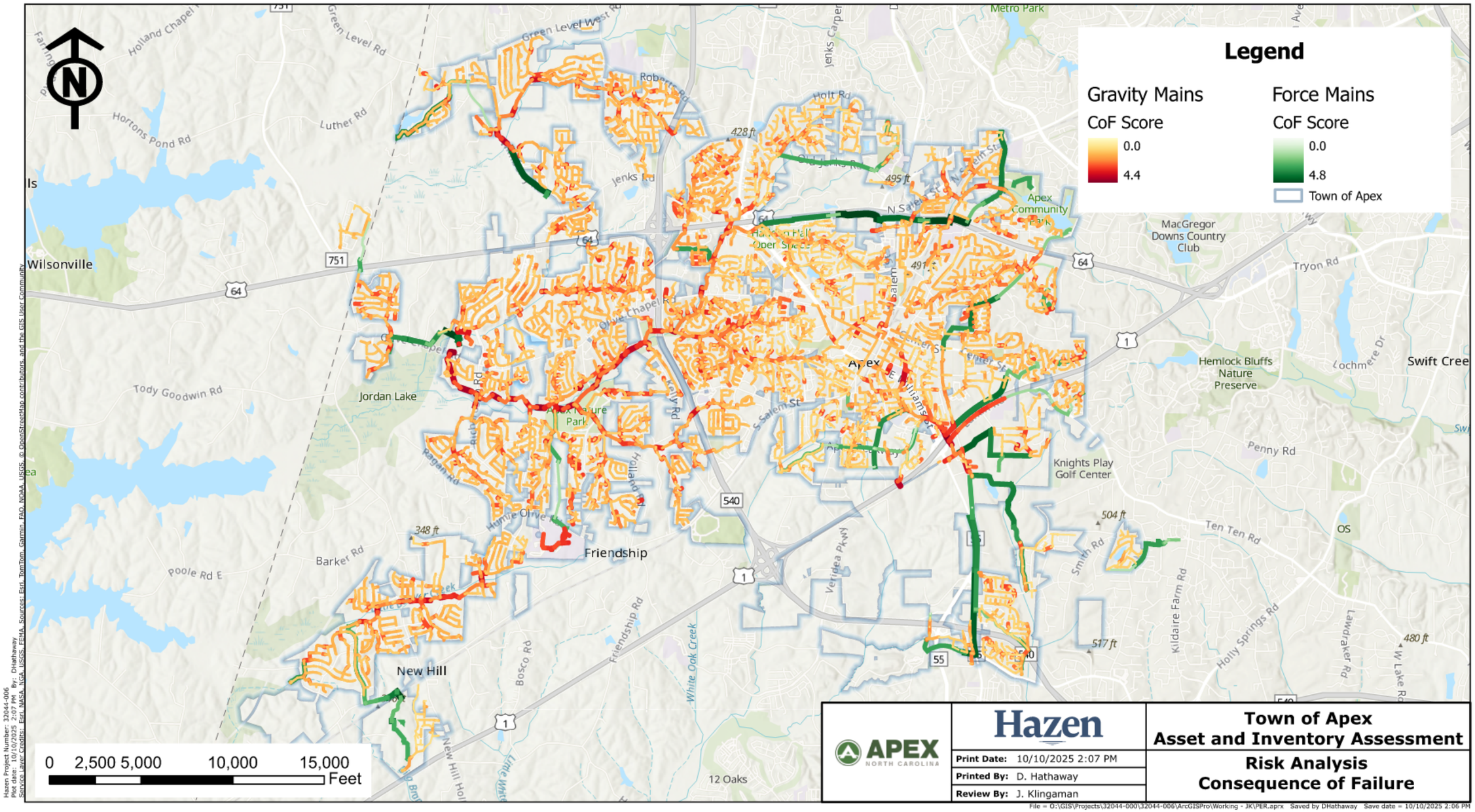


Figure 3-1: Consequence of Failure Map for Gravity Mains and Force Mains

3.2 Likelihood of Failure

LoF score informs the severity of asset conditions and is used to inform asset replacement needs. It is based on inspected condition as well as anticipated condition, including RUL. The following sections summarize the LoF scoring methodology and results.

3.2.1 LoF Scoring Methodology

Gravity mains for which field inspection data (pole camera, CCTV) was obtained were assigned LoF scores based on inspection results. In the absence of this information, age and material data, work order history, and proximity of gravity mains to force main discharges criteria were used. Each criterion was assigned a score from 1 to 5, ranging from excellent to very poor. Additionally, each criterion was assigned a weight to define the typical relative importance in assessing the overall likelihood of failure. The LoF criteria, weightings, and scoring framework are provided in Table 3-3 and Table 3-4.

Table 3-3: Likelihood of Failure Criteria for Gravity Mains

Criteria	Description	Weight (%)	Data Source	1 – Excellent	2	3	4	5 – Very Poor	Analysis Notes
If inspection data is available, use the inspection results, as described in the two rows below									
CCTV Inspection	Score based on PACP quick structural rating (QSR) from CCTV inspection	100%	PACP database from Vision NC inspection	First digit is 0 or 1	First digit is 2	First digit is 3	First digit is 4	First digit is 5	Numeric analysis using the first digit of the QSR reported in the PACP database
Pole Camera Inspection	Score based on video review	100%	Video files from inspection	Score 1 - No defects observed	Score 2 - Some defects observed	Score 3 - Minor O&M and/or structural concerns observed	Score 4 - Significant O&M and/or structural concerns observed	Score 5 - Immediate action recommended	Numeric analysis based on review of the videos provided by Vision NC
Else, use the following three rows									
Age & Material (Gravity Main)	Score based on the percentage RUL compared to total EUL (see Error! Reference source not found.)	50%	Town of Apex Open Data Gravity Main Layer	30% or less of useful life expended	50% or less of useful life expended	70% or less of useful life expended	90% or less of useful life expended	More than 90% of useful life expended	Useful life expended was calculated as the ratio of asset age to EUL, based on “INSTALL_YR” and “Material” fields.
Work Orders	Score based on quantity of recent reactive work orders	25%	Data Request Made to Town of Apex	Default	N/A	(1) “Contracted Services Gravity” or “Remove Blockage Gravity” work order	(1) “Repair Gravity” or “Trenchless Pipe Patch” work order	2+ work orders	All work orders provided by the Town categorized as “Contracted Services Gravity”, “Remove Blockage Gravity”, “Repair Gravity”, or “Trenchless Pipe Patch” (see Appendix A)
Downstream of Force Main Discharge	Determine score based on how far downstream the segment is from a force main discharge	25%	Town of Apex Open Data Gravity and Force Main Layers	1,500+ feet from all discharge points	750-1,500 feet from all discharge points	250-750 feet from all discharge points	100-250 feet from all discharge points	Within 100 feet of a discharge point	Distance, as calculated in ArcGIS Pro, from any FM discharge manhole in the downstream direction.

Table 3-4: Likelihood of Failure Criteria for Force Mains

Criteria	Description	Weight (%)	Data Source	1 – Excellent	2	3	4	5 – Very Poor	Analysis Notes
Age & Material (Force Mains)	Score based on the percentage RUL compared to total EUL (see Error! Reference source not found.)	100%	Town of Apex Open Data Force Main Layer	30% or less of useful life expended	50% or less of useful life expended	70% or less of useful life expended	90% or less of useful life expended	More than 90% of useful life expended	Useful life expended was calculated as the ratio of asset age to EUL, based on “INSTALL_YR” and “MATERIAL” fields.

3.2.2 Likelihood of Failure Results

The criteria, scoring rubrics, and weightings were combined to determine overall LoF score for each of the sewer collection system assets. This section provides a high-level summary of the LoF scoring results. A full list of assets and their associated LoF scores are included in the GIS deliverable. The LoF scoring results for gravity sewer and force mains are displayed geospatially in Figure 3-2. Maps displaying geospatial results of each LoF criteria can be found in Appendix B.

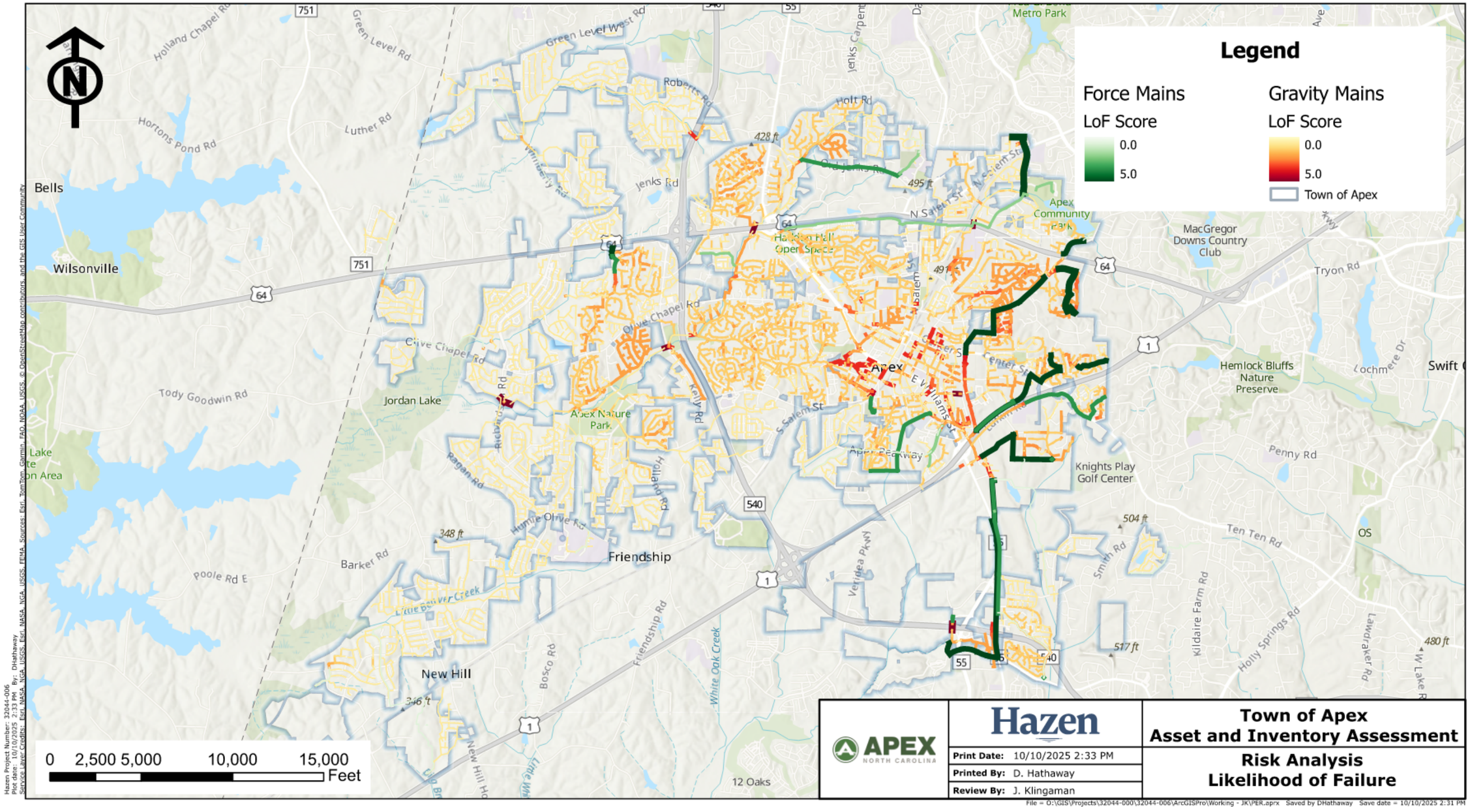
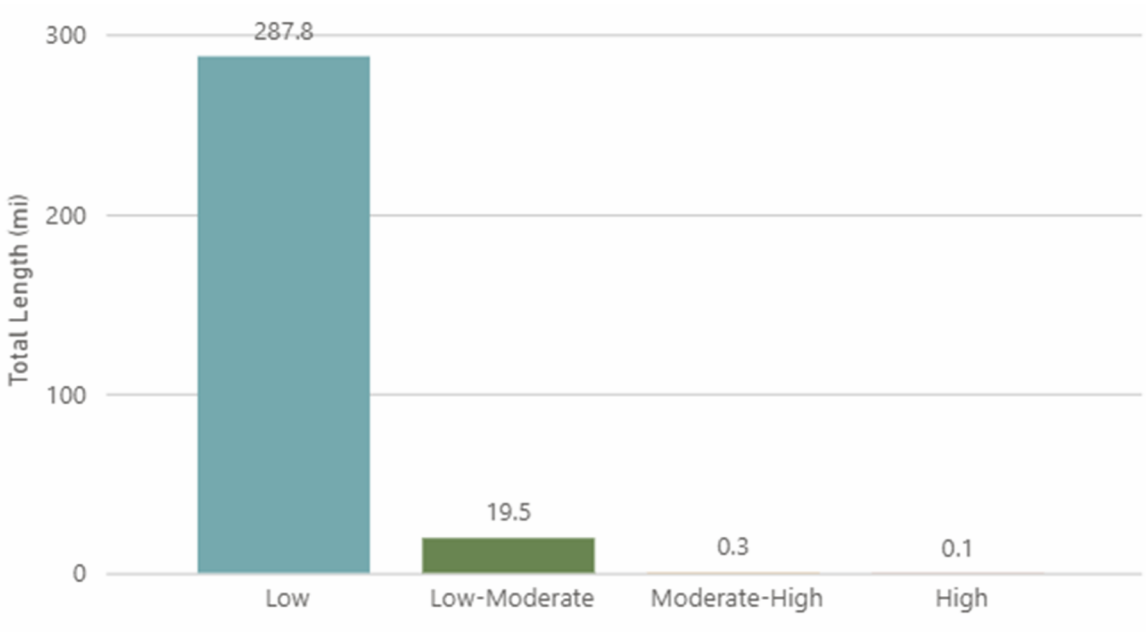


Figure 3-2: Likelihood of Failure Map for Gravity Mains and Force Mains

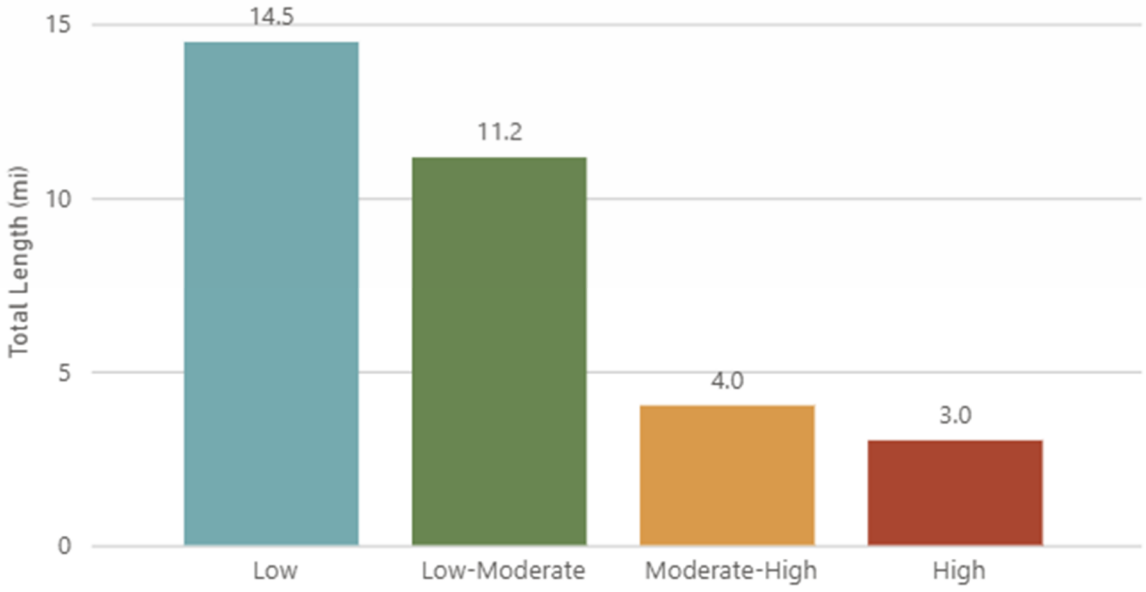
4. Risk Assessment Results

As discussed in previous sections, overall risk scores were calculated as the product of CoF and LoF. This section provides a summary of the sewer collection system asset risk profile. A full list of assets and their associated risk scores were provided to the Town in the GIS deliverable.

The sewer main assets were categorized into four risk levels: Low, Low-moderate, Moderate-high, and High. Figure 4-1 summarizes the total length of system assets within each risk level. The figure shows that over 90% of gravity main length is considered low risk and less than 0.1% of gravity main length is considered high risk. Over 40% of force main length is considered low risk and less than 10% of force main length is considered high risk.



(a) Gravity Mains

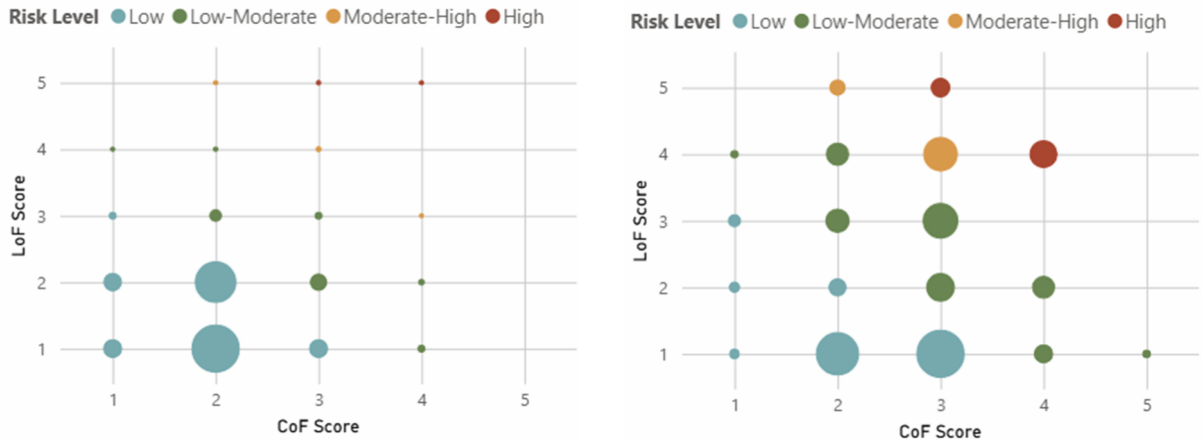


(b) Force Mains

Figure 4-1: Total System Length by Risk Level

To provide greater context to these results, Figure 4-2 illustrates the distribution of assets based on CoF and LoF scores, categorized by risk level. The size of each data point represents the total length of the assets. This visual shows that the majority of the Town of Apex's gravity mains are evaluated to have a consequence of failure of 2 and a likelihood of failure of 1-2. The consequence of failure for force mains is concentrated between 2 and 3 with a more evenly distributed likelihood of failure 1-5. Assets requiring

the most immediate attention are the highest risk assets in the top right of the visual that have both high PoF and CoF scores.



(a) Gravity Mains (b) Force Mains

Figure 4-2: Asset Risk Distribution by CoF and LoF Scores

The risk matrices presented in Table 4-1 and Table 4-2 show the distribution of asset risk level in more granularity, by length in miles, based on CoF and LoF scores.

Table 4-1: Risk Matrix for Gravity Mains

	LOF Score					
CoF Score	1	2	3	4	5	**Criticality Totals**
1	15.35	14.95	0.90	0.08		**31.27**
2	140.29	101.02	4.95	0.09	0.06	**246.41**
3	15.31	12.22	0.86	0.17	0.07	**28.62**
4	0.87	0.39	0.03		0.05	**1.35**
Condition Totals	**171.82**	**128.57**	**6.74**	**0.34**	**0.18**	**307.65**

Table 4-2: Risk Matrix for Force Mains

	LOF Score					
CoF Score	1	2	3	4	5	**Criticality Totals**
1	0.13	0.18	0.29	0.06		**0.66**
2	5.78	0.73	1.53	1.36	0.54	**9.94**
3	7.37	2.25	3.73	3.47	0.89	**17.71**
4	0.84	1.33		2.12		**4.29**
5	0.06					**0.06**
Condition Totals	**14.19**	**4.48**	**5.55**	**7.02**	**1.44**	**32.67**

These results are not unexpected for a system in which 90% of the gravity main system is 8” or smaller PVC or DIP and over 50% of the system was installed within the last 20 years. Additionally, the EUL is smaller for force mains than for gravity mains of the same material, resulting in higher LoF for force mains (see Table 2-4). To better understand where the high-risk assets are, the risk score is mapped in Figure 4-3 and the risk level is mapped in Figure 4-4. Due to the relatively low risks resulting from this risk analysis of the relatively new Town of Apex sewer collection system, the risk score symbology is scaled to provide greater color variation across the system. Refer to the GIS deliverable for actual total risks scores. The maps show that the higher-risk assets gravity mains are larger diameter and those that were inspected and found to have significant defects. The higher-risk force mains are a mix of DIP and PVC mains which were installed prior to 1996.

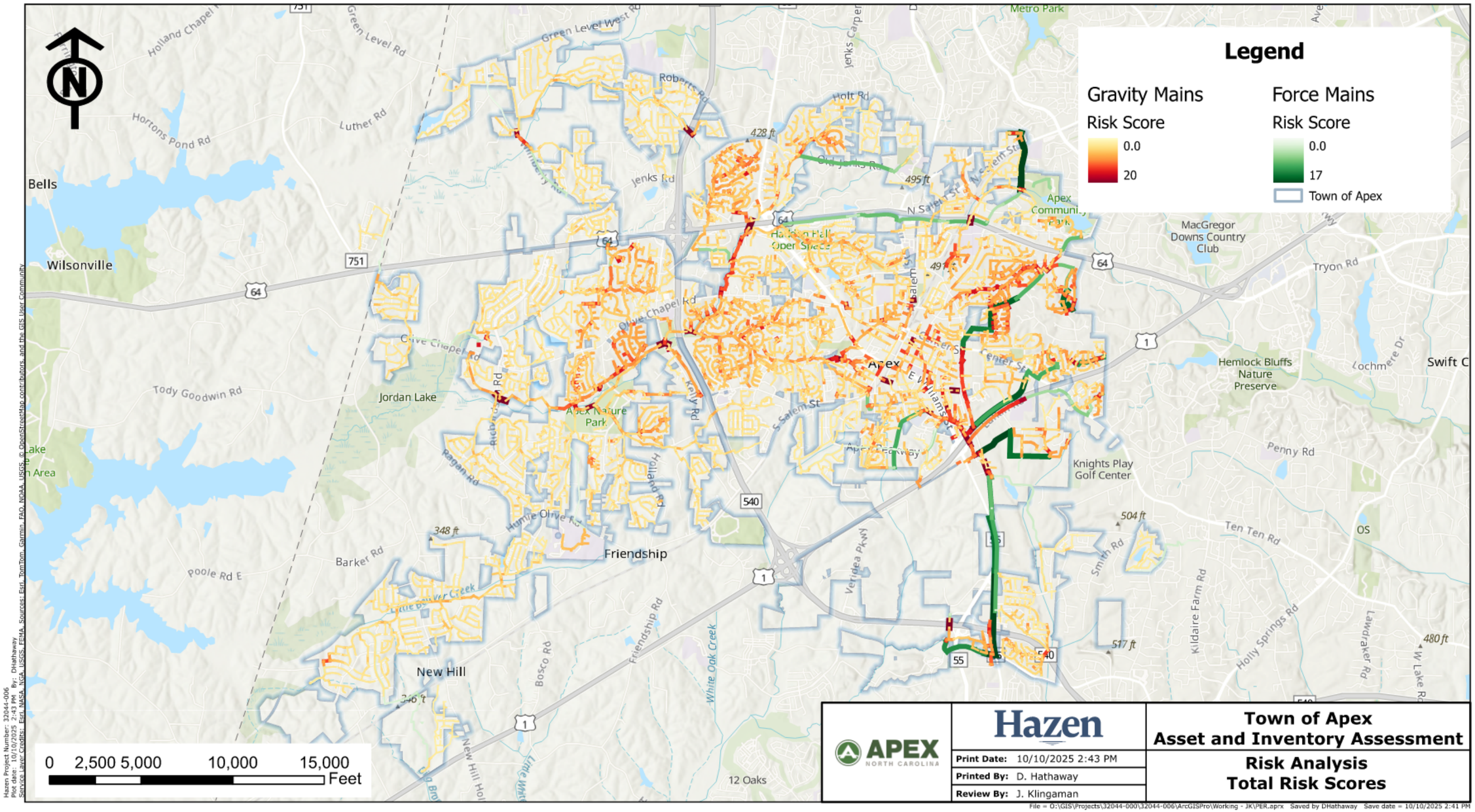


Figure 4-3: Map of Risk Scores for Gravity and Force Mains

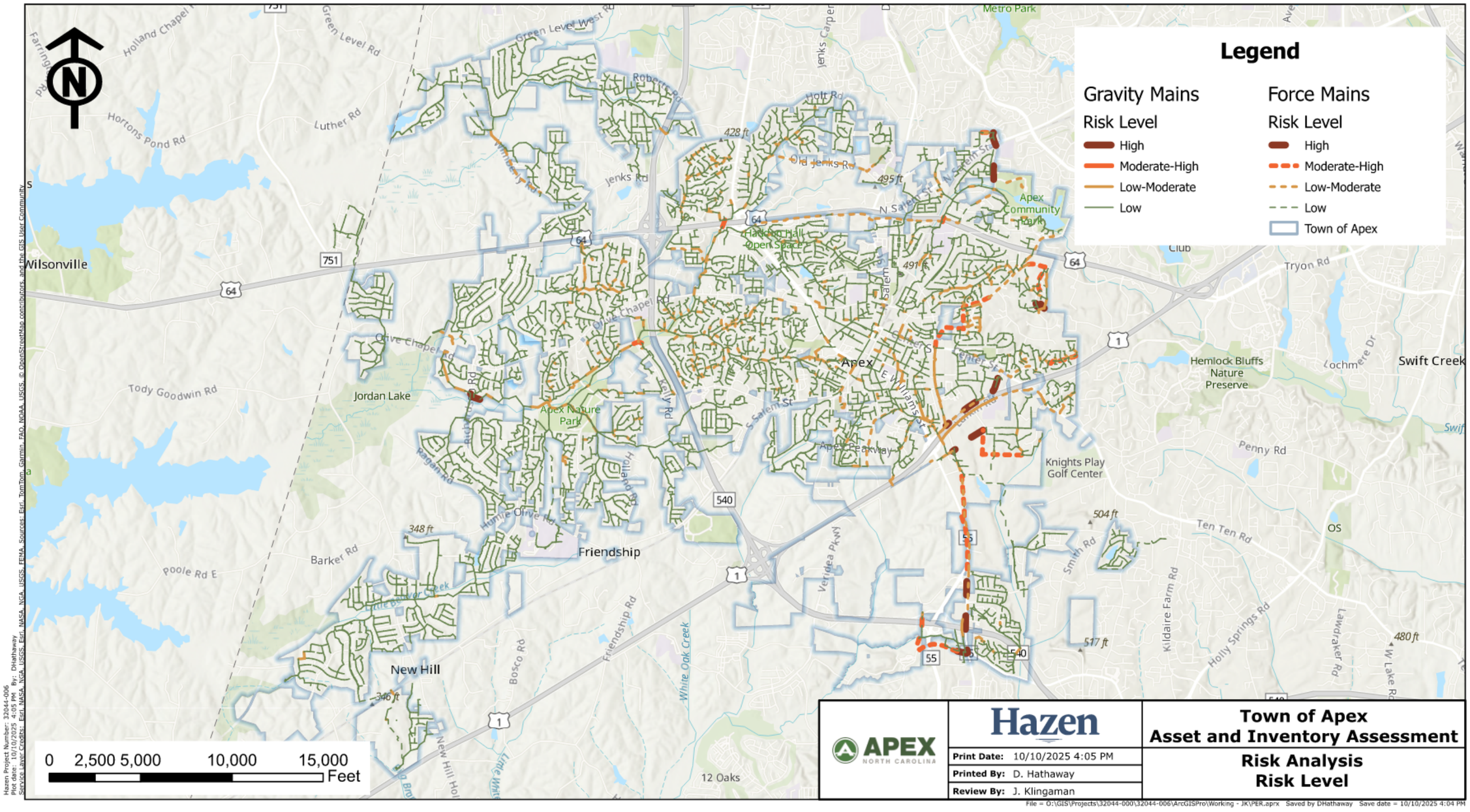


Figure 4-4: Map of Risk Level for Gravity and Force Mains

5. Financial Forecasting

As part of the asset evaluation, Hazen developed a long-term forecast of renewal and replacement (R&R) costs for the sewer collection system linear assets. The following section summarizes the cost assumptions that were used to develop sewer collection system renewal costs as well as long-term financial forecast results.

5.1 Cost Assumptions

Hazen analyzed recent bid tabs for local renewal and replacement projects to determine approximate replacement value for the existing sewer collection system. These high-level costs are not site-specific but rather provide a long-term view of potential replacement funding needs within the sewer collection system. Planning level costs are presented in Table 5-1. All costs are presented in 2025 dollars.

5.2 Long-term Financial Forecast

Table 5-1: Planning Level Costs for Gravity and Force Mains by Diameter

Diameter (inches)	Force Main ($/lf)	Gravity Sewer Main ($/lf)	CIPP Lining ($/lf)	Bore and Jack ($/lf)
6	900	N/A	N/A	1600
8	950	1100	550	1600
10	1050	1150	600	1600
12	1100	1250	650	1600
16	1300	1400	800	1600
18	1350	1500	850	1600
24	1600	1700	1000	2500
30	1950	2050	1200	2500
36	2250	2400	1400	2500
42	2600	2700	1550	5000
48	2950	3050	1750	5000

The following costing assumptions were utilized for the replacement costing shown below.

5.2.1 Sewer Main Costing Assumptions

- Costs are only reflective of one-time replacement of existing gravity and force mains
- Sewer main replacement is inclusive of service line reconnection, manholes, and bypass pumping and is an “all-in” cost per linear foot
- Sewer main replacement is assumed to occur in the street and costs are inclusive of asphalt restoration and traffic control

- Gravity Sewer main replacement assumes a depth of 12’ or less
- Force main replacement assumes a depth of 3’ or less
- Costs assume a size-on-size replacement with PVC or FRP pipe
- Costs are assumed to be system-wide averages for planning level estimates but may underpredict costs for difficult, site-specific considerations
- Costs do not capture easement acquisition, planning, or design, and are raw costs with no contingency applied
- Bore and jack prices are considered for all assets crossing secondary routes, highways, or railroads

5.3 Asset Renewal Financial Forecast

The replacement costs presented in Table 5-1 were applied to each gravity and force main. Figure 5-1 presents estimated replacement costs categorized by the year in which the asset is projected to exceed its expected useful life. All costs are presented in 2025 dollars.

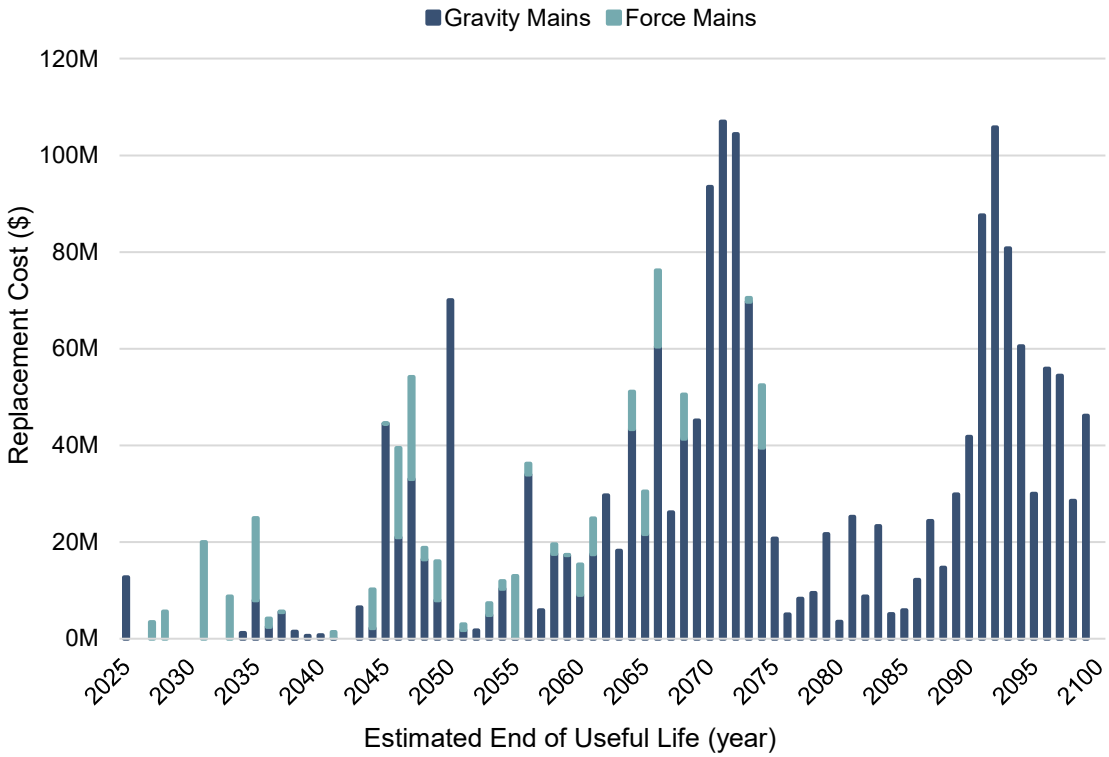


Figure 5-1: Long-term Financial Forecast

Since the Town has experienced rapid growth in the last 30 years, many of the Town’s sewer collection assets have significant remaining useful life. Therefore, the short-term renewal forecast is much smaller than the replacement needs expected in 20 years and beyond. Refinement of LoF scoring with field

condition assessment will help identify early failures and opportunities for investment in the system, which can level long-term spending rates. This desktop model predicts replacement needs may ramp up beginning in 2045 with additional peaks around 2070 and 2090. Verifying actual condition of the system through inspection will help ensure the Town is well-prepared to ramp up replacement when and where it is needed.

6. Recommendations

This desktop analysis provides a basis for both near-term and long-term actions. In the near-term, Hazen recommends several efforts to collect asset condition data through inspection projects which can help refine and target costly renewal efforts and refine long-term funding needs. **Hazen recommends that the Town continue to invest in inspection and targeted main replacement to stay ahead of early failures and maintain the right size main replacement budget as the system ages. While these inspection efforts are beginning, Hazen recommends the Town proceeds with replacement projects for high-risk assets.**

Following initial data collection from inspection efforts, Hazen recommends utilizing the collected asset condition information to help inform long-term renewal and replacement budgets.

Several categories of projects are recommended as part of the asset management program for the sewer collection system.

- Near-term recommended projects: These projects are early capital projects for infrastructure replacement which can proceed while inspection projects are ongoing.
- Asset Inspections: These projects are recommended to refine data and asset LoF scores to improve replacement prioritization, capital improvement plan (CIP) project packaging, and financial forecasting.
- Data Management & Workflow Improvements: These projects address asset management-related data needs and may help reduce the staffing burden for data tracking and analysis.

6.1 Near-term Recommended Projects

As noted in the risk evaluation, the majority of the Town water distribution and sewer collection systems have significant remaining useful life and, therefore, the bulk of the recommendations are focused on asset inspection to find early signs of failure where renewal can avoid failure and extend asset life. Hazen reviewed the results of the asset evaluation and developed two project recommendations that address high risk sewer collection pipes.

6.1.1 Trunk Line to Apex WRF

This trunk line consists of 30-36” DIP that runs from Perry Rd in the north to the Apex WRF in the south and was inspected as part of this AIA project. The inspection showed frequent surface damage and corrosion defects, as well as attached deposits. Given the criticality of this trunk line, **Hazen recommends a near-term project to develop a Preliminary Engineering Report evaluating options for rehabilitation or replacement of this line.** The preliminary engineering report should include hydraulic modeling as necessary to determine current capacity limitations and future capacity needs to appropriately size the replacement.

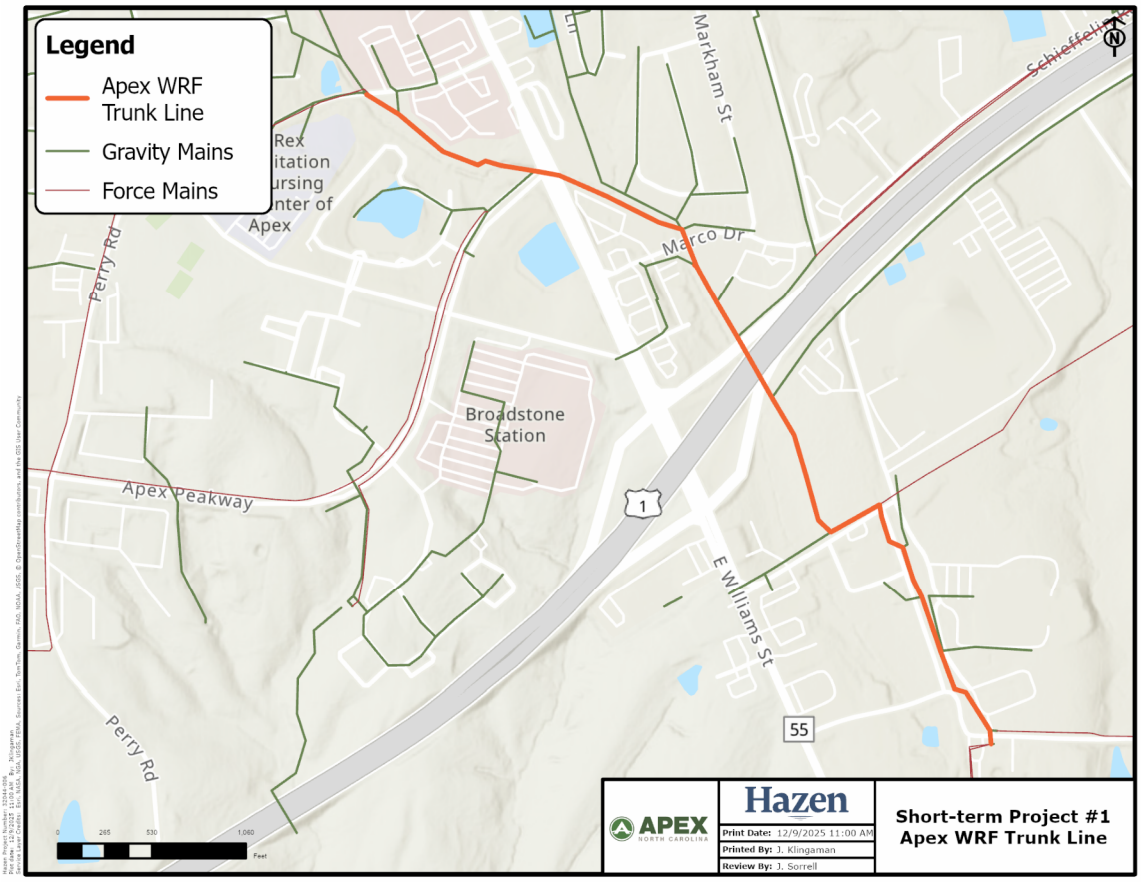


Figure 6-1: Short-term Project – Apex WRF Trunk Line

6.1.2 Beaver Creek Interceptor

This interceptor consists of 30-42" diameter DIP that runs from NC-540 in the east to the Beaver Creek pump station in the west. Portions of the line were inspected as part of this AIA project. The pole camera inspection showed significant corrosion relatively early in the lifespan of these assets. Given the criticality of this trunk line, **Hazen recommends a near-term project to perform a full condition assessment utilizing CCTV to refine useful life assumptions and identify sections which need rehabilitation.**

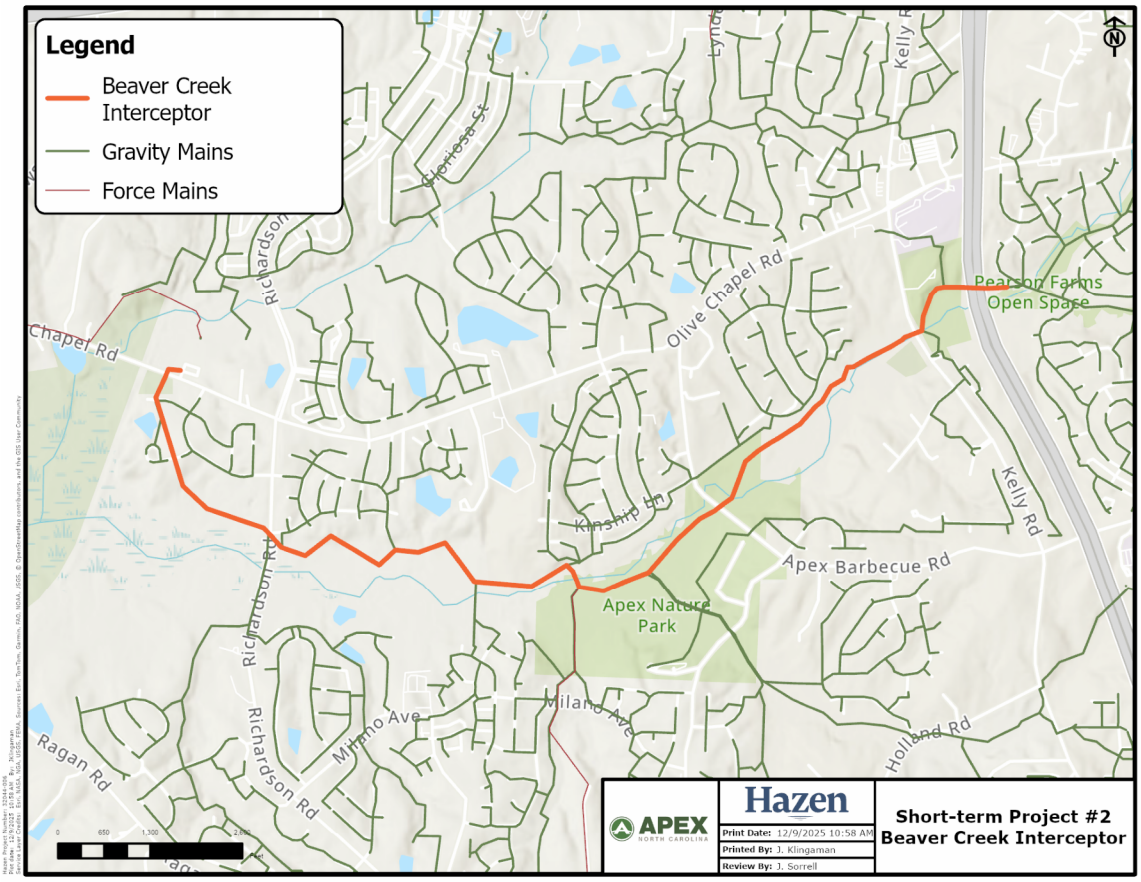


Figure 6-2: Short-term Project – Beaver Creek Interceptor

6.2 Asset Inspections

Inspections serve as a critical data source for asset management programs, helping to ensure that the right renewal and replacement activities are programed at the right time for high-risk assets. Hazen recommends several categories of inspection which can provide cost effective insights. These inspections are anticipated to cost a small percentage of overall replacement cost, while providing data to reduce risk of catastrophic failures.

6.2.1 Gravity Main Inspections

Closed-circuit television (CCTV) of gravity mains is generally anticipated to cost <1% of the cost of asset replacement. Additionally, CCTV inspections allow for identification of defects prior to catastrophic failure. In many cases, assets may develop cracks, fractures, corrosion, and holes before finally failing in a collapse or sinkhole. CCTV can provide early detection, allowing for repair or replacement and avoiding SSOs, sink holes, and costly emergency repairs.

In the near-term, Hazen recommends continuing CCTV efforts targeting 10% of the gravity sanitary sewer system annually. Year 1 inspections should begin prioritizing high risk assets with a CoF of 4 or 5 as well as assets that are likely to be subject to corrosion (such as DIP) and those downstream of

a force main discharge. Subsequent years' inspections should continue prioritizing asset inspections based on risk.

These inspections provide quick feedback on those assets which have the highest risk or may be subject to accelerated corrosion. Many of these assets are larger diameter or are under high traffic streets or other areas which increase the consequence of failure scoring. CCTV efforts are typically less than 1% of the total replacement cost of such pipes.

If desired, a flexible approach with an allowance for additional inspections can provide a tool for the Town to extend the inspection limits when the vendor encounters significant defects. Pole camera inspections can be an effective tool for identifying areas for additional CCTV inspection.

6.2.2 Force Main Inspections

Hazen recommends continued refinement of the force main LoF results to focus future inspection efforts on the highest priority areas. **Hydraulic modeling is recommended to identify smaller force main segments which may be subject to corrosion due to air pockets.**

Hazen recommends the Town establish an annual budget for force main condition assessment. The near-term budget should include hydraulic modeling and inspections to verify wall loss on metallic force mains at high points and downhill segments where air pockets may be present.

Initially, ultrasonic wall thickness testing at high points can provide an opportunity to verify both internal and external corrosion and provide direct condition assessment data for the assets inspected. Performing these inspections can also help inform a business case for whether more detailed condition assessment technologies, including free-swimming and tethered inspection technologies for wall loss or leak detection, may provide value.

6.2.3 Permanent Flow Metering

Hazen recommends that the Town implement permanent flow metering at strategic points throughout its gravity sewer system to assist in the development of a wastewater hydraulic model.

6.3 Data Management Recommendations

In addition to funding and project recommendations, Hazen has several recommendations for the Town's data management to ensure crucial asset data is tracked, accessible, and maintained into the future.

6.3.1 GIS Attribute Updates

Throughout the present risk analysis, Town of Apex gravity and force main fields were flagged for future maintenance and updates. **Hazen recommends attribute data updates as follows:**

- Install Date and INSTALL_YR are redundant. Install Date is incomplete whereas INSTALL_YR is complete. Hazen recommends either consolidating these fields or ensuring they remain in sync as assets are edited.

- Liner Type is nearly incomplete. Hazen recommends adding a liner type/material for each asset which is retrofitted with a liner.
- From Manhole/To Manhole and US_MANHOLE/DS_MANHOLE are redundant and not fully coincident. Hazen recommends avoiding duplicate use/display of data.
- Upstream/Downstream elevations are only about 50% complete; slope cannot be calculated. Hazen recommends obtaining the elevation of each asset.
- UTIL_DEPTH is 99% incomplete. Hazen recommends assigning a depth to each asset.

Hazen recommends including LoF and CoF scores in the standard asset attribute information to help inform and plan routine maintenance activities and repairs. Routine maintenance is especially important for pipes with high CoF scores since the impact of failure is substantial. Additionally, when planning capital projects and repairs, pipes with high PoF scores should be prioritized to reduce system risk.

- LoF:
  - Field Type: Integer (1-5, with 5 as the most severe)
  - Field can be used to validate repair work orders to see if these were known pipes with potential for failure.
- CoF:
  - Field Type: Integer (1-5, with 5 as the most critical)
  - Field allows others in the Town to see if their work would impact a high consequence pipe.

6.3.2 Master CCTV Database

Hazen recommends that the Town invest in establishing and maintaining a master database for CCTV data. A master CCTV database would allow the Town to easily update the LoF score of gravity mains based on inspections. Additionally, centralized CCTV data will improve future replacement projections and allow the Town to determine the appropriate useful lives of pipes based on inspections and failure rates of pipes in their system. This software may support map views of CCTV results and more efficient workflows for syncing internal inspections and incorporating CCTV provided by external vendors.

6.3.3 Wastewater Hydraulic Model

Currently, the Town does not have a wastewater hydraulic model and Hazen was not able to utilize model results for asset evaluation. **Hazen recommends that the Town create a wastewater hydraulic model to uniformly evaluate the hydraulic performance of the collection system.** The hydraulic model will enable the Town to identify portions of the collection system that are undersized and should be prioritized for upgrades and can also provide valuable information about inflow and infiltration throughout the system which can be utilized to prioritize inspection and rehabilitation efforts.

6.4 Recommended Workflow for Asset Evaluation Updates

The asset evaluation described in this TM was compiled from a variety of data sources described in Section 2.2. These data sources were input into a risk analysis tool to assign LoF, CoF, and risk scores to each linear collection system asset. The results of the risk analysis summarize LoF, CoF, and risk scores. In the future, when new or updated data sources are available, they can be input in the Risk Model to update the asset evaluation. Detailed documentation of how to run the risk model tool is included in Appendix C.

6.4.1 Annual Project Identification Schedule

The Town is currently planning its rehabilitation budget and project packaging on an annual basis. **To allow adequate time for updating data, running the risk model, identifying projects, and reviewing with stakeholders, Hazen recommends the schedule presented in Table 6-1 for updating the risk analysis.** The goal of this schedule is to ensure that asset information, risk results, proposed projects, and budgeting information are ready in time for the Town to make necessary decisions. The timeline below may be condensed based on the processes the Town chooses to follow.

Table 6-1. Recommended Annual Update Schedule

Month	Task	Task Lead
Early April	Export work order data from Cityworks.	Cityworks Administrator
	Export CCTV data.	CCTV Project Manager
	Update project schedules, budgets, and extents.	Project Managers
	Complete updates to GIS based on updated project information.	GIS Team
Mid-April	Complete preprocessing of Cityworks data.	Cityworks Administrator
	Compile and export latest GIS data.	GIS Team
	Complete preprocessing of GIS data.	Water Resources Team
	Complete preprocessing of CCTV data.	Water Resources Team
May	Run the Risk Model for updates	GIS Team
June	Update Financial Forecasting Model	Water Resources Team
July	Complete project packaging and review with subject matter experts.	Water Resources Team
August	Workshops to review project list.	Engineering and Operations Staff
September	Finalize Draft Project List	Engineering Staff

6.5 Conclusions and Future Guidance

The asset evaluation and analyses performed to date and summarized in this TM apply a risk evaluation framework to the sewer collection system linear assets. Town employees at all levels should work to maintain and improve asset databases and systems to ensure that information stays current and accurate.

Using the consistent and repeatable risk assessment methodology implemented through this asset evaluation effort, the Town will gain benefits from better-informed decisions made by field staff, engineers, and executives.

Additionally, this effort will provide the Town with the data necessary to prioritize improvement projects for the sewer collection system to mitigate infrastructure risk to the greatest degree.

Throughout this report, Hazen has added recommendations for the Town of Apex in **orange text**. These recommendations have been compiled into the table below.

Table 6-2. Summary of Recommendations

Section	Recommendation
6	Continue to invest in inspection and targeted main replacement to stay ahead of early failures and maintain budget
	Proceed with replacement projects for high-risk assets while inspection program develops
	Following initial data collection from inspection efforts, Hazen recommends utilizing the collected asset condition information to help inform long term renewal and replacement budgets.
6.1.1	Implement project in the near-term for the trunk line to the Apex WRF
6.1.2	Implement project in the near-term for the Beaver Creek Interceptor
6.2.1	Beginning proactive CCTV inspection of 10% of the gravity sanitary sewer system annually
6.2.2	Hydraulic modeling to identify smaller force main sections which may be subject to corrosion due to air pockets
	Establish an annual budget for force main condition assessment, including hydraulic modeling and wall loss inspections
6.3.1	Update lacking attribute fields in GIS database
	Include CoF and LoF scores in the standard asset attribute information to help inform and plan routine maintenance activities and repairs
6.3.2	Establish and maintain a master database for CCTV data
6.3.3	Develop a system-wide wastewater hydraulic model to uniformly evaluate the hydraulic performance of the collection system
6.4.1	Follow a schedule to allow for data updates, risk model updates, project identification, and stakeholder review.

Appendix A: Risk Model Inputs

Reactive Work Orders

DESCRIPTION	WORKORDERID Hierarchy - WORKORDERID	WORKORDERID Hierarchy - ENTITYUID	ACTUALFINISH DATE - Year	ACTUALFINISH DATE - Month	ACTUALFINISH DATE - Day	Address	Location	Status	Submit To	Project Start Date	Comments	Instructions
Remove Blockage Gravity	55490	SEGSL1060	2020	January	21							
Remove Blockage Gravity	105537	SEGSL1146	2020	November	13	701 E WILLIAMS ST, APEX	Apex Coin	CLOSED	Mills, James	2020-11-12 03:17 PM	We flush up to tins tall st to under stop the sewer line	Manholes are backed up up causing the service to back up.
Remove Blockage Gravity	105537	SEGSL1147	2020	November	13	701 E WILLIAMS ST, APEX	Apex Coin	CLOSED	Mills, James	2020-11-12 03:17 PM	We flush up to tins tall st to under stop the sewer line	Manholes are backed up up causing the service to back up.
Remove Blockage Gravity	4208	SEGSL11927	2018	October	9	White Oak Pond Rd.	Residential	CLOSED	Mote, Michael	2018-10-09 07:27 AM	We finished cleanup on 10/9. About 150 ft. of the creek was jetted and cleaned. Sandbags were also used and the manholes were cleaned out.	Remove the blockage that is causing an SSO.
Remove Blockage Gravity	110524	SEGSL12052	2020	December	11	2819 Clifton Oaks Dr.	JORDAN POINTE	CLOSED	Carroll, Jordan	2020-12-11 07:30 AM	Flushed 380 feet to remove debris out of line.	Remove debris from the gravity main.
Trenchless Pipe Patch Gravity	3299	SEGSL1220	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1272	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL13426	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Contracted Services Gravity	2707	SEGSL1343	2018	August	29	Olive st	Olive st	CLOSED	Fontaine, Tim	2018-08-30 11:04 AM	Crawler pipe line quoted 500.00 per service there are 3 services	Slip liner has moved. need to re cut services This will be assigned to Crawler pipe line
Remove Blockage Gravity	228623	SEGSL13750	2022	August	18	806 AMLEY PL, APEX	Townes at North Salem Phases 1, 2	CLOSED	Underhill, Anthony	2022-08-17 03:13 PM		
Repair Gravity	21010	SEGSL13769	2019	May	7	1025 MARKHAM ST	APEX MOBIL ESTATES	CLOSED	Cotton, Seth	2019-05-06 09:00 AM	BILL CONTRACTOR PER JIMMY C	Cable or conduit drilled through the main
Remove Blockage Gravity	142412	SEGSL1430	2021	June	10	1013 Wabberly Lane	Obstruction in the main approx 45 feet into main from manhole in cut-de-sac.	CLOSED	Carroll, Jordan	2021-06-10 08:00 AM	Flushed line	Use root cutting head if it appears to be a root.
Trenchless Pipe Patch Gravity	3299	SEGSL1435	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1510	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Contracted Services Gravity	15951	SEGSL1567	2019	March	22	415 Olive st	415 Olive st	CLOSED	Fontaine, Tim	2019-02-18 10:00 AM	wo14823	contract crawler to make repairs. we may need to plug upstream and pump and haul for this repair
Trenchless Pipe Patch Gravity	3299	SEGSL1785	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1787	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1822	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1823	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL1952	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	151622	SEGSL2309	2021	July	27	403 Ivey Glen	403 Ivey Glen	CLOSED	McDuffie, Adam	2021-07-27 07:15 AM	Pipe patch was unsuccessful. Had to dig up the pipe to remove patch and repair the sewer line.	Install pipe patch in 8 inch clay pipe.
Repair Gravity	45687	SEGSL2479	2019	November	22	1004 Senoma Place	VINTAGE GROVE	CLOSED	Cotton, Seth	2019-10-31 11:45 AM	REPLACED 3' OF MAIN AND REPLACED THE TAP.	Repair main , the pipe is crushed in at the top at the tap for 1002 Senoma Pl. The area is marked with paint and video footage is on the parent work order. Measures 5.3 ft deep at main, the lateral measures at 3.5 ft deep.
Repair Gravity	68088	SEGSL2606	2020	April	22	413 N SALEM ST	Residential	CLOSED	Byrd, Ricky	2020-04-23 10:15 AM	Replaced 2' section of sewer main.	
Repair Gravity	69019	SEGSL2613	2020	July	17	413 N SALEM ST	Residential	CLOSED	Byrd, Ricky	2020-06-16 09:00 AM	Met with Lambert s on site and Coordinated with Ricky for the work to be done on June 16th	Cable was found running through sewer line approx 25 feet from Downstream Manhole. Will need to be removed to make Pipe repair. MCI will be on site to excavate and remove cable.
Repair Gravity	125769	SEGSL2786	2021	March	17	5412 APEX PEAKWAY	Commercial	CLOSED	Cotton, Seth	2021-03-11 03:11 PM	CAMERA WAS STUCK IN THE MAIN LINE. CUT A 3 FT SECTION OUT AND GOT THE CAMERA OUT.	
Repair Gravity	1330	SEGSL2795	2018	August	7	502 FAIRVIEW RD 27502	502 FAIRVIEW RD 27502	CLOSED	Lancaster, Alex	2018-07-11 06:00 PM	Sewer line running in or through creek bed dirt around and under being eroded so placed large pieces of rip rap around pipe in outfall area	
Repair Gravity	141121	SEGSL326	2021	June	2	1001 LEXINGTON FARM RD, APEX	Lexington Farms	CLOSED	McDuffie, Adam	2021-06-02 05:58 PM	Pipe was successfully patched.	Pipe patch the joint where roots were intruding.
Remove Blockage Gravity	277925	SEGSL3739	2023	April	7	1606 CONE AVE, APEX	KNOLLWOOD ESTATES	CLOSED	Milliron, Jacob	2023-04-07 03:27 PM	Sewer blockage located in SEGSL3739. Blockage in gravity main causing customers lateral lines to back up. Flushed line with vac truck to remove blockage.	
Repair Gravity	141805	SEGSL3911	2021	July	6	2109 Abby Knoll Drive	Haddon Hall	CLOSED	Carroll, Jordan	2021-06-28 08:00 AM	Pipe patched a hole in the line	Install pipe patch in 8inch main on Line Segment SEGSL3911. Main has a hole at approx 8 to 11 o'clock.
Remove Blockage Gravity	47736	SEGSL3981	2019	November	18	1202 PARK SUMMIT BLVD	Outfall	CLOSED	Fontaine, Tim	2019-11-18 06:52 AM	we aiso clean up and put line down and straw down to	
Remove Blockage Gravity	89707	SEGSL461	2020	August	25	1130 CLASSIC RD, APEX	1130 CLASSIC RD, APEX APEX	CLOSED	McDuffie, Adam	2020-08-26 08:12 AM	Flushed SEGSL461 to removed blockage from pushing debris out of the gravity sewer line	
Remove Blockage Gravity	24059	SEGSL6075	2019	May	22	Apex Elementary School	Apex Elementary School	CLOSED	McNeill, Keithy	2019-05-22 05:33 PM		remove blockage on main line.
Remove Blockage Gravity	24059	SEGSL6076	2019	May	22	Apex Elementary School	Apex Elementary School	CLOSED	McNeill, Keithy	2019-05-22 05:33 PM		remove blockage on main line.
Repair Gravity	106210	SEGSL6225	2020	December	2	407 S TUNSTALL AVE, APEX	Residential	CLOSED	Byrd, Ricky	2020-11-16 02:56 PM	Cut out 18" section of pipe and replaced with new piece.	There is a cable intruding through the top of the gravity main that needs to be removed and pipe will need to be repaired.
Repair Gravity	218198	SEGSL6785	2022	July	1	1507 Kelly Rd, Apex, NC, 27502	Commercial	CLOSED	Cotton, Seth	2022-07-01 07:22 AM	CONTRACTOR FOUND THE SEWER LINE WITH A HOLE IN THE TOP OF THE LINE. WE REPLACED THE LINE ALL THE WAY BACK TO THE MANHOLE.	
Remove Blockage Gravity	13205	SEGSL7579	2019	February	28	1117 Giby dr	Mobile Estates	CLOSED	Mills, James	2019-02-26 08:00 AM	And i shot up the main sewer line to under stop it	This is a private line, remove blockage and re establish sewer flow. Contact Larry Taylor, mobile estates property manager. 919-669-2738.
Trenchless Pipe Patch Gravity	3299	SEGSL798	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL799	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Trenchless Pipe Patch Gravity	3299	SEGSL801	2018	September	28	Multiple Locations	TSR Project Ph 1 Multiple Locations	CLOSED	Fontaine, Tim	2018-07-30 09:00 AM	this is Ph 1 work order 55 services (TSR)	Crawler Pipe Line will be installing TSR's (Trenchless sewer service repairs)
Remove Blockage Gravity	10369	SEGSL805	2019	January	30	916 James st	James st	CLOSED	Mills, James	2019-01-29 02:30 PM	We wend back to eclean the sewer line	
Repair Gravity	74315	SEGSL805	2020	June	3	920 JAMES ST, APEX	920 JAMES ST, APEX	CLOSED	Lancaster, Alex	2020-06-02 09:12 AM	Myself ,Jakwan, Adam,jordon and Cameron cut out bad section of seeer line and replaced with a newer piece of 4 inch di pipe and 2 ferncos placed rock under pipe for foundation and then covered	The 4inch line is pit cast pipe and has been damaged by phone line instillation. the sewer line is only a few inches deep.
Remove Blockage Gravity	38735	SEGSL8325	2019	September	12	351 Parlier Dr	Outfall The Pines at Wake Crossing	CLOSED	McNeill, Keithy	2019-09-12 05:01 PM	We removed 3 , 4 inch plugs from Manhole SEMH6058, Along with 1, 10 inch main line plug , 5 feet into the main still inflated with a rope attached to it. We lightly flushed this section along with CCTV inspected it to verify structural integrity. W	

Reactive Work Orders

DESCRIPTION	WORKORDERID Hierarchy - WORKORDERID	WORKORDERID Hierarchy - ENTITYUID	ACTUALFINISH DATE - Year	ACTUALFINISH DATE - Month	ACTUALFINISH DATE - Day	Address	Location	Status	Submit To	Project Start Date	Comments	Instructions
Remove Blockage Gravity	54994	SEGSL939	2020	January	14	1472 SALEM CREEK DR	1472 SALEM CREEK DR APEX	CLOSED	McDuffie, Adam	2020-01-14 02:30 PM	wo55008 is or flushing this outfall	
Remove Blockage Gravity	54994	SEGSL960	2020	January	14	1472 SALEM CREEK DR	1472 SALEM CREEK DR APEX	CLOSED	McDuffie, Adam	2020-01-14 02:30 PM	wo55008 is or flushing this outfall	

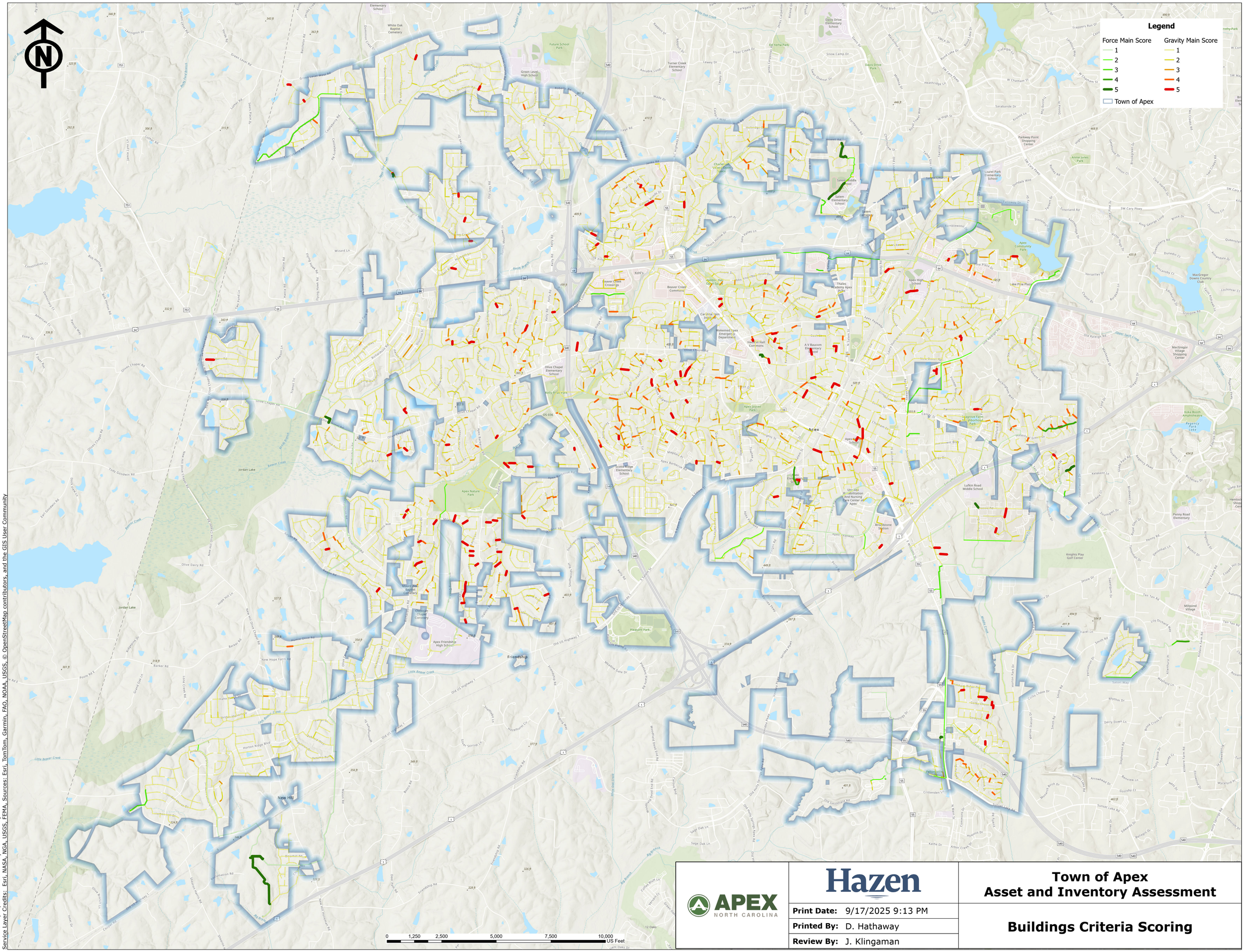
2020 Insitu Relining

DESCRIPTION	WORKORDERID	ENTITYUID	Year	Month	Day
Contracted Services Gravity	64220	SEGSL11041	2020	May	28
Contracted Services Gravity	64220	SEGSL2074	2020	May	28
Contracted Services Gravity	64220	SEGSL2093	2020	May	28
Contracted Services Gravity	64220	SEGSL2108	2020	May	28
Contracted Services Gravity	64220	SEGSL2156	2020	May	28
Contracted Services Gravity	64220	SEGSL2189	2020	May	28
Contracted Services Gravity	64220	SEGSL2945	2020	May	28
Contracted Services Gravity	64220	SEGSL2982	2020	May	28
Contracted Services Gravity	64220	SEGSL3014	2020	May	28
Contracted Services Gravity	64220	SEGSL3027	2020	May	28
Contracted Services Gravity	64220	SEGSL3032	2020	May	28
Contracted Services Gravity	64220	SEGSL3061	2020	May	28
Contracted Services Gravity	64220	SEGSL3062	2020	May	28
Contracted Services Gravity	64220	SEGSL3096	2020	May	28
Contracted Services Gravity	64220	SEGSL3127	2020	May	28
Contracted Services Gravity	64220	SEGSL3130	2020	May	28
Contracted Services Gravity	64220	SEGSL3131	2020	May	28
Contracted Services Gravity	64220	SEGSL3139	2020	May	28
Contracted Services Gravity	64220	SEGSL3140	2020	May	28
Contracted Services Gravity	64220	SEGSL3141	2020	May	28
Contracted Services Gravity	64220	SEGSL3213	2020	May	28
Contracted Services Gravity	64220	SEGSL3242	2020	May	28
Contracted Services Gravity	64220	SEGSL3270	2020	May	28
Contracted Services Gravity	64220	SEGSL3522	2020	May	28
Contracted Services Gravity	64220	SEGSL3523	2020	May	28
Contracted Services Gravity	64220	SEGSL3525	2020	May	28
Contracted Services Gravity	64220	SEGSL3528	2020	May	28
Contracted Services Gravity	64220	SEGSL3557	2020	May	28
Contracted Services Gravity	64220	SEGSL3558	2020	May	28
Contracted Services Gravity	64220	SEGSL3561	2020	May	28
Contracted Services Gravity	64220	SEGSL3578	2020	May	28
Contracted Services Gravity	64220	SEGSL3584	2020	May	28
Contracted Services Gravity	64220	SEGSL3739	2020	May	28
Contracted Services Gravity	64220	SEGSL3763	2020	May	28
Contracted Services Gravity	64220	SEGSL3829	2020	May	28
Contracted Services Gravity	64220	SEGSL3847	2020	May	28
Contracted Services Gravity	64220	SEGSL3873	2020	May	28
Contracted Services Gravity	64220	SEGSL3880	2020	May	28
Contracted Services Gravity	64220	SEGSL3889	2020	May	28
Contracted Services Gravity	64220	SEGSL3890	2020	May	28
Contracted Services Gravity	64220	SEGSL5106	2020	May	28

2025 Linings

LINE SEGMENT	UPSTREAM MH	DOWNSTREAM MH	ADDRESS	LOCATION	PIPE MATERIAL	PIPE SIZE	LENGTH
SEGSLl482	SEMH4144	SEMH4143	1006 Marco Dr.	Behind Los Tres	Ductile Iron	8	105.7 FT
SEGSL4825	SEMH4774	SEMH627	803 E Williams st.	Behind Mi Cancun	Ductile Iron	8	141.8 FT
SEGSL298	SEMH6932	SEMH4481	875 Lufkin Rd.	OUTFALL	Ductile Iron	16	329.9 FT
SEGSL281	SEMH4482	SEMH4458	875 Lufkin Rd.	OUTFALL	Ductile Iron	16	231.9 FT
SEGSL11547	SEMH4458	SEMH6932	875 Lufkin Rd.	OUTFALL	Ductile Iron	16	109.8 FT

Appendix B: Risk Maps



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Service Layer Credits: Esri, NASA, NGA, USGS, FEMA, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

APEX NORTH CAROLINA

Hazen

Print Date:	9/17/2025 9:13 PM
Printed By:	D. Hathaway
Review By:	J. Klingaman

Town of Apex
Asset and Inventory Assessment

Buildings Criteria Scoring

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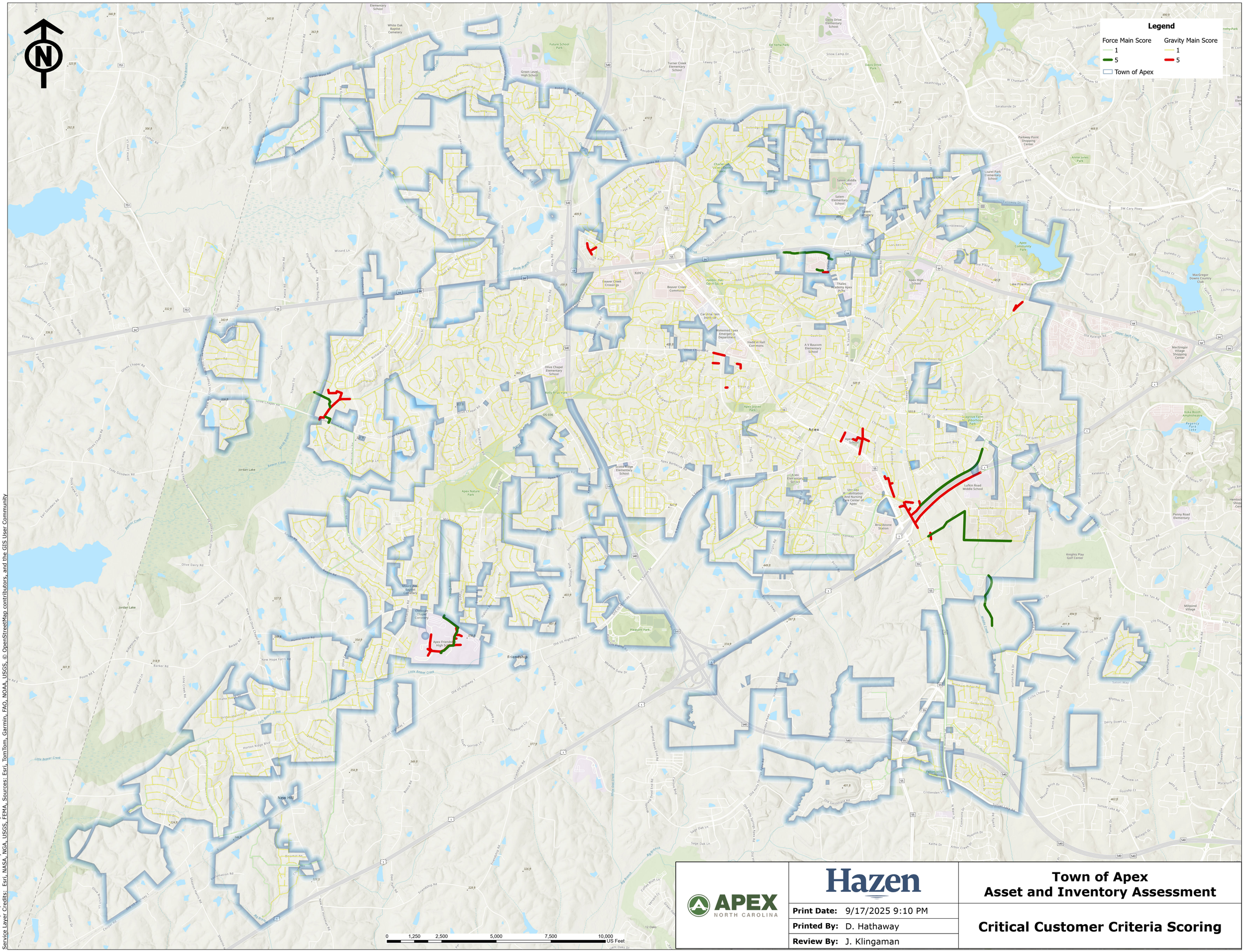

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APEX NORTH CAROLINA

Hazen

Print Date:	9/17/2025 9:10 PM
Printed By:	D. Hathaway
Review By:	J. Klingaman

Town of Apex
Asset and Inventory Assessment

Critical Customer Criteria Scoring

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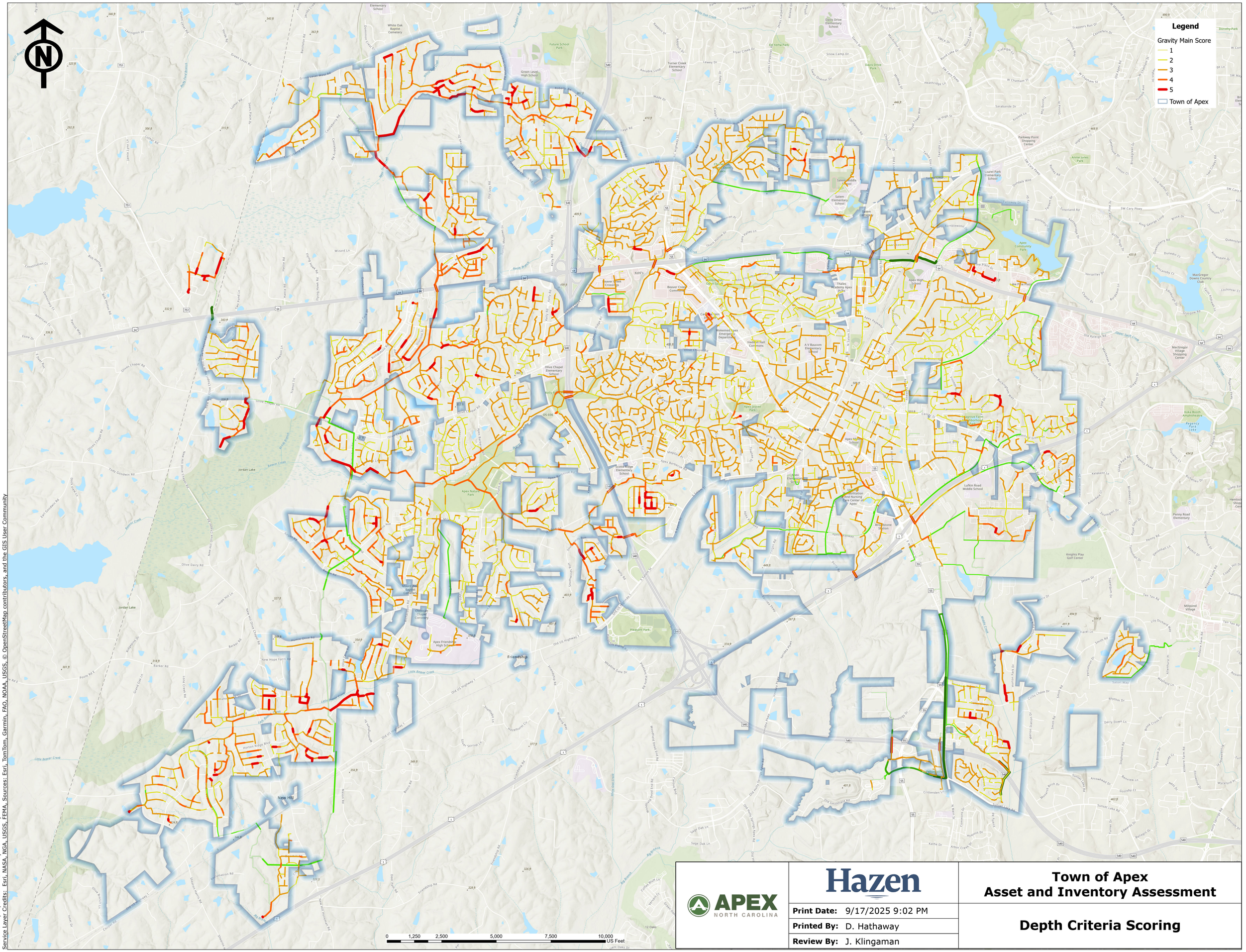

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APEX NORTH CAROLINA

Hazen

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Printed By:	D. Hathaway
Review By:	J. Klingaman

Town of Apex
Asset and Inventory Assessment

Depth Criteria Scoring

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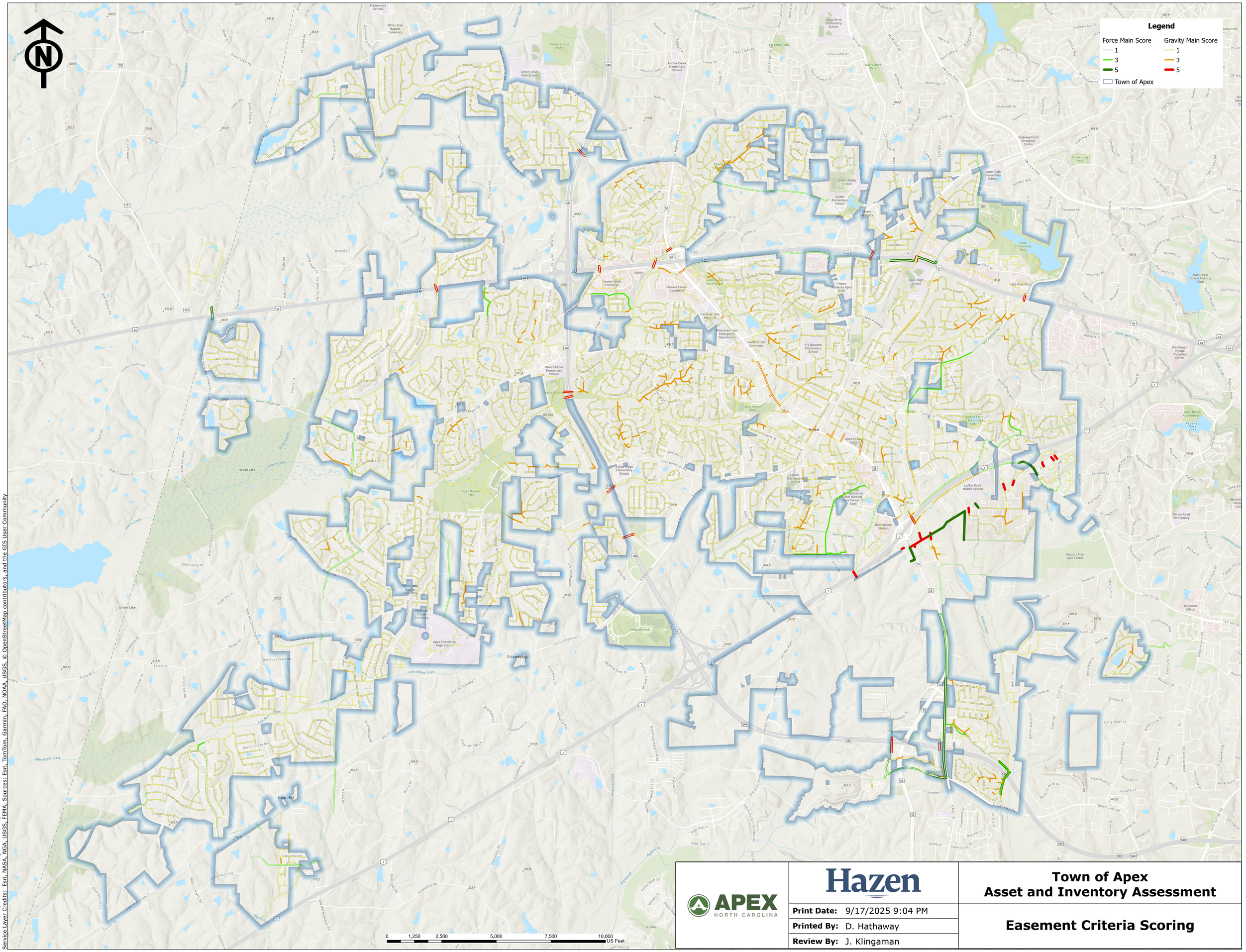

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Service Layer Credits: Esri, NASA, NGA, USGS, FEMA, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

APEX NORTH CAROLINA

Hazen

Town of Apex
Asset and Inventory Assessment

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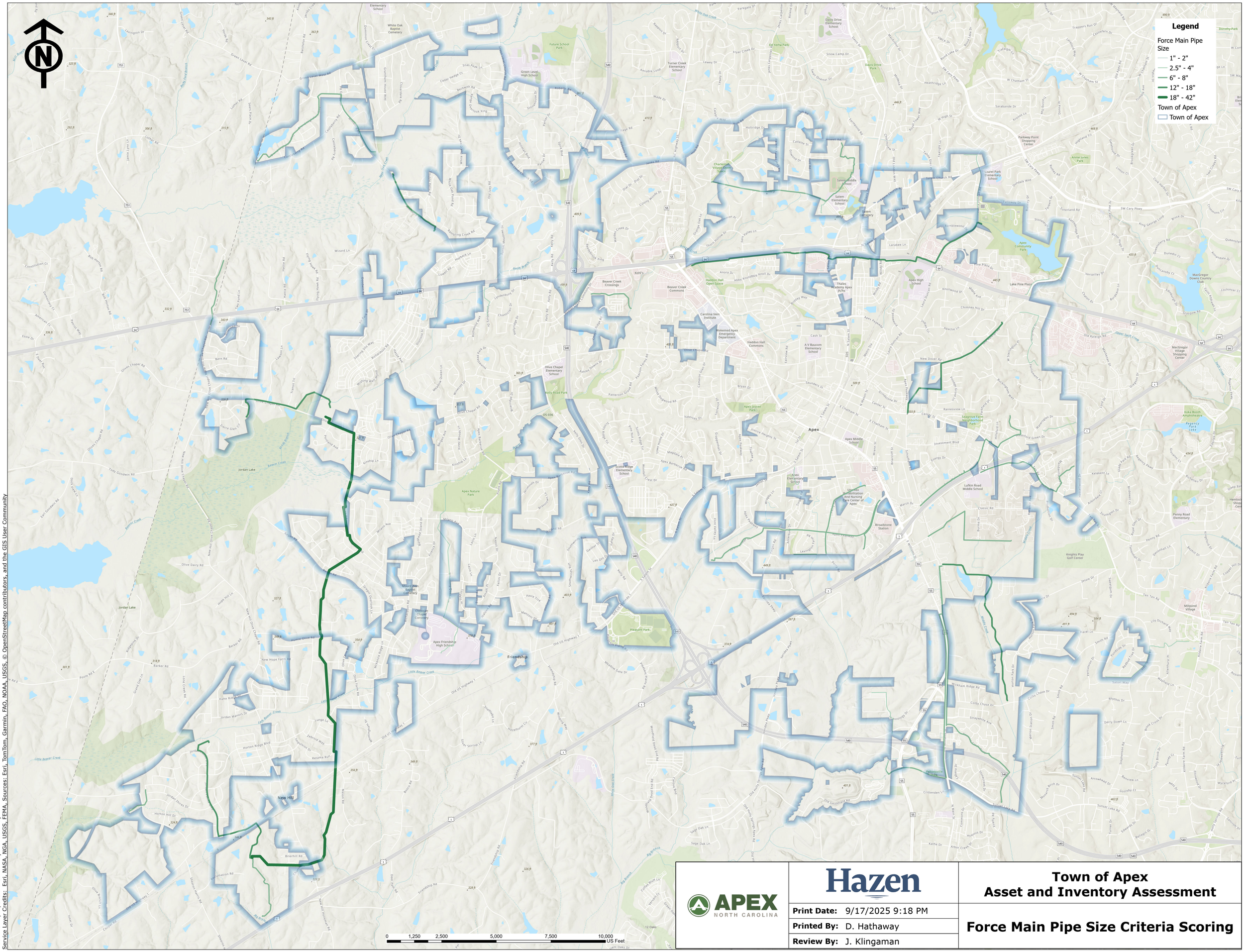
Printed By: D. Hathaway
Review By: J. Klingaman

Easement Criteria Scoring



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Hazen

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Review By:	J. Klingaman

Town of Apex
Asset and Inventory Assessment

Force Main Pipe Size Criteria Scoring

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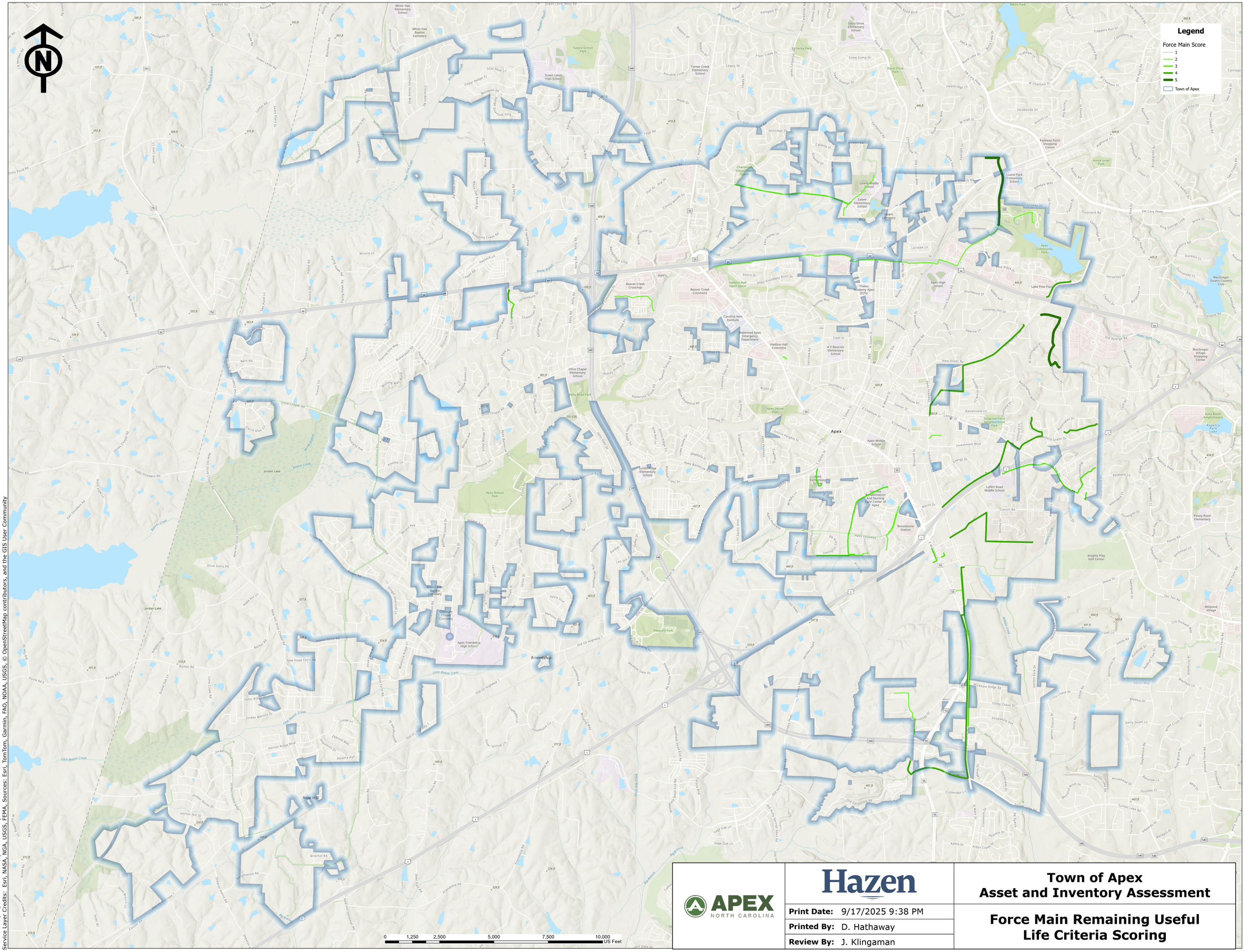

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Town of Apex
Asset and Inventory Assessment

Force Main Remaining Useful Life Criteria Scoring

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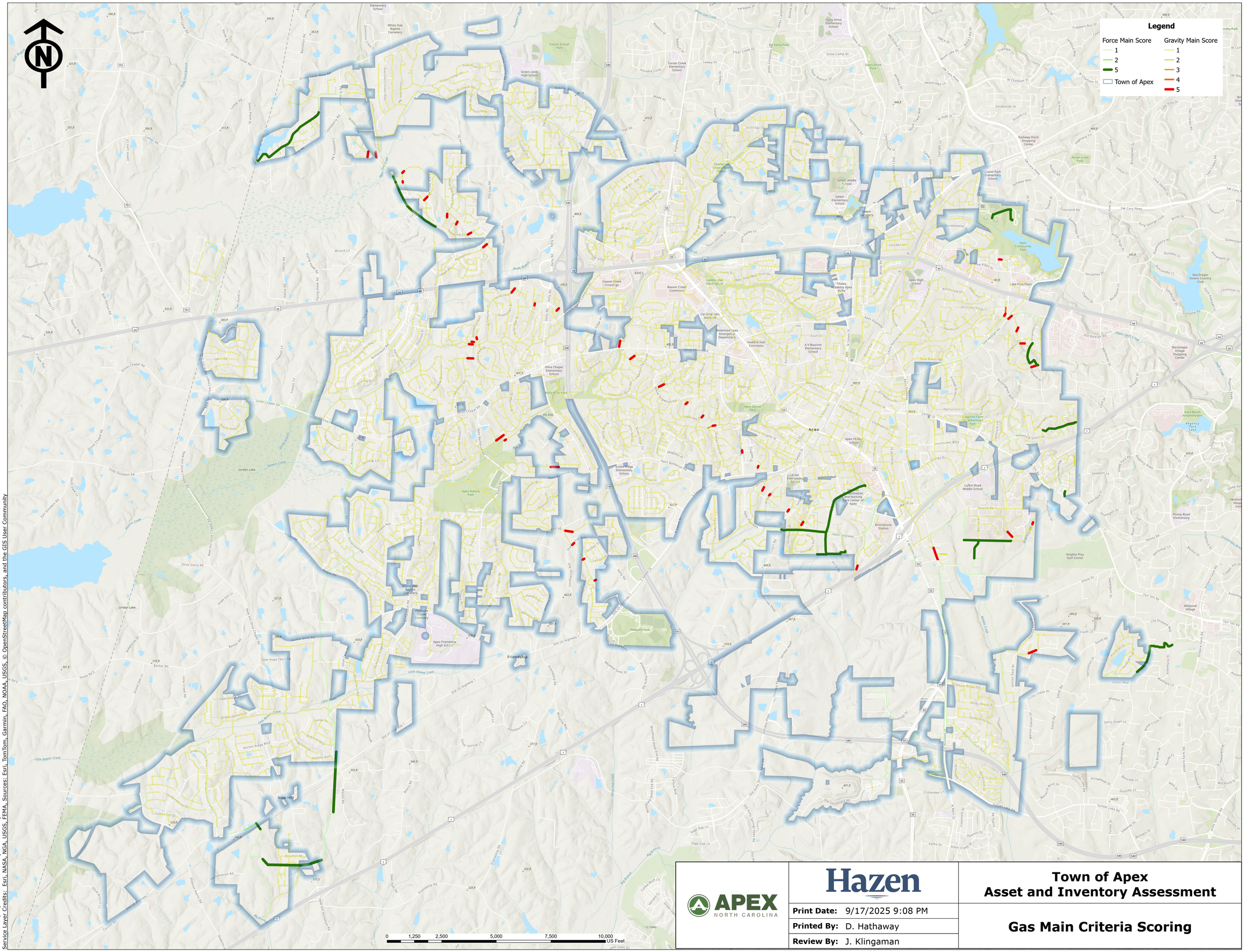

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Town of Apex
Asset and Inventory Assessment

Gas Main Criteria Scoring

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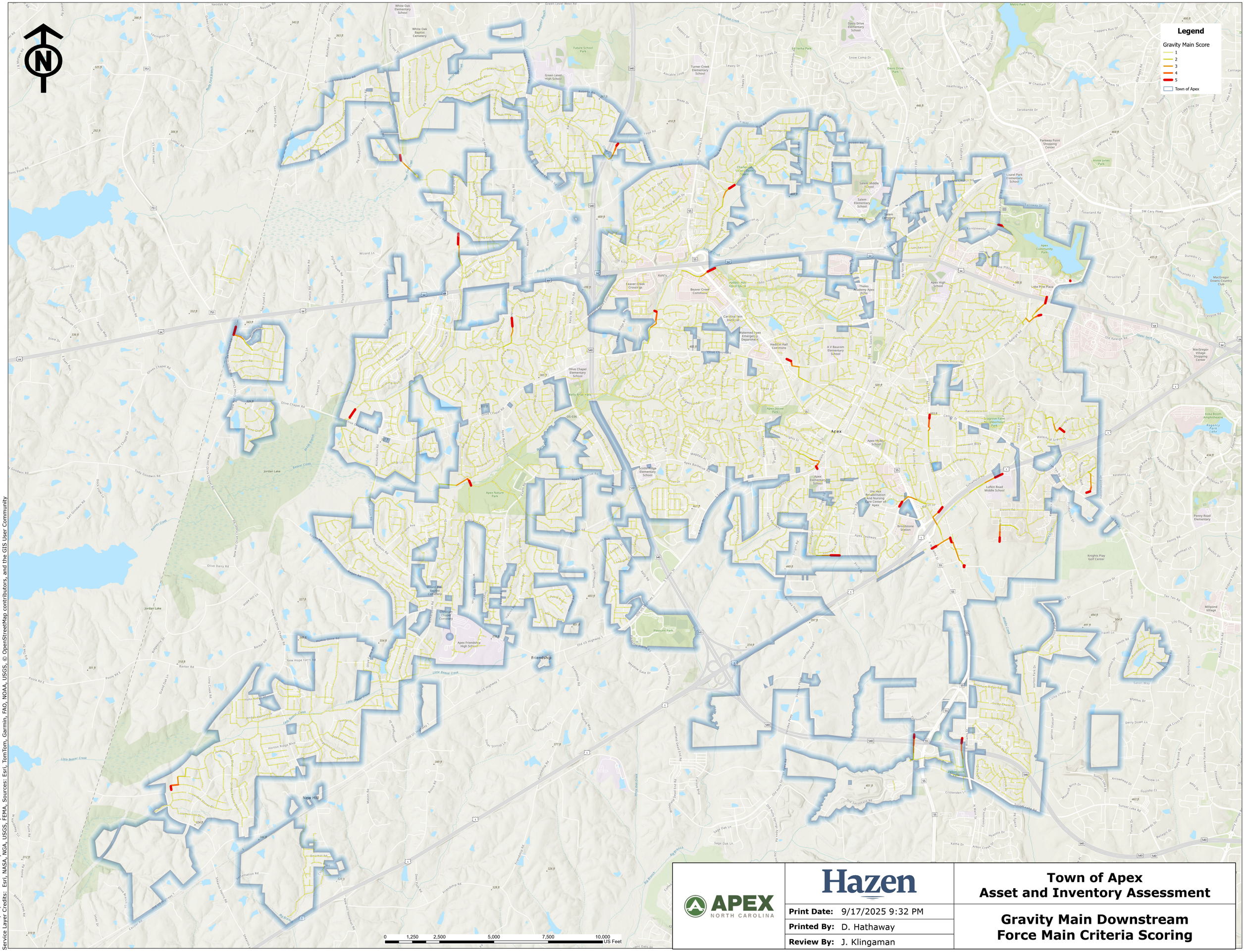

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Town of Apex
Asset and Inventory Assessment

Gravity Main Downstream Force Main Criteria Scoring

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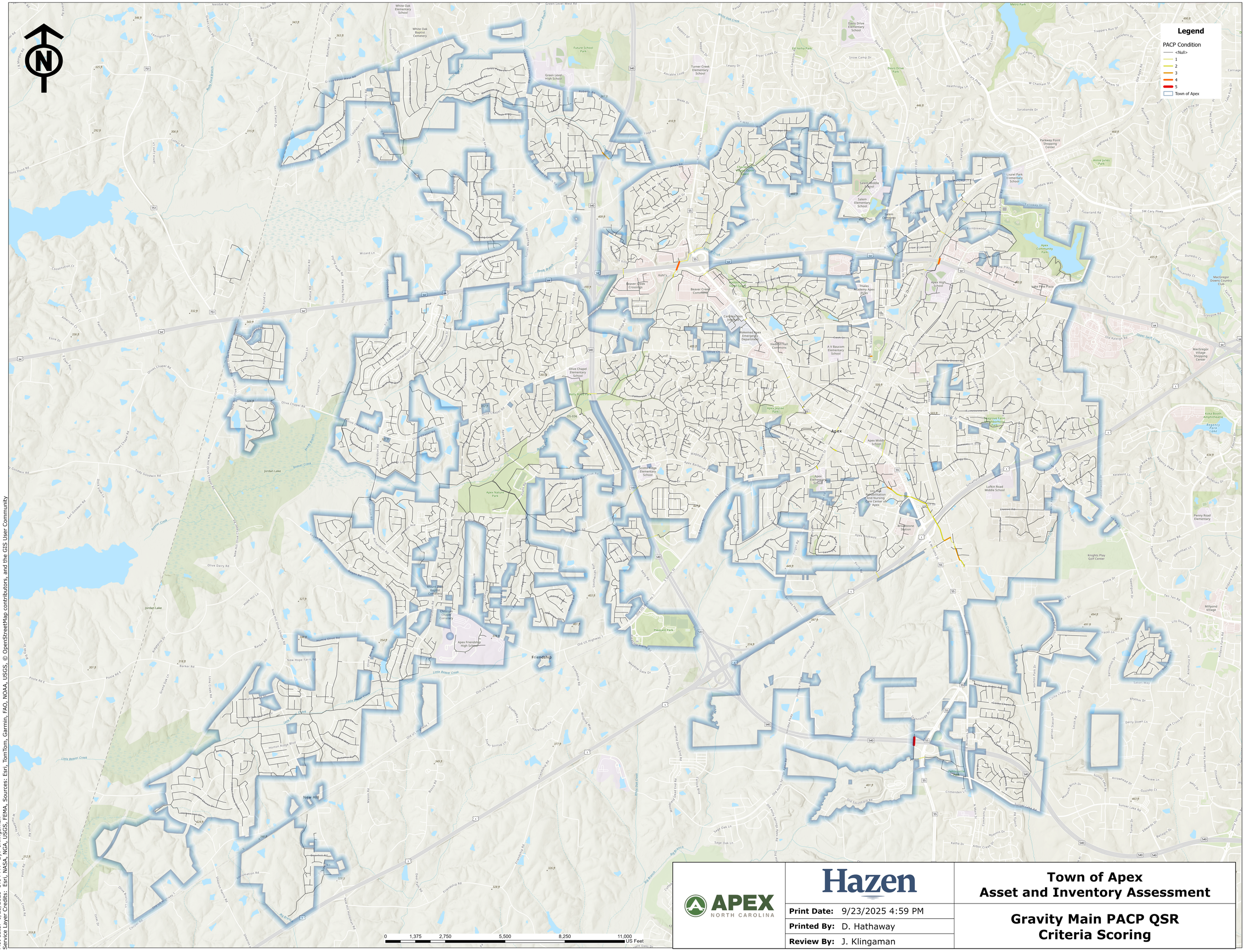

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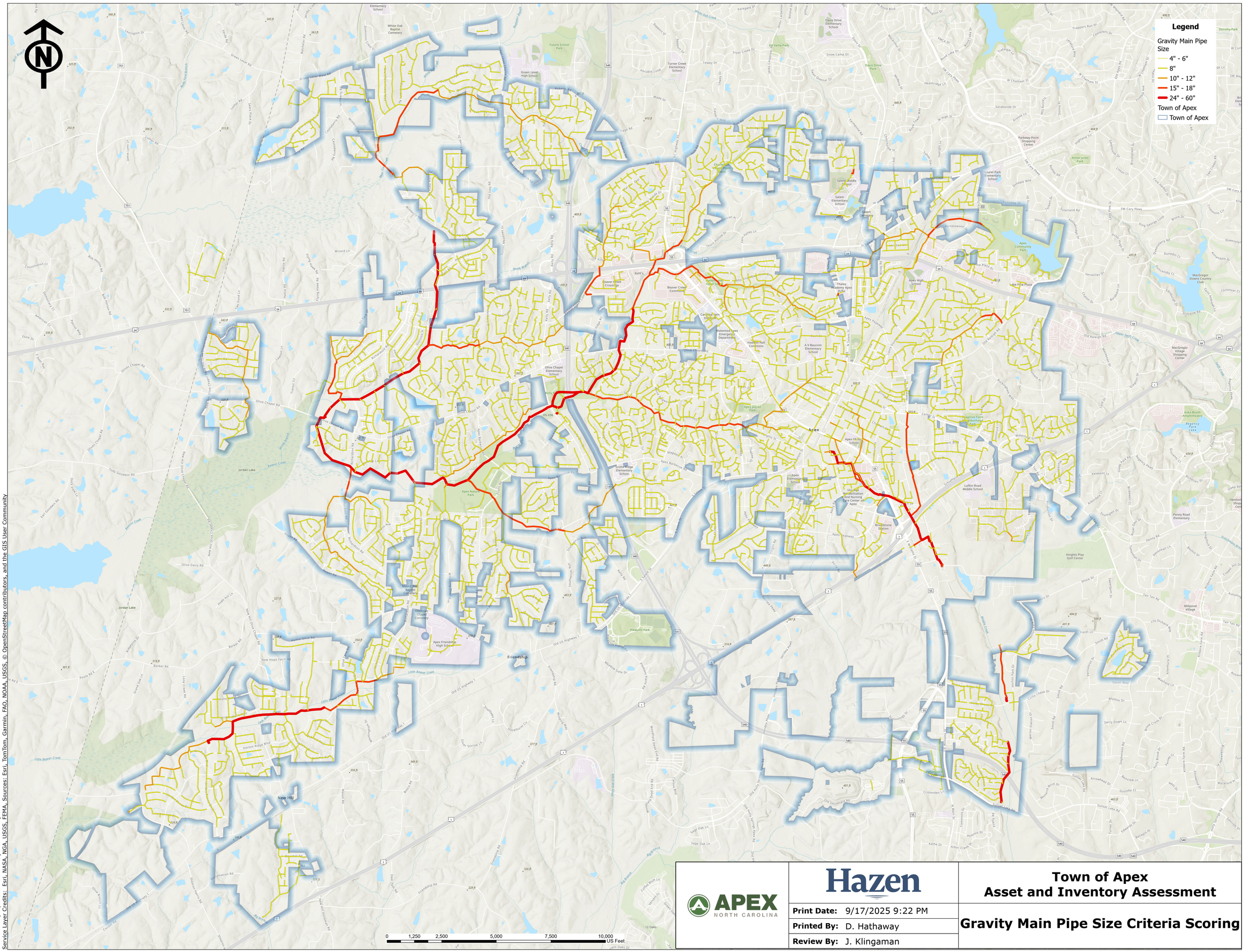

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Town of Apex
Asset and Inventory Assessment

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Gravity Main Pipe Size Criteria Scoring

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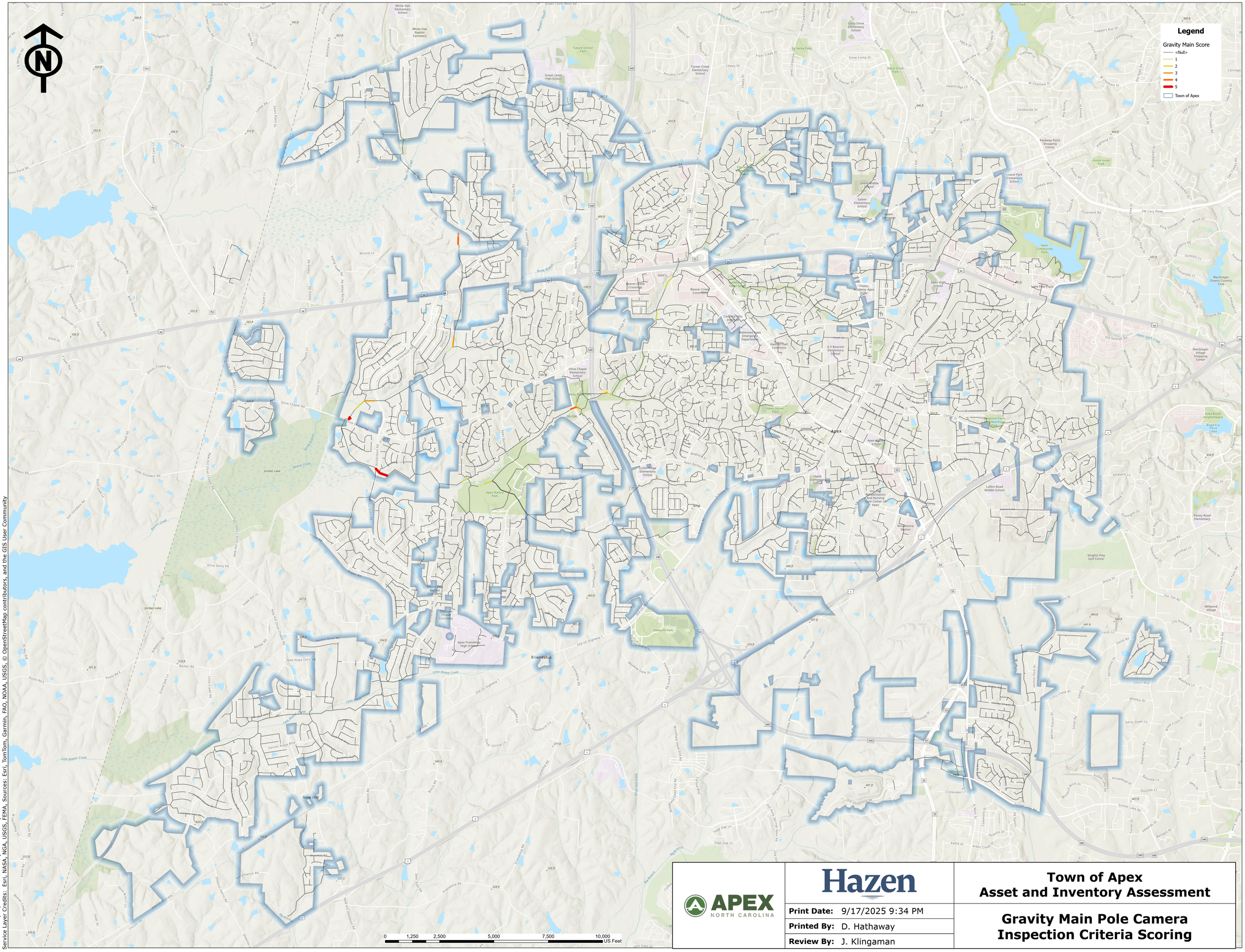

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Town of Apex
Asset and Inventory Assessment

Gravity Main Pole Camera Inspection Criteria Scoring

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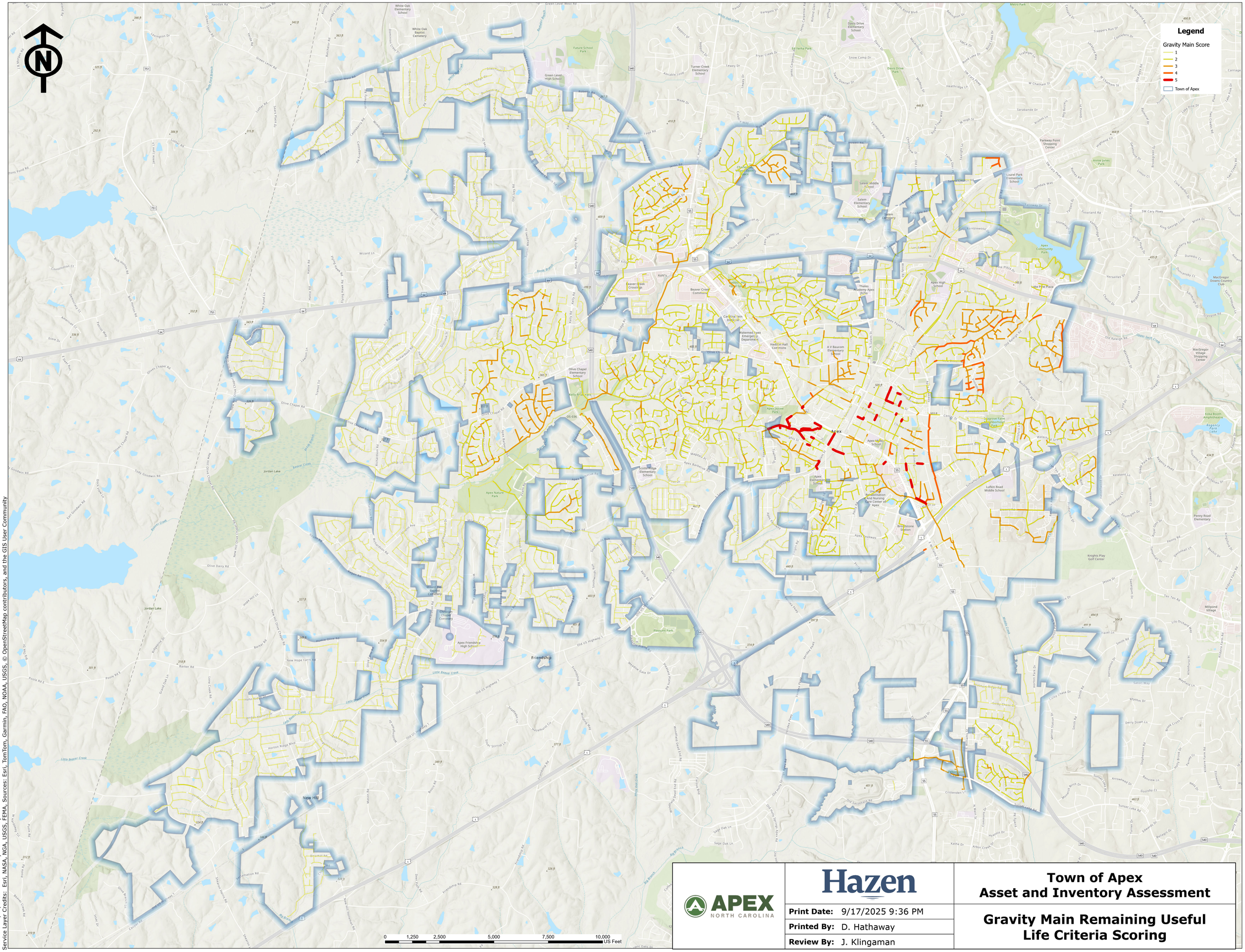

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Asset and Inventory Assessment

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Gravity Main Remaining Useful Life Criteria Scoring

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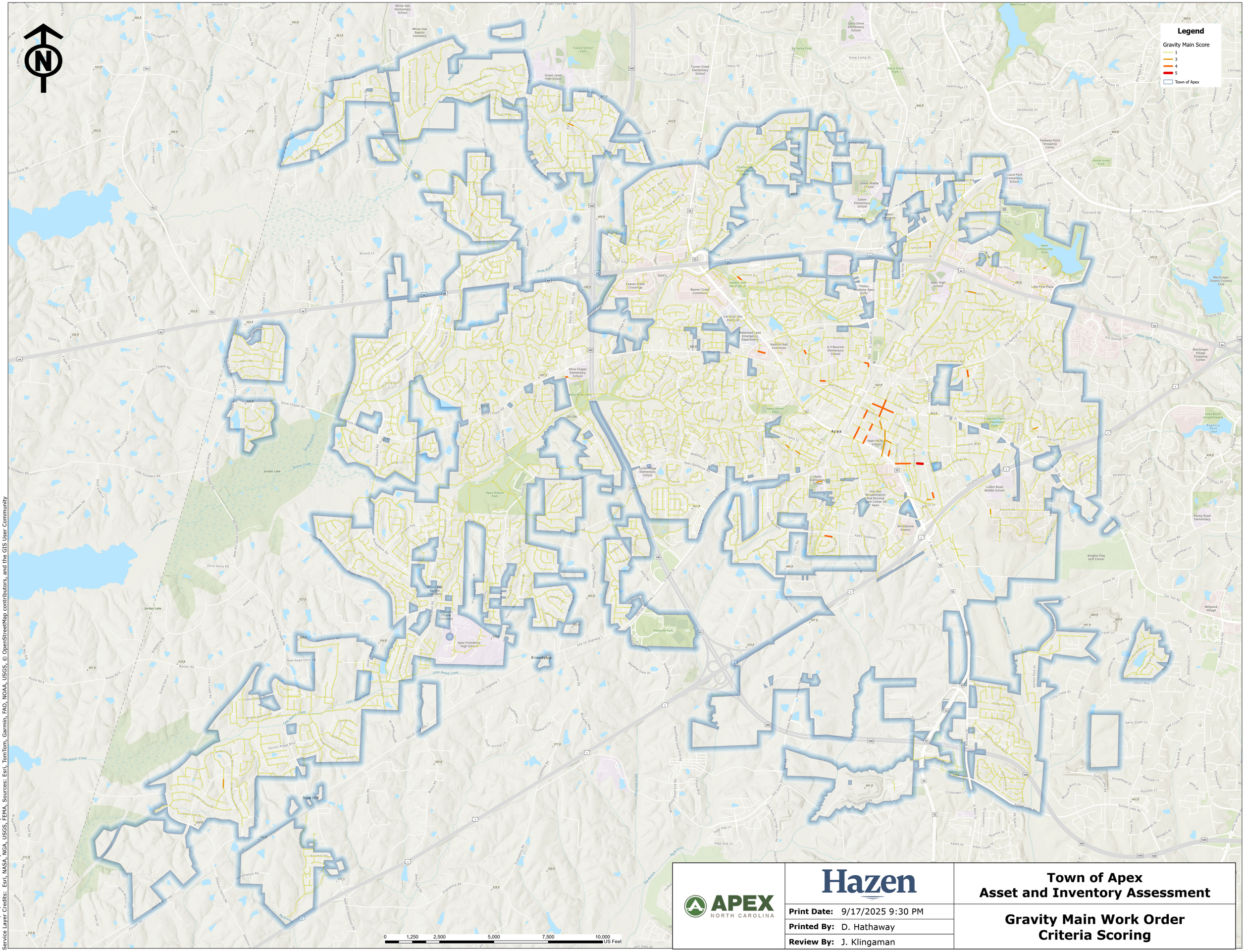

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Town of Apex
Asset and Inventory Assessment

Gravity Main Work Order Criteria Scoring

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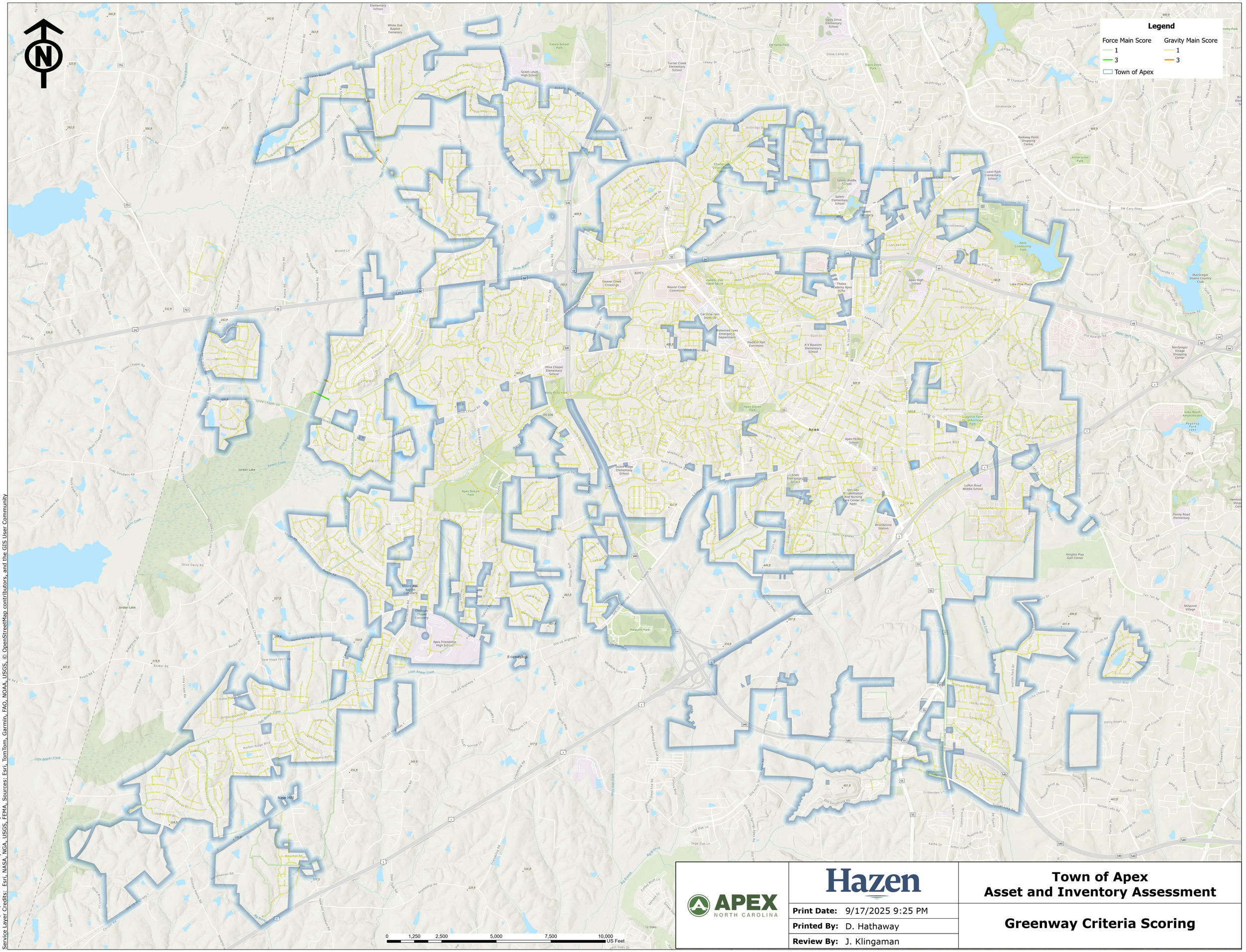

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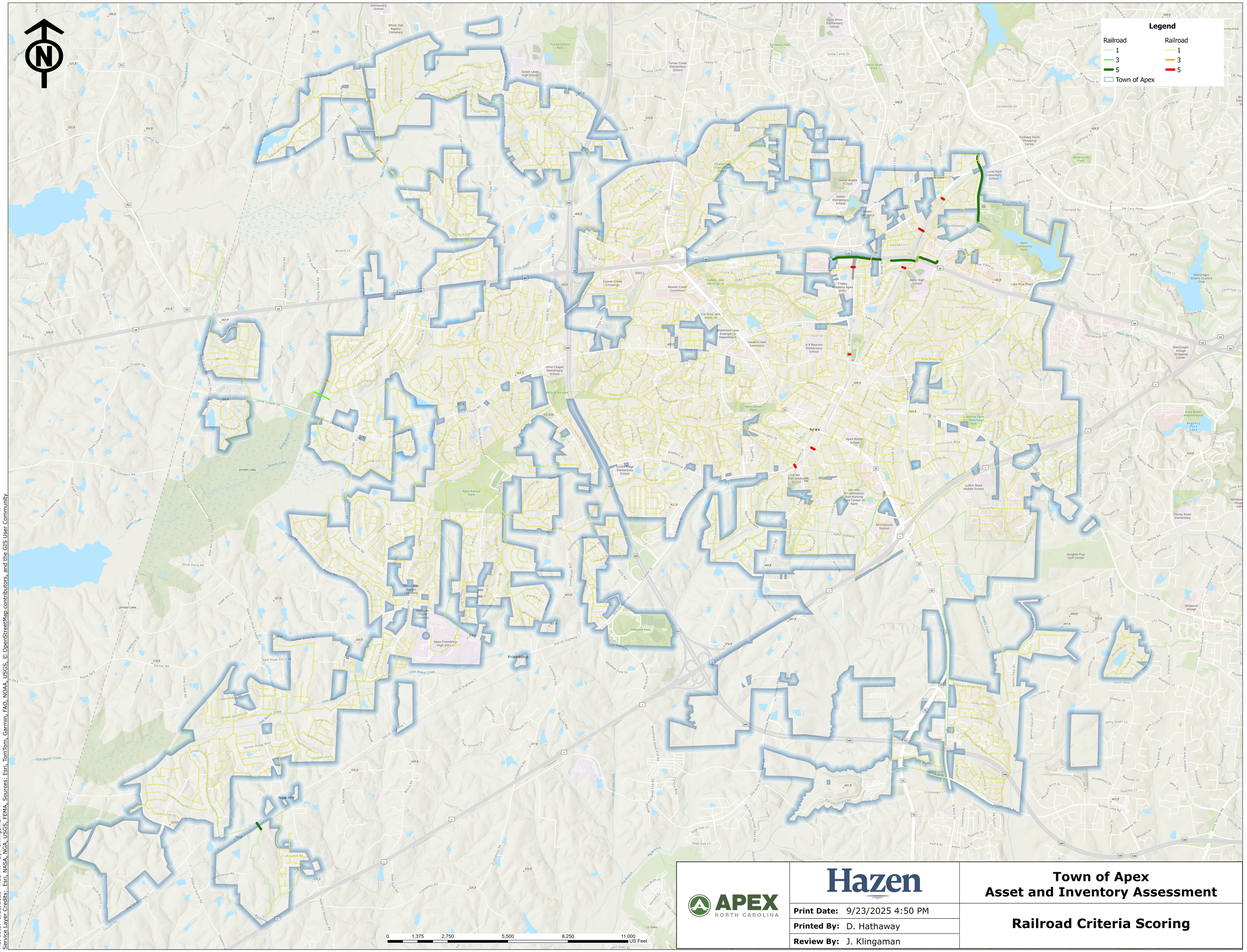
Town of Apex
Asset and Inventory Assessment

Greenway Criteria Scoring



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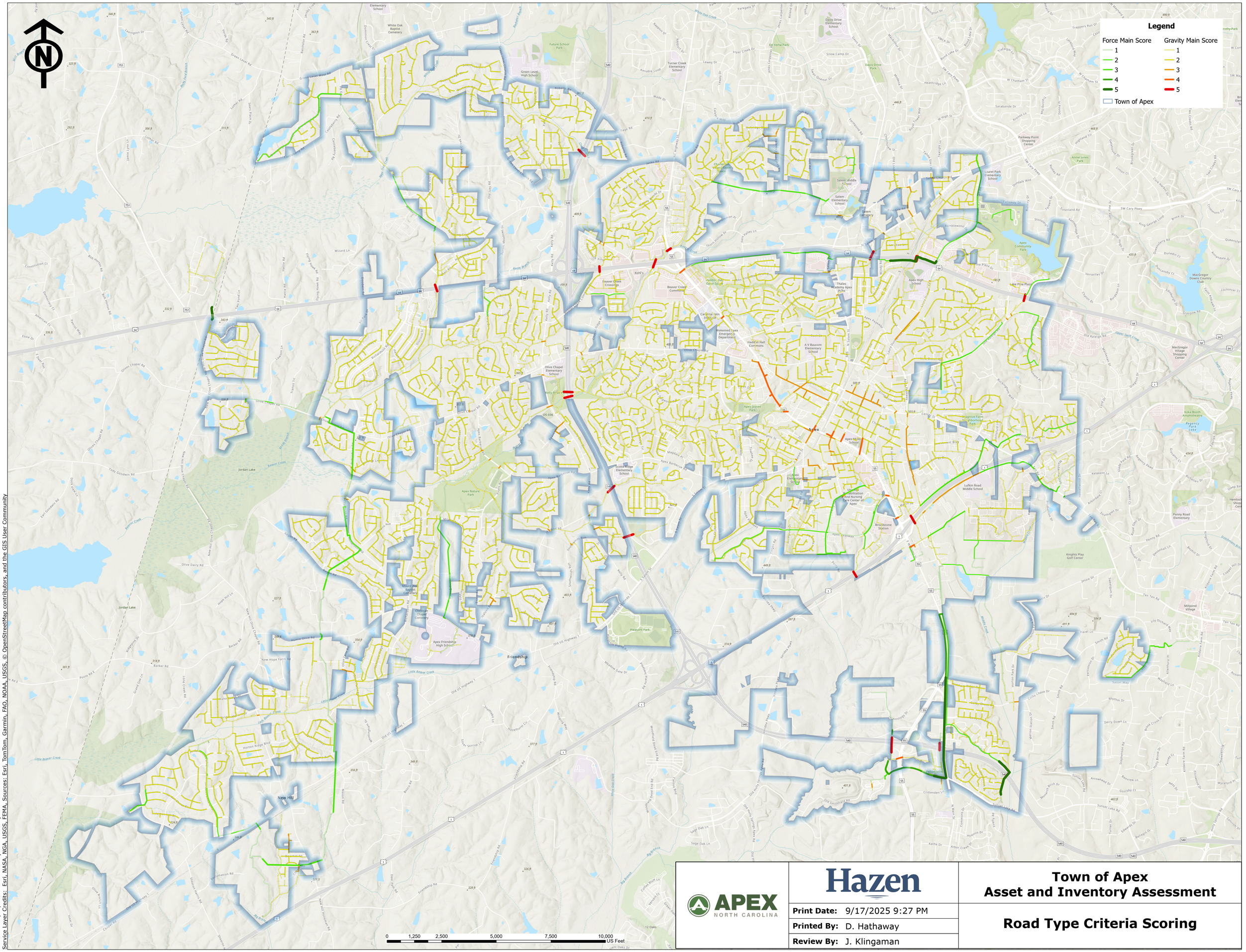
Review By:	J. Klingaman

Town of Apex
Asset and Inventory Assessment

Railroad Criteria Scoring



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Town of Apex
Asset and Inventory Assessment

Road Type Criteria Scoring

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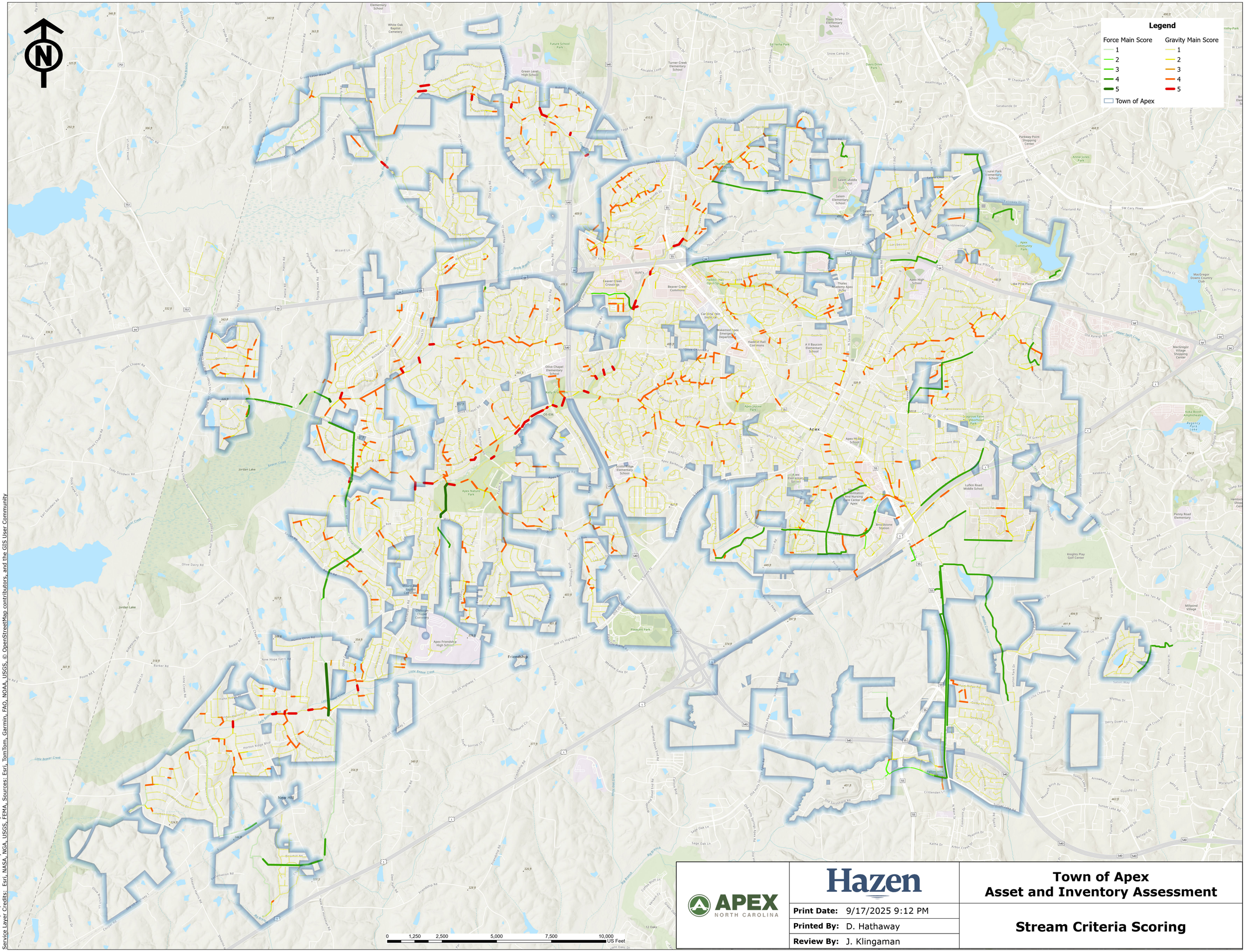

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Town of Apex
Asset and Inventory Assessment

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Review By: J. Klingaman

Stream Criteria Scoring

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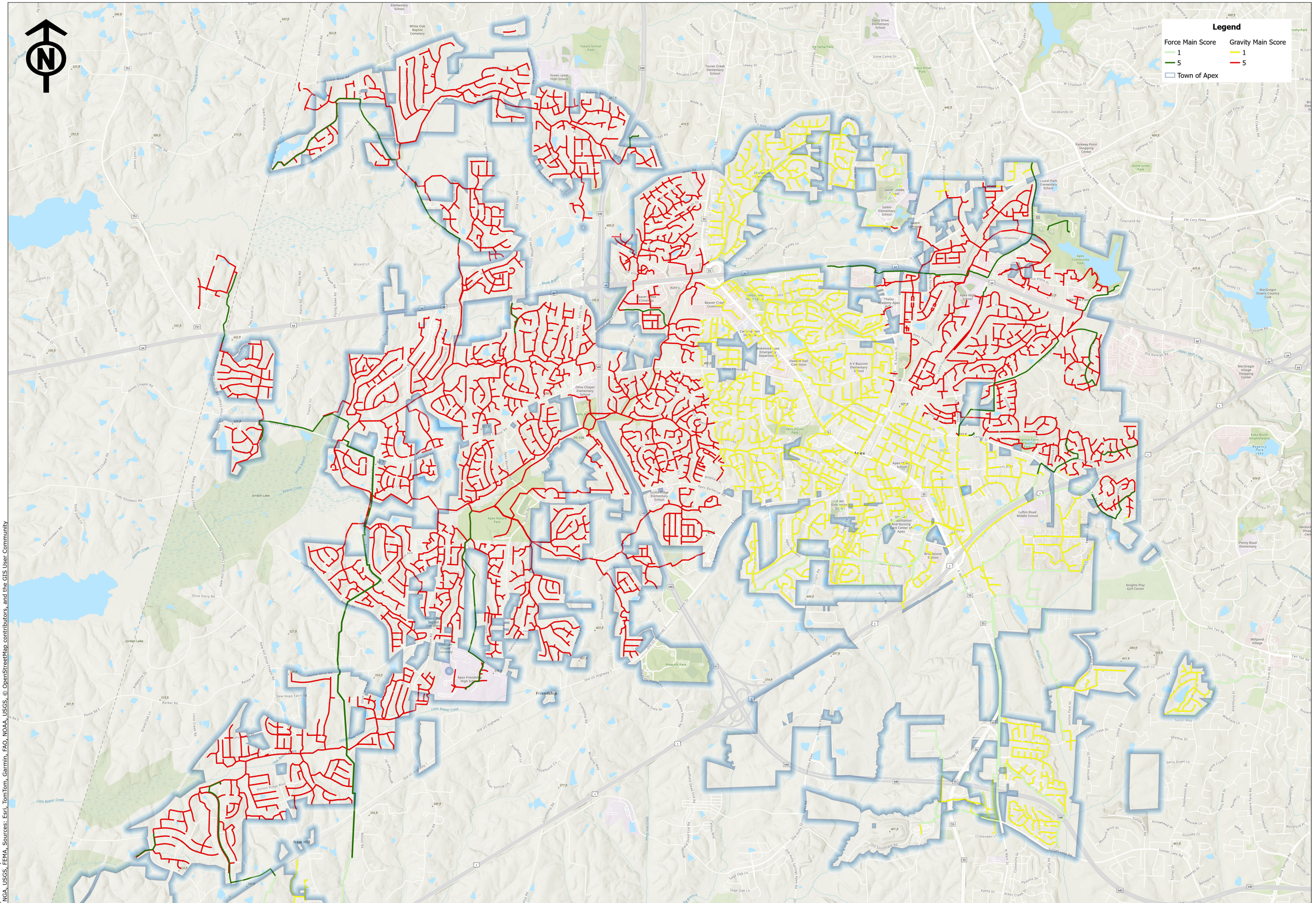

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Service Layer Credits: Esri, NASA, NGA, USGS, FEMA, Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

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Asset and Inventory Assessment

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Watershed Criteria Scoring

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Appendix C: SPARC Tool Documentation

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October 13, 2025



Spatial Risk Configuration Documentation

SPARC Version 1.3

Introduction

The Spatial Risk Configuration Tool was developed to streamline the creation of GIS-based risk models. It is accessible, leveraging widely used, standard software; user friendly, requiring minimal time and expertise to deploy; fast running, enabling near real-time model updates for collaboration; and self-documenting, expediting reporting and QC.

Hazen staff with experience in Asset Management are likely familiar with risk modeling to determine the likelihood of failure, consequence of failure, and overall risk for critical assets. This important service supports capital planning projects. Effective risk modeling requires customization to reflect available data, local geographic conditions, and specific priorities. However, custom-developed models can be cumbersome, making it time-consuming and costly to implement specific priorities, perform updates, and visualize changes. Revisiting outdated models after years of dormancy, data changes, staff turnover, and reevaluating arcane code from Python scripts or ModelBuilder workflows remains a challenge. The Spatial Risk Configuration (SPARC) Tool was developed to address these challenges by offering a streamlined and unified approach to risk modeling at Hazen.

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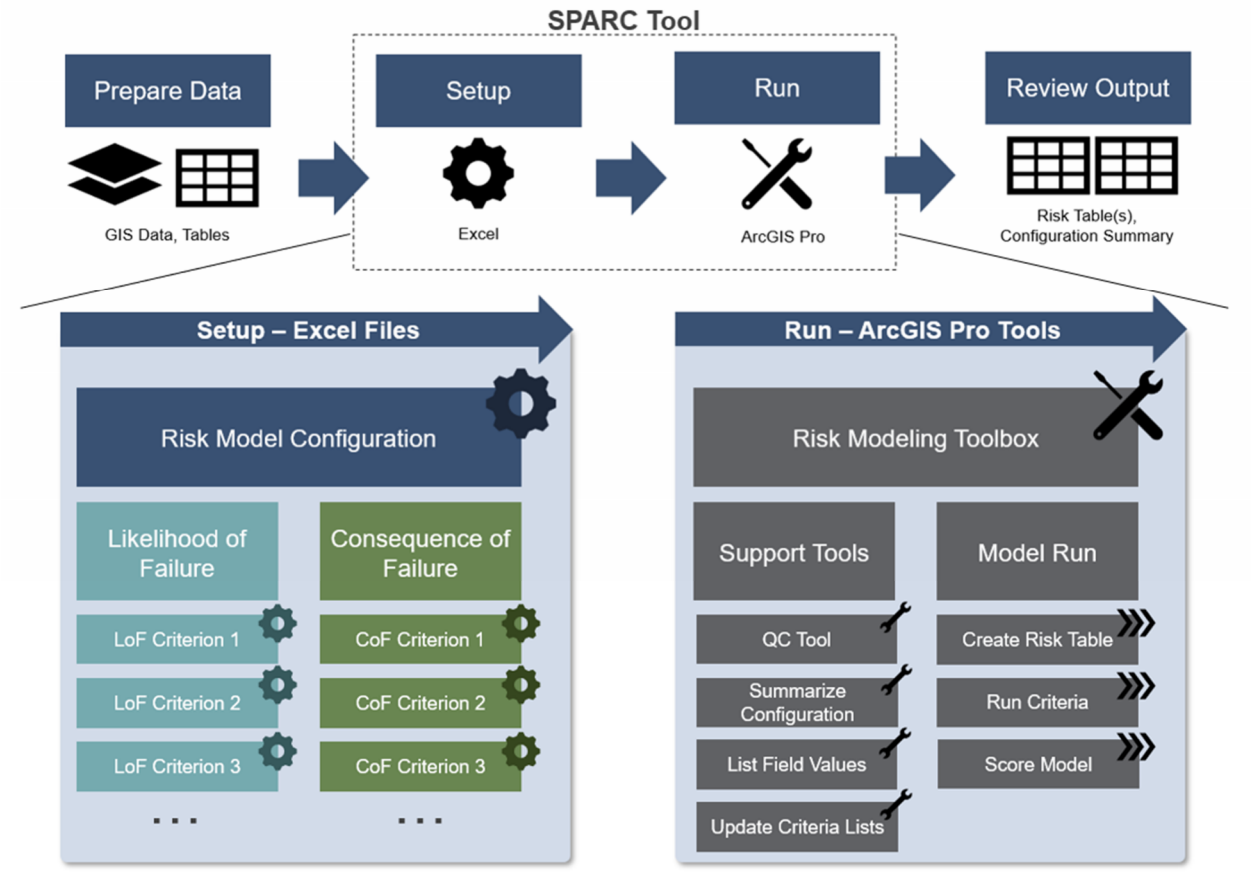
Tool Overview

The SPARC tool is a framework for developing GIS-based risk models using Excel and ArcGIS Pro. The structure is divided between the two software platforms into two distinct parts – a **setup** component and a **run** component. From Excel, users set the input data sources, choose from different configuration parameters, and set the scoring rules for likelihood of failure (LOF), consequence of failure (COF), and overall risk. From a toolbox in ArcGIS Pro, users run and score the model, storing the results in a table. The ArcGIS toolbox also includes support tools such as quality control (QC) analysis and configuration summarization to assist with validation and documentation.

Figure 1: Role of SPARC in risk modeling process



The tool is distributed as a .zip package that can be extracted to expose the toolbox, configuration files, templates, and supporting documentation. As a GIS-based tool, the data sources used by SPARC must be GIS layers or tables referenced by the configuration files. Model outputs are written to a user-specified table within a file geodatabase. This table can be joined to a GIS layer for data visualization or exported to other formats, such as Excel, for further analysis. The Risk Tables can be duplicated and modified to test alternative configurations or to preserve historical versions to track changes over time.

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Table 1: Formatting of Risk Table output from SPARC

Asset Identifier	LOF Criterion 1	LOF Criterion 2	…	COF Criterion 1	COF Criterion 2	…	LOF Score	COF Score	Risk Score
SSGMN10986	5	5	…	2	5	…	5	4	20
SSGMN10987	2	3	…	1	4	…	2.5	3	7.5
SSGMN10995	3	1	…	2	2	…	1.5	2.5	5
SSGMN10894	4	3	…	2	4	…	4	4	16
SSGMN10877	2	4	…	5	1	…	3	3.5	10.5

While SPARC is a complete tool, it is not comprehensive of every modeling scenario or data processing requirement. Many situations require data cleanup and preprocessing to prepare inputs for the tool, and more advanced analyses – such as hydraulic modeling – fall outside of SPARC's scope. In such cases, results from external analyses can be incorporated into SPARC as GIS layers or tables and scored using the same configuration framework as other inputs. Care should be taken to document external analyses – including data sources, methods, and outputs – to ensure that transparency and reproducibility of the entire modeling process are retained.

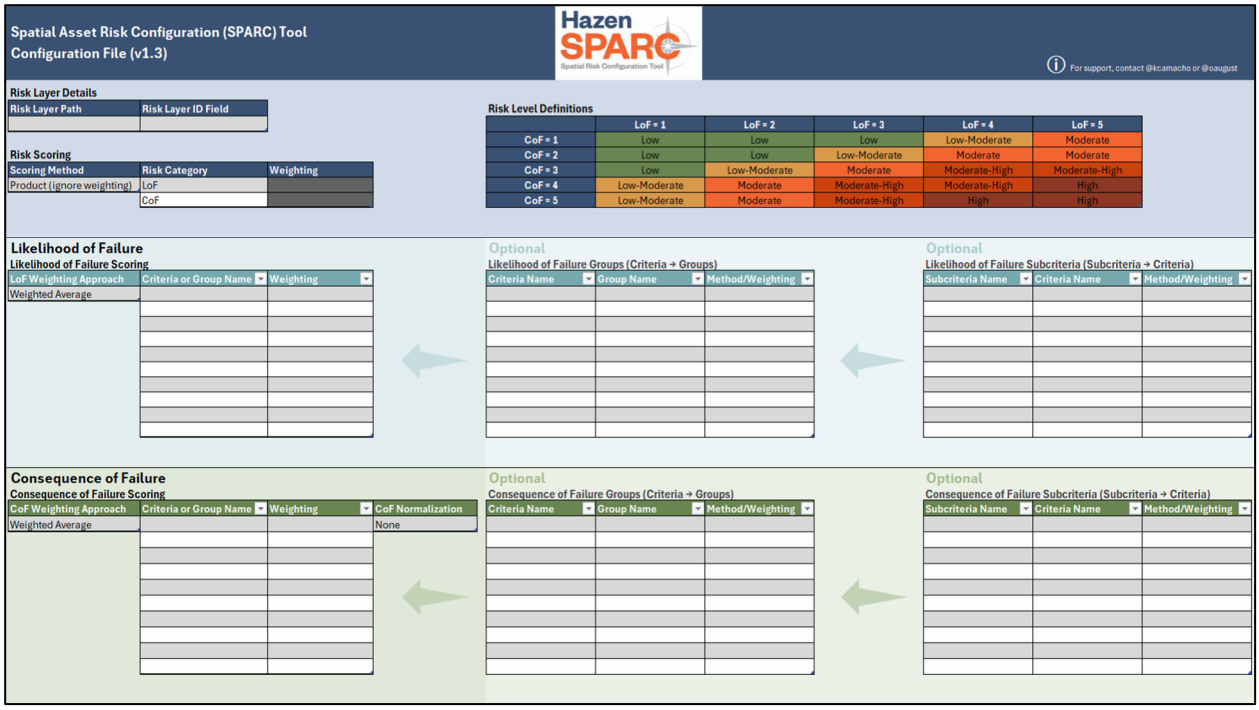
Tool Reference

This section serves as a reference guide for the configuration templates and toolbox used by the SPARC tool. The configuration templates fall under the **setup** component of SPARC and are used to create criteria rubrics and define scoring for the risk model. The toolbox tools are used to **run** the risk model.

Configuration File Reference

Risk Model Configuration.xlsx is found at the top level of the SPARC file structure. It is used to specify how to score/weigh the risk criteria to develop the LOF, COF, overall risk scores, and risk level. It is also where the Risk Layer (e.g., gravity mains, force mains) path and unique ID are defined for the model. It contains the highest-level configuration parameters for the risk model. In situations where different risk models share some of the same criteria scoring rules, it is possible to duplicate the Risk Model Configuration file and use the same file structure for the two models. This will not affect the ability of the risk models to run in parallel, although it may muddle the model setup.

Figure 2: Risk Model Configuration file



The table below summarizes the available methods for weighting, grouping, and normalizing criteria and risk scores. Across all parameters, user-defined weightings can be any positive number; the weightings are normalized, meaning 60/20/20 and 0.3/0.1/0.1 will produce the same scoring results.

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Table 2: Risk Model Configuration dropdown parameters

Parameter	Scoring Options	Description
Risk Scoring Method	• Product • Weighted Average	Determines the method for combining LOF and COF into a single risk score. “Product” multiplies the two and “weighted average” uses user-defined weightings to calculate risk score.
Risk Level Definitions	• Low • Mow-Moderate • Moderate • Moderate-High • High	Establishes the reported risk level for each combination of LOF and COF. This risk level will be added to the Risk Table as a field following the risk score field.
LOF/COF Weighting Approach	• Weighted Average • (Weighted Average + Max)/2	Provides options for criteria weighing for LOF/COF scoring. The alternative weighting method ensures that any individually high criterion score will contribute significantly to the overall score.
COF Normalization	• None • Min-Max • Percentile	Provides normalization options for skewed COF score distributions.
Grouping Method	• Highest • Priority • Mean • Weighted Average	Enables different approaches for grouping criteria or subcriteria. The “highest” method uses the highest score of all the criteria in the group. “Priority” will take the score from priority 1 if it is not null, otherwise it will take the score from priority 2, and so on. “Mean” uses the mean score of all the criteria in the group. To use the “weighted average” method, type the weight for each criterion into the Method/Weighting column rather than using the dropdown menu.

Criteria Template Reference

Criteria templates can be accessed within the tool files under **Templates > Criteria Rubrics**, and are organized into four categories: **Categorical**, **Numeric**, **Distance-Based**, and **Special Cases**. Use this section to determine which template best fits the scoring needs of your project’s criteria.

Table 3: Criteria templates

	Template	Use when scoring based on…	Example
Categorical	Categorical	a specific **non-numeric field** located in the Risk Layer	Pipe Material - score based on the material type of each asset
	Categorical ID Join	a **non-numeric field** from a **table** that can be joined to the Risk Layer	Categorical Inspection Data (good, fair, bad) - Join a table with categorical inspection results by asset ID
	Categorical Spatial Join	a **non-numeric field** from a **separate layer** that can be spatially joined (i.e., intersected) with the Risk Layer	Easements - intersect with easement layer and score based on easement type
	Filtered Categorical Spatial Join	a **non-numeric field** from a **separate layer** that can be spatially joined (i.e., intersected) with a **filtered subset** of the Risk Layer	Soil Corrosivity - intersect soil corrosivity layers with only metallic pipes

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	Template	Use when scoring based on…	Example
Distance	Distance	the **distance** from a **separate layer** to the Risk Layer	Proximity to Waterbody - score based on the distance to the waterbody features
	Distance + Numeric	the **distance** and **numeric field** in a **separate layer** to the Risk Layer	Numeric Road Type (200, 400, 810) - score based on distance and road type value
	Distance + Categorical	the **distance** and **non-numeric field** in a **separate layer** to the Risk Layer	Building Type (Hospital, Municipal, Commercial) - create scoring rules based on distance and building type
	Count within Distance	the **count of features** from a **separate layer** within a specified **distance** to the Risk Layer	# of SSOs - join with point layer of SSOs and count the number of SSOs within a certain distance
Numeric	Numeric	a specific **numeric field** located in the Risk Layer	Pipe Diameter - score based on the values in the diameter field
	Numeric ID Join	a **numeric field** from a **table** that can be joined to the Risk Layer	Hydraulic modeling results table - join the table with results (e.g., fire flow, pressure, headloss) to the Risk Layer based on asset ID
	Numeric Spatial Join	a **numeric field** from a **separate layer** that can be spatially joined (i.e., intersected) with the Risk Layer	Hydraulic modeling results layer - intersect the hydraulic modeling layer with results (e.g., fire flow, pressure, headloss) to the Risk Layer based on a search distance
Special Cases	Remaining Useful Life	their **material** and **installation date** (or liner material and installation date)	Remaining Useful Life
	PACP Condition	the NASSCO PACP Quick Rating scores from CCTV data	PACP Condition

How to Use Criteria Rubrics

Each criterion is configured with its own criteria rubric based on one of the above templates. Criteria rubrics should be copied and pasted into either the "Likelihood of Failure" or "Consequence of Failure" folder, depending on which scoring they apply to, and then populated to reflect how the criteria should be scored. It is recommended to update the names of the criteria files to reflect the criteria they represent; however, **DO NOT alter criteria folder names, tab names, or table names** as these are used by the script to identify what and how to run.

Toolbox Reference

The toolbox **Hazen SPARC Toolbox.atbx** is stored at the top level of the SPARC file structure. Add the toolbox from an ArcGIS Pro project to access its tools. Below is a summary and guide on the use of the various toolbox tools. The toolbox is divided into two toolsets: **Model Tools**, which contains helpers used to aid in the configuration of a risk model, and **Model Run**, which is used to run a configured risk model. When running any of the tools below, remember to close the configuration files in order to avoid file read errors.

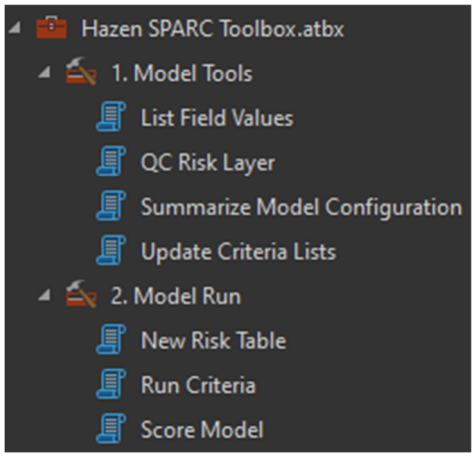


Table 4: Hazen SPARC Toolbox summary

Toolset	Tool Name	Inputs	Output
Model Tools	**List Field Values**	• GIS Layer • Field Name	Lists all unique field values in geoprocessing messages.
	Run QC	• Risk Model Configuration File • Risk Table	Writes QC findings to geoprocessing messages. A detailed warning will be raised if any issues are found.
	Summarize Model Configuration	• Risk Model Configuration File • Output Folder Location • Output File Name • Overwrite Existing File	Writes model configuration summary to Excel file at the user defined name and location.
	Update Criteria Templates	• Risk Model Configuration File	Updated Risk Model Configuration file with dropdowns to select criteria names.
Model Run	**New Risk Table**	• Risk Model Configuration File • Output Risk Table	Creates a new Risk Table in user defined location.
	Run Criteria	• Risk Model Configuration File • Select LOF Criteria • Select COF Criteria • Add or Update Source of Score Field • Risk Table	Performs criteria analyses and populates criteria scores and (optionally) source of score in fields in the selected Risk Table.
	Score Model	• Risk Model Configuration File • Select Scoring • Add Intermediate Group/Category Scores • Risk Table	Calculates risk scores and populates fields in the selected Risk Table.

List Field Values

```
Querying values in field PRIM_OCC...
Unique value list:
Aviation; Colleges/Universities; Emergency Response; Entertainment and Recreation; Food/Drugs/Chemicals; General
Services; Ground; Heavy; Hospital; Institutional Dormitory; Light; Manufactured Home; Medical Office/Clinic;
Multi - Family Dwelling; None; Nursing Home; Other Educational Buildings; Personal and Repair Services; Pre-K -
12 Schools; Professional/Technical Services; Religious; Retail Trade; Single Family Dwelling; Temporary Lodging;
Theaters; Unclassified; Veterinary/Pet ; Wholesale Trade
```

Description: For a given GIS layer, list all unique values of the selected field. The output values can be viewed in the geoprocessing details.

Use: This helper is useful when developing a rubric for a categorical criterion. For attributes that use a domain or contain many unique values, it can be cumbersome to extract all the different values manually and sort through them to develop the categorical scoring rules. With this tool, the values are extracted automatically and can be copied over to the rubric and sorted to define scoring buckets.

Run QC

```
Reading configuration file...
Risk layer path: C:\Users\kcam
Spatial Reference: NAD_1983_St
Datum: D_North_American_1983
(✓) No duplicate IDs found.
(✓) No geometry issues found.
QC Complete.
```

```
The following risk table fields are not sourced from a configuration
The following risk table fields contain NULL values: pacp_scoring, di
Some configured scores are absent from the risk table.
  The following score(s) are missing from field <customer_type>: [5]
```

Description: Perform basic QC of the risk layer or model results.

Use: One of the requirements of SPARC is that the risk layer contains an attribute with a unique asset identifier for each asset. Another assumption of the tool is that its features have valid geometry for spatial join operations. Before running a risk model, use the Run QC tool with the "QC Risk Layer" to ensure that these assumptions are met and the risk layer will run without error. After running the risk model and scoring, use the "QC Results" option to perform basic data checks on the model results.

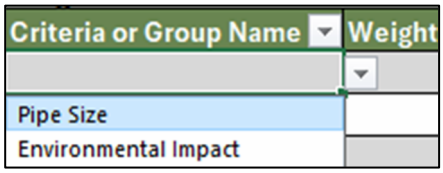
Summarize Model Configuration

Criteria	Risk Category	Data Source	1	2	
PACP QSR	Likelihood of Failure	SewerGravityMain, SewerGravityMain	0 <= Condition Score <= 1	1 < Condition Score <= 2	2 < Condi
Remaining Useful Life	Likelihood of Failure	SewerGravityMain	0.9 < Percent life remaining	0.72 < Percent life remaining <= 0.9	0.52 < Per
Remaining Useful Life- Liner	Likelihood of Failure	SewerGravityMain	0.6 < Percent life remaining	0.48 < Percent life remaining <= 0.6	0.3467 < P
Building	Consequence of Failure	SewerGravityMain, buildingfootprint_buildingfootprint	15 <= distance	10 <= distance < 15	5 <= dista
Diameter	Consequence of Failure	SewerGravityMain	0 <= diameter < 8		8 <= diam
Hospital & Emergency Facilities	Consequence of Failure	SewerGravityMain, HealthMedical	300 <= distance	200 <= distance < 300	100 <= dis
Malls and Shopping Centers	Consequence of Failure	SewerGravityMain, Parcels_MallsShoppingCenters	250 <= distance, stcd = 1500;1520	100 <= distance < 250, stcd = 1500;1520	25 <= dist
Pond	Consequence of Failure	SewerGravityMain, waterbody_waterbodies_1	250 < distance, 1 <= subtype < 2	100 < distance <= 250, 1 <= subtype < 2	distance
Railroad	Consequence of Failure	SewerGravityMain, North_American_Rail_Network_Lines	50 <= distance		
Road Type	Consequence of Failure	SewerGravityMain, street_streets			distance
Schools	Consequence of Failure	SewerGravityMain, education_education	150 < distance	75 < distance <= 150	50 < dista
Sewer Depth	Consequence of Failure	SewerGravityMain	RA_Depth < 6	6 <= RA_Depth < 8	8 <= RA_D

Description: Read the LOF and COF criteria rubric files and generate a summary Excel file documenting the LOF/COF configuration.

Use: The configurations for a risk model developed with the SPARC tool are distributed across numerous criteria rubrics. This tool takes parameters from the rubric files and compiles them into a single table for review or documentation purposes. The template for this table is stored under **Templates > Configuration Summary.xlsx**, which can be modified to meet the style needs of the project.

Update Criteria Lists



Description: Read the LOF and COF criteria from the configuration folders to get the names and aliases of all criteria. Update the configuration file with these names and aliases.

Use: In the Risk Model Configuration.xlsx file, the user sets the scoring methods and weightings for the various criteria. Dropdown lists are used to select criteria names without risk of misspelling or other data entry errors. This tool is necessary for populating the dropdowns.

New Risk Table

OBJECTID *	Asset Identifier
3	SSGMN100003
10	SSGMN100010
15	SSGMN100015
21	SSGMN100021

Description: Create a new Risk Table to store risk model results.

Use: The SPARC risk modeling approach uses the Risk Table to store its model outputs, including all criteria and risk scores. The initial table produced by this tool will contain only one field with the unique asset identifiers present in the risk layer. As the following Run Criteria and Score Model tools are run, other fields will be added to the Risk Table containing these results.

Run Criteria

Remaining Useful Life	Gravity Pipe Size	Environmental Impact
2	1	1
2	1	1
2	1	1
2	1	1
5	1	1

Description: Select any number of criteria to run. Each criterion will run by following the settings in its configuration file. Outputs are stored/updated in their unique fields in the chosen Risk Table. If the option to "Add or Update Source of Score Field" is selected, the final value used to determine the score for the criteria will be added to the Risk Table as well.

Use: Only run this tool on criteria with completed criteria rubrics. This tool calculates criteria scores and populates the Risk Table with results. The option to "Add or Update Source of Score Field" can be used to add an additional field for each criterion that can be used to assist with QC of the resulting score. How these fields are populated will vary depending on the criteria types being run. As criteria rubrics are updated, this tool can be used to rerun the criteria and overwrite their scores in the Risk Table.

Score Model

LoF Score	CoF Score	Risk Score	Risk Level
4	3.5	14	Moderate-High
4	3.5	14	Moderate-High
4	3.5	14	Moderate-High
3	4	12	Moderate-High

Description: Score likelihood of failure and consequence of failure based on parameters set in the Risk Model Configuration File. This can only be run after the "Run Criteria" tool has populated the Risk Table with criteria scorings.

Use: Once criteria have been scored, use this tool to calculate and populate overall Likelihood of Failure, Consequence of Failure, Risk Score, and/or Risk Level. If your configuration file includes criteria grouping, you can optionally select “Add Intermediate Group/Category Scores” to add calculated group scores to the table in addition to the risk scores.

Hazen

Model Setup and Run

This section details the steps required to develop a risk framework, populate the necessary tables, assign COF and LOF scores, and visualize the resulting data.

Populate Criteria Rubric Templates

Once the criteria that will be used in the risk model have been selected, the criteria rubric templates can be populated. One rubric will be created for each criterion in the model, and that template will be stored in the LOF or COF folder of the risk model project folder, whichever is applicable.

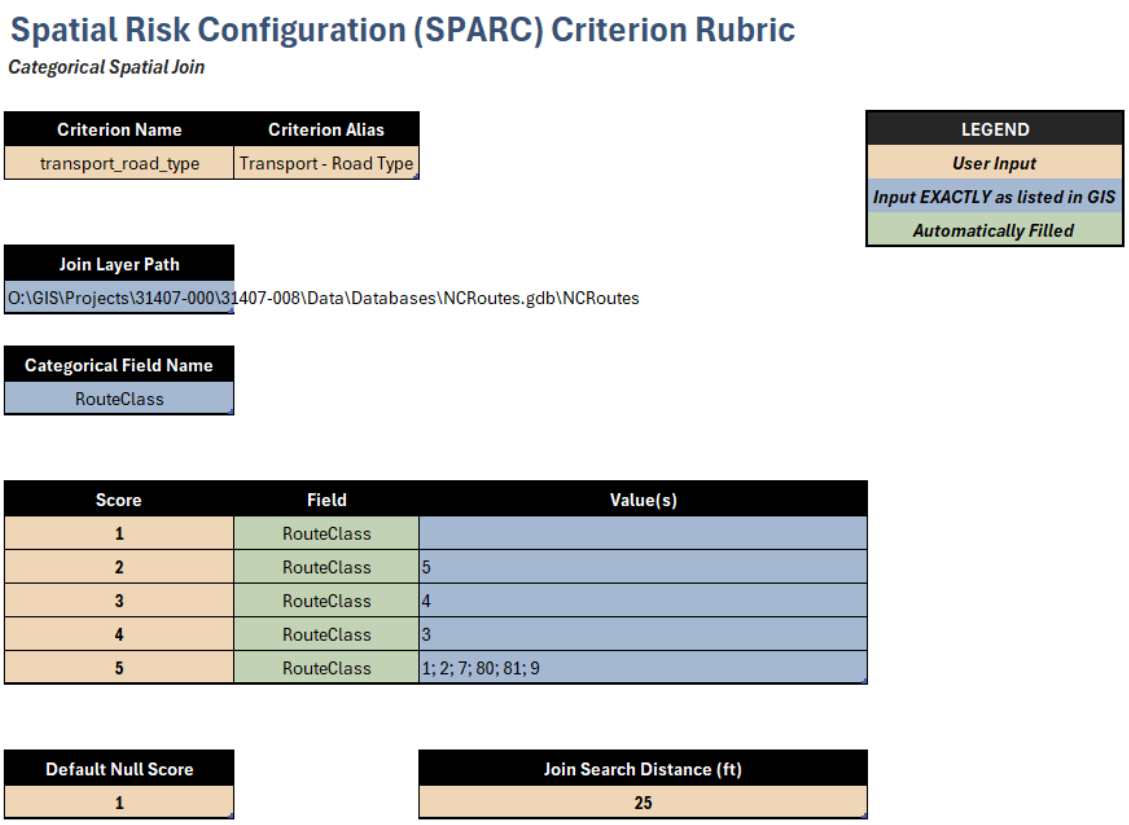
For each criterion:

1. Create a duplicate of the selected template (e.g. Numeric, Distance ID Join). Move this duplicate template into the COF or LOF folder, whichever is applicable.

2. Populate the template with the criteria field name, scores, and corresponding criteria field value(s). Populating the default null score is optional. Leaving it blank will result in assets that cannot be evaluated having a NULL score. Depending on the risk modeling approach, this may or may not be acceptable.

3. Most templates also require the user to define the location of another layer (e.g. if we are doing a Distance criteria, we would define the GIS layer location of the attributes to which distance is being measured) or additional field names (e.g. if we are doing a Distance + Numeric Criteria, we would define the conditional field name). Populate all available fields to ensure that the model can run as designed.

Figure 3: Example Criterion Rubric Template for Transportation - Road Type



Spatial Risk Configuration (SPARC) Criterion Rubric

Categorical Spatial Join

Criterion Name	Criterion Alias
transport_road_type	Transport - Road Type

LEGEND
User Input
Input EXACTLY as listed in GIS
Automatically Filled

Join Layer Path
O:\GIS\Projects\31407-000\31407-008\Data\Databases\NCRoutes.gdb\NCRoutes

Categorical Field Name
RouteClass

Score	Field	Value(s)
1	RouteClass	
2	RouteClass	5
3	RouteClass	4
4	RouteClass	3
5	RouteClass	1; 2; 7; 80; 81; 9

Default Null Score
1

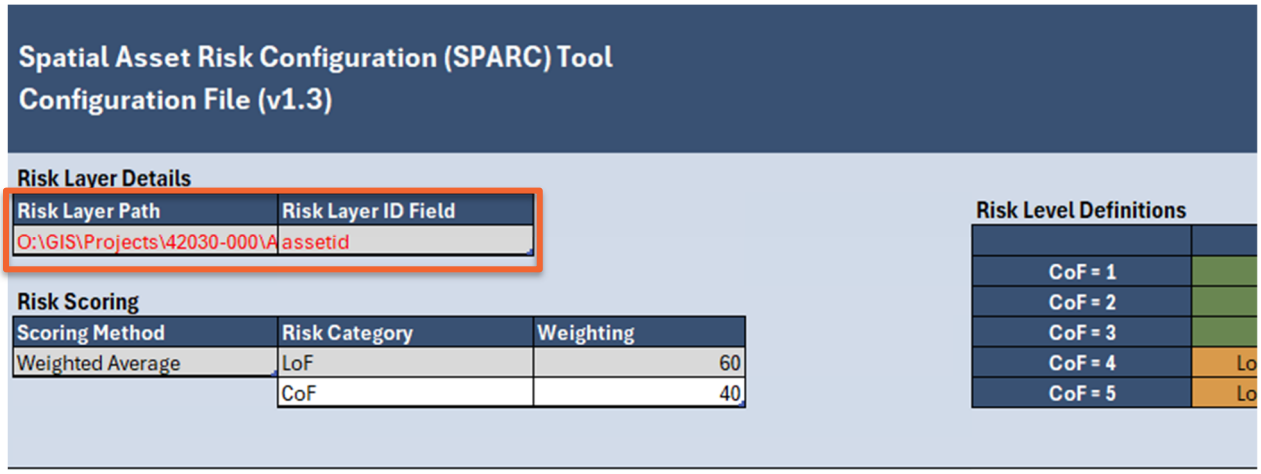
Join Search Distance (ft)
25

Populate Configuration File

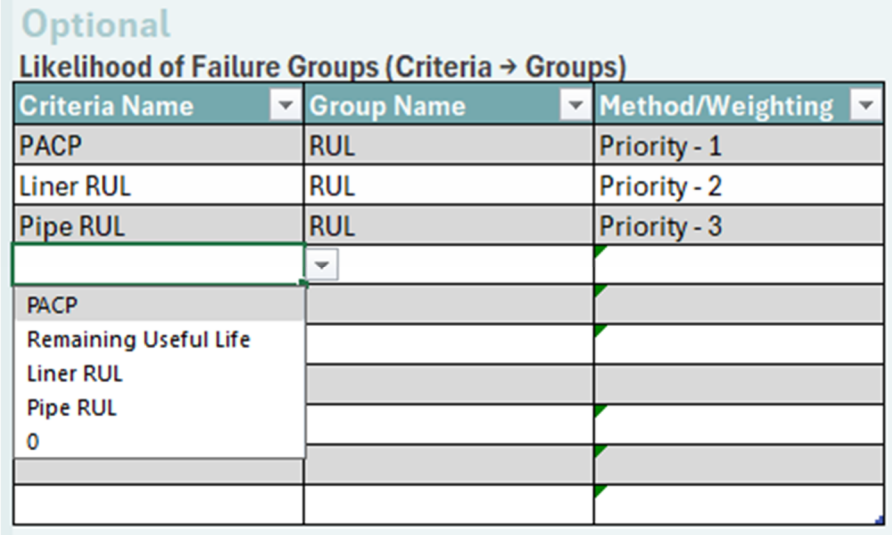
Once all criteria rubric templates have been populated and the risk framework has been developed, the Configuration File can be populated.

1. Open **Risk Model Configuration.xlsx** (feel free to rename this file) and input the path to the risk layer and the ID field. Save and close.

Figure 4: Risk layer details within Configuration File

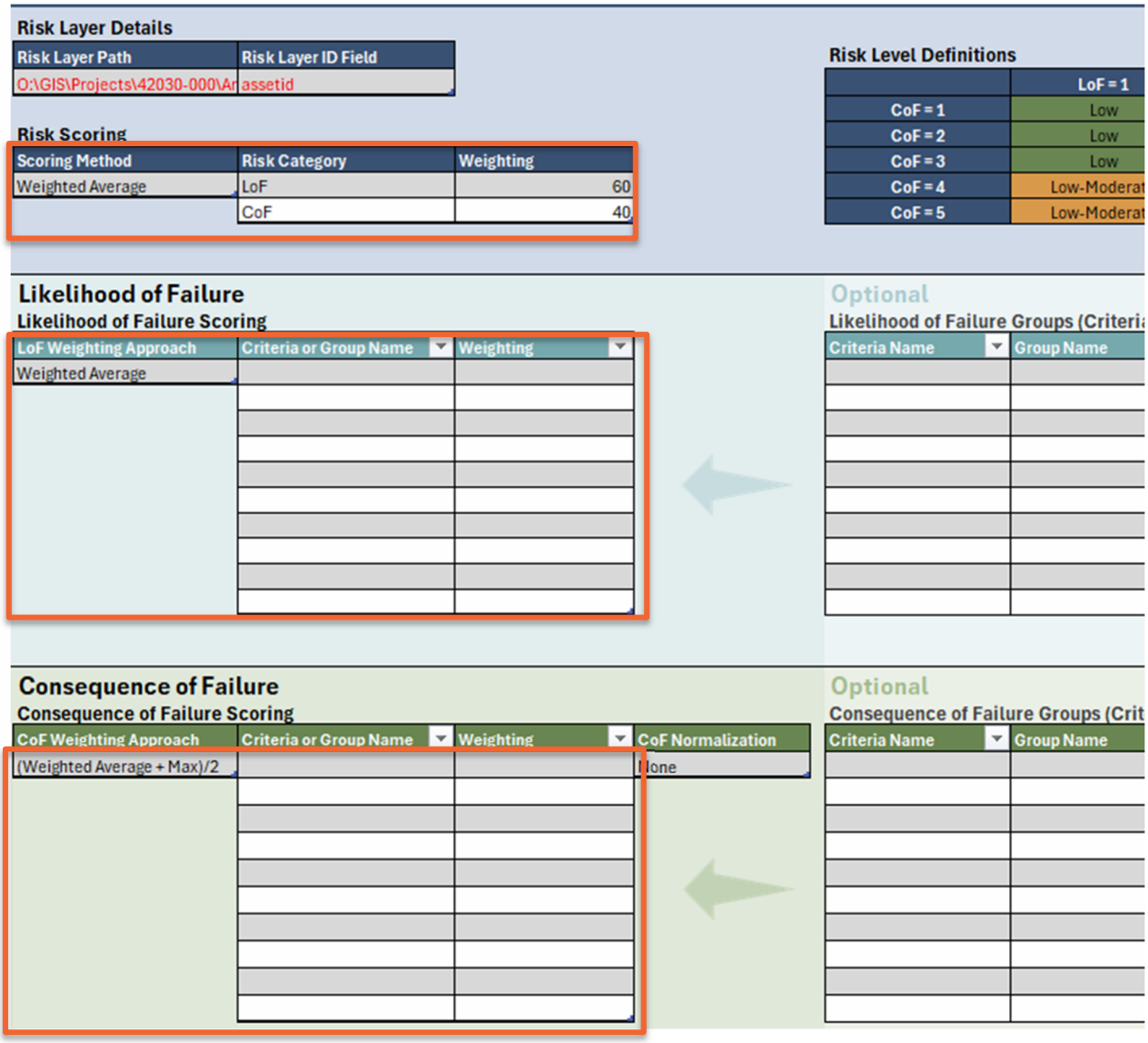


2. In ArcGIS Pro, run the **Update Criteria Lists** tool from the Hazen SPARC toolbox. Use the Risk Model Configuration file as the input. This will add dropdowns to the configuration file for all the criteria saved in the Likelihood of Failure and Consequence of Failure folders.



3. Fill out the parameters in the Risk Model Configuration file for Risk Scoring, Risk Level Definitions, COF/LOF Weighting Approach, Likelihood of Failure Scoring, and Consequence of Failure Scoring. It is acceptable if the configuration file is partially completed; an incomplete Risk Model Configuration file can still run criteria scoring and generate risk scores.

Figure 5: LOF, COF, and Risk Scoring within Configuration File

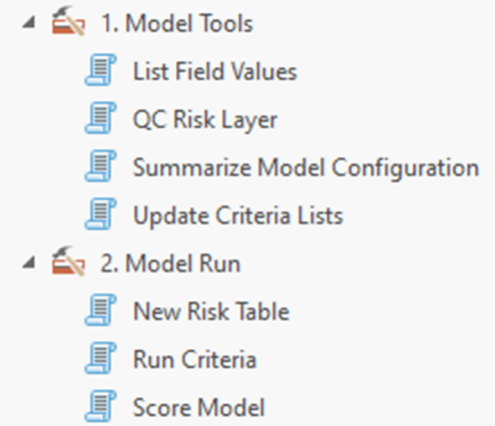


4. Where required by the model design, create criteria groups by selecting criteria, assigning a group name, and selecting a Method/Weighting approach. If a second level of grouping is required, subcriteria can be created as well following a similar method.

Run Model

Scoring the model is completed within ArcGIS Pro using the **Hazen SPARC Toolbox**.

Figure 6: Risk Model Toolbox



To fully score the model for the first time – including LOF, COF, and overall risk scores – all three of the **Model Run** tools must be executed. However, if you are in the process of developing the framework and are only interested in reviewing score distributions for different criteria, you will not need to run the "Score Model" tool.

1. **New Risk Table**

    - Click the folder next to Risk Model Configuration File to specify the file path of the Configuration File, or pull it in from the Contents pane.

    - Click the folder next to Risk Table to specify the file path and name of the Risk Table. The specified output location should be a file geodatabase.

    - Click Run.

2. **Run Criteria**

    - Click the folder next to Risk Model Configuration File to specify the file path of the Configuration File, or drag it in from the Contents pane.

    - Click the dropdown arrow next to Select LOF Criteria or Select COF Criteria to select the criteria to calculate. Any number of these criteria can be run at the same time.

        - Select the checkbox next to the Search bar in the pop-up window to select all criteria in the dropdown menu.

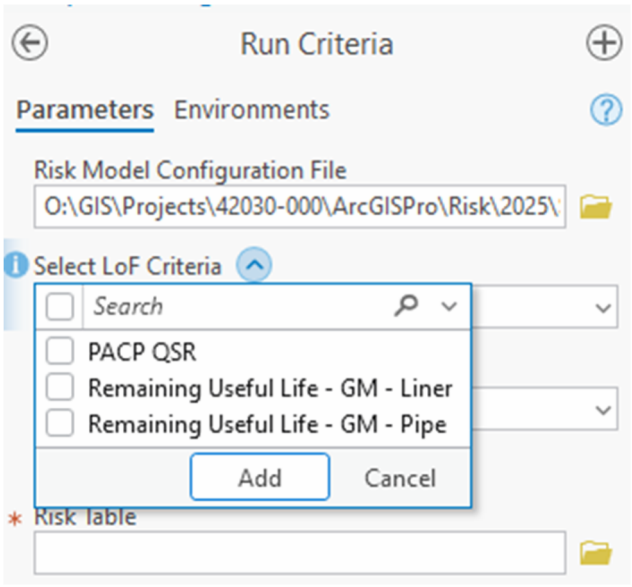
    - If desired, check the "Add or Update Source of Score Field" to add additional criteria scoring information to the Risk Table.

        - This adds or updates the data fields that provide context as to how each criterion was calculated. For example, the "Diameter Source of Score" field would be the

diameter of the asset, and the "Diameter" column would be the 1-5 risk score determined using that Source of Score.

- Click the folder next to the Risk Table to specify the file path of the Risk Table, or drag it in from the contents pane.
- Click Run.

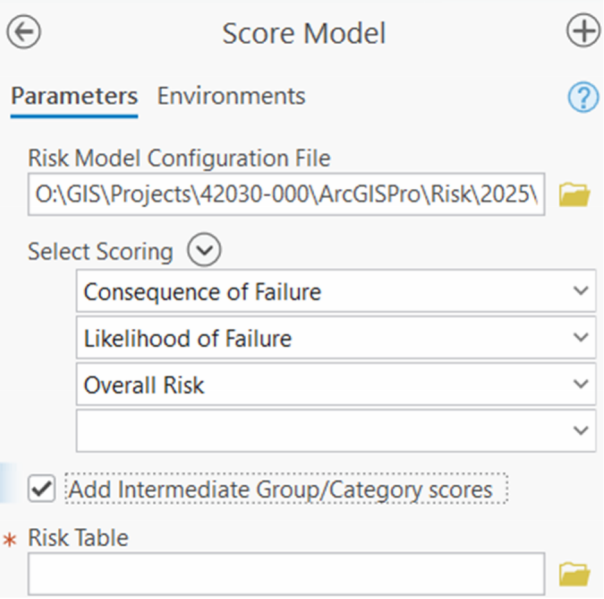
Figure 7: Run Criteria configuration within the risk model



3. Score Model

- Click the folder next to Risk Model Configuration File to specify the file path of the Configuration File, or pull it in from the Contents pane.
- Click the dropdown arrow next to Select Scoring to select what scoring should be calculated: LOF, COF, and/or Overall Risk.
- Optionally, check the box to "Add Intermediate Group/Category Scores".
    - This option adds fields to the Risk Table for the intermediate criteria/groups created when calculating the risk scores. Check this option if the intermediate scores are required for QC or reporting.
- Click the folder next to the Risk Table to specify the file path of the Risk Table, or drag it in from the Contents pane.
- Click Run.

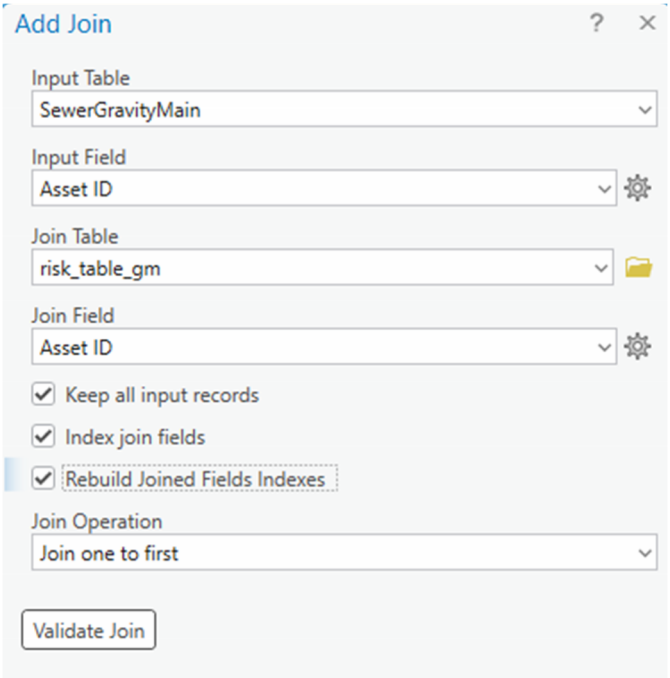
Figure 8: Score Model configuration within the risk model



Visualize Results

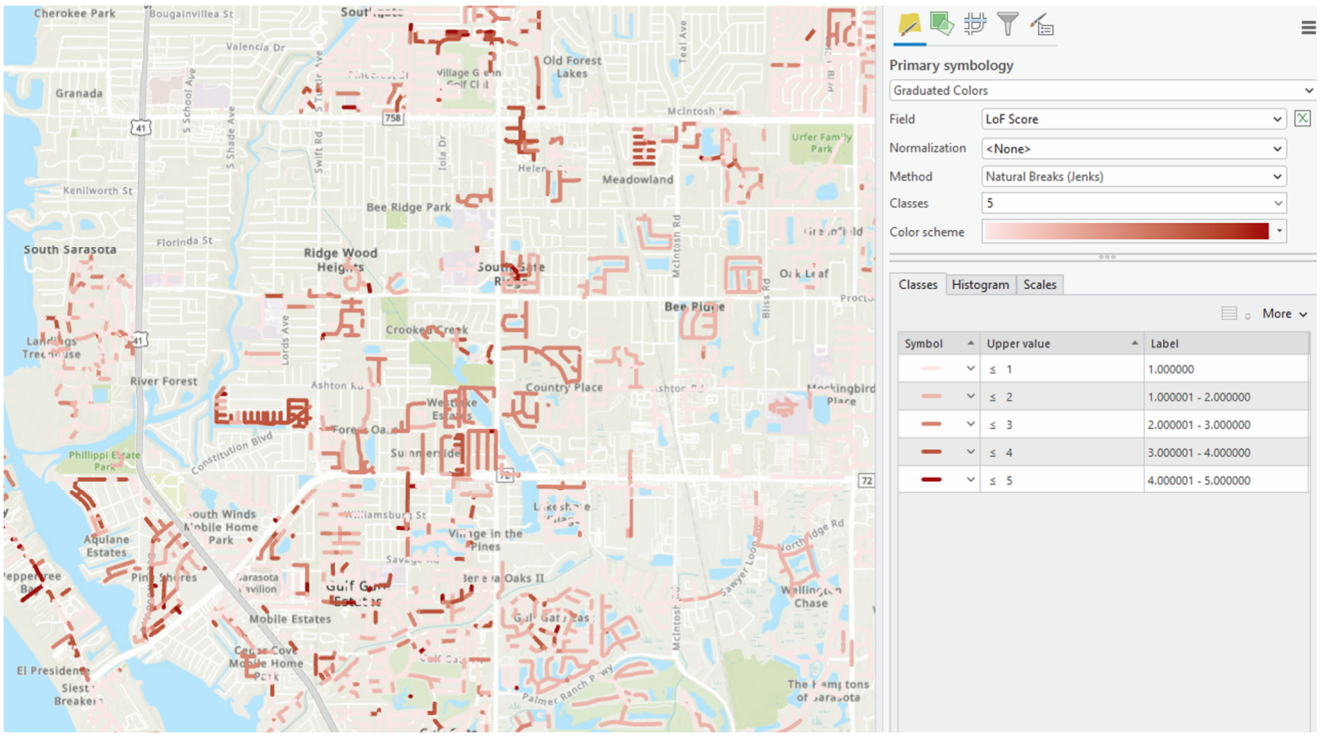
After the LOF, COF, and Overall Risk scoring tools have ran, these results can be joined back to the asset layer(s) to visualize the results. Joining the asset layer to the Risk Table to which the tool outputs are written ensures that the joined table will automatically update to reflect any updates to the Risk Table.

Figure 9: Join risk layer to Risk Table



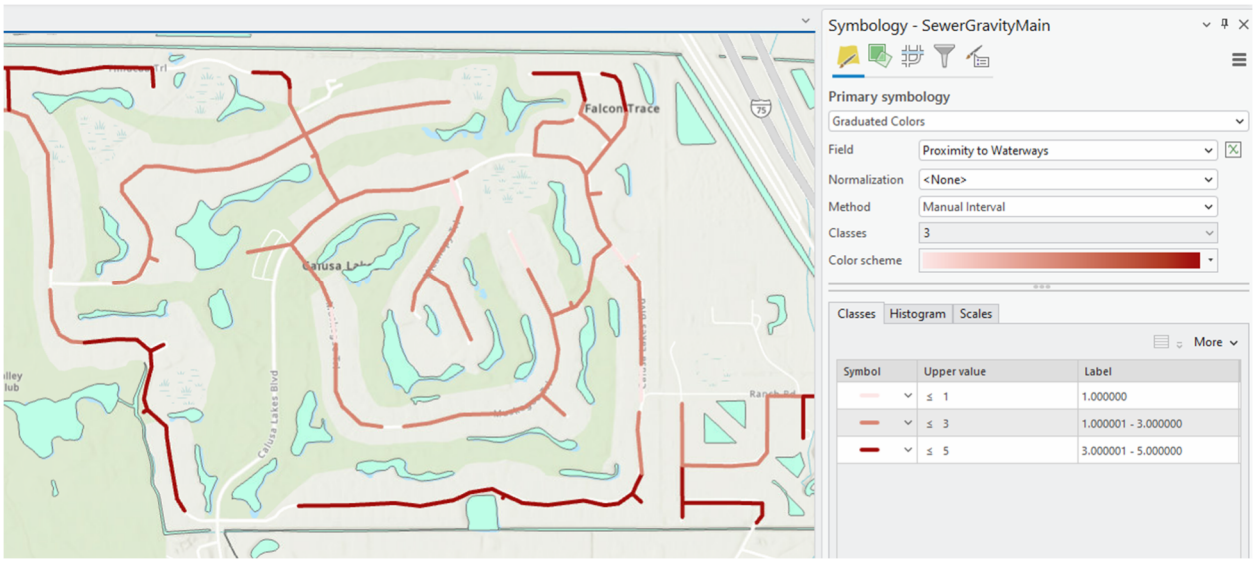
Symbology can be set so that the user can visually determine areas where a particular score or source of score was significantly higher than average. Graduated colors is an effective symbology method to do so.

Figure 10: Symbolize assets by risk score



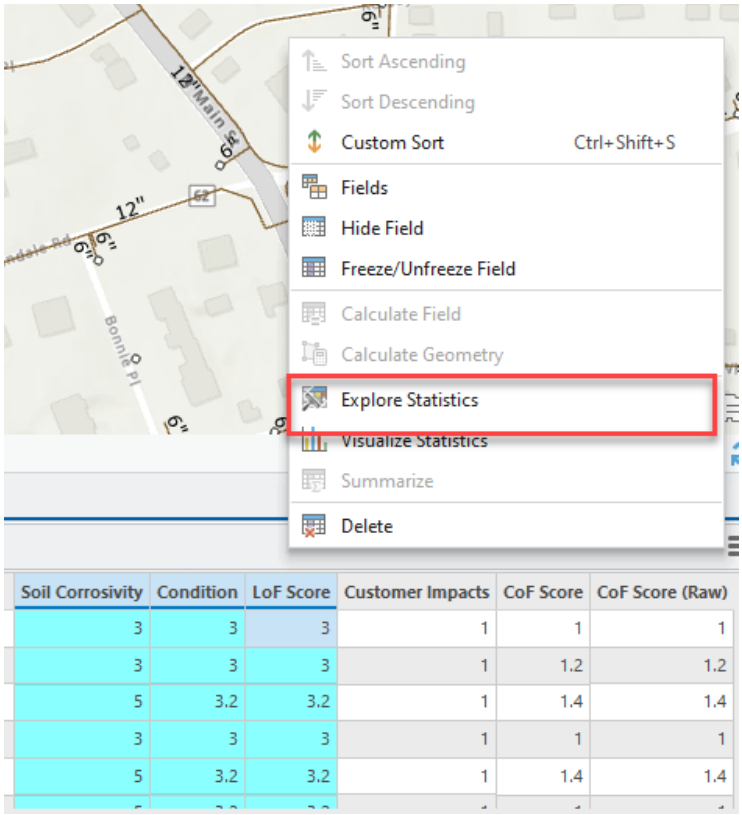
Visualizing results can also be helpful in QA/QC of model results. For example, resulting Distance to Roadways scores can be viewed along with Roadways GIS data to ensure that the results seem to align with the scoring criteria.

Figure 11: QAQC risk results in GIS



To review the distribution of results, plots can be created for any fields of interest in your Risk Table within ArcGIS Pro using the Explore Statistics feature.

Figure 12: Explore Statistics



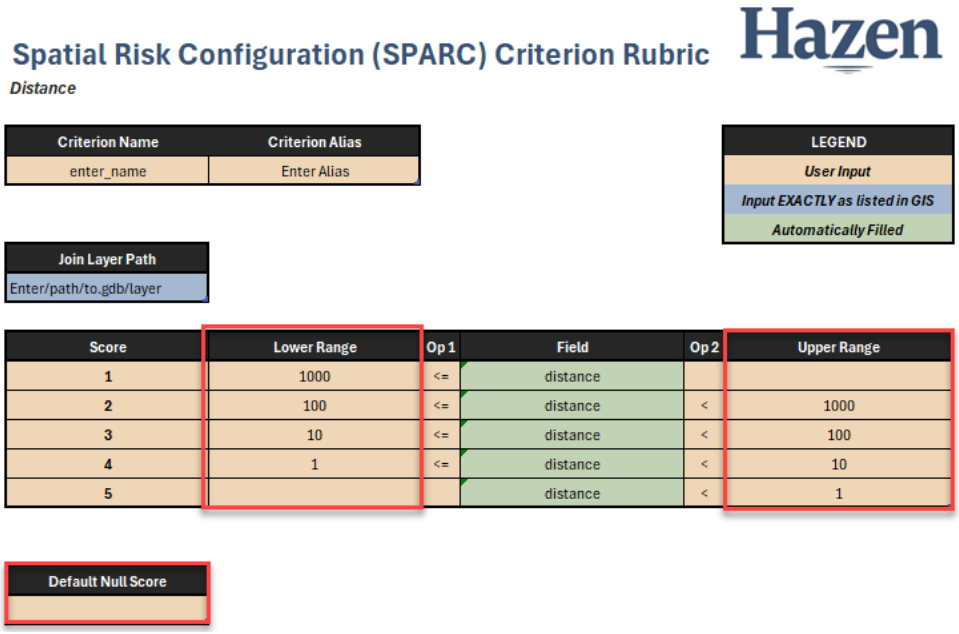
Model Updates

Throughout the risk model development and during risk result validation, it is common to update components of the risk model. The following sections detail how to complete common updates to a SPARC tool configuration.

Adjusting Scoring Rubrics

One of the most common updates during risk model development is adjustments to the criteria template scoring rubrics. Changes to the definitions of a 1-5 score for each criterion can easily be made. These may include changes to the Value(s), Lower and Upper Ranges, the Join Search Distance, and Default Null Score. Some are highlighted in **red** in an example criterion below.

Figure 13: Adjust scoring ranges for risk criteria



Spatial Risk Configuration (SPARC) Criterion Rubric

Distance

Criterion Name	Criterion Alias
enter_name	Enter Alias

LEGEND
User Input
Input EXACTLY as listed in GIS
Automatically Filled

Join Layer Path
Enter/path/to.gdb/layer

Score	Lower Range	Op 1	Field	Op 2	Upper Range
1	1000	<=	distance		
2	100	<=	distance	<	1000
3	10	<=	distance	<	100
4	1	<=	distance	<	10
5			distance	<	1

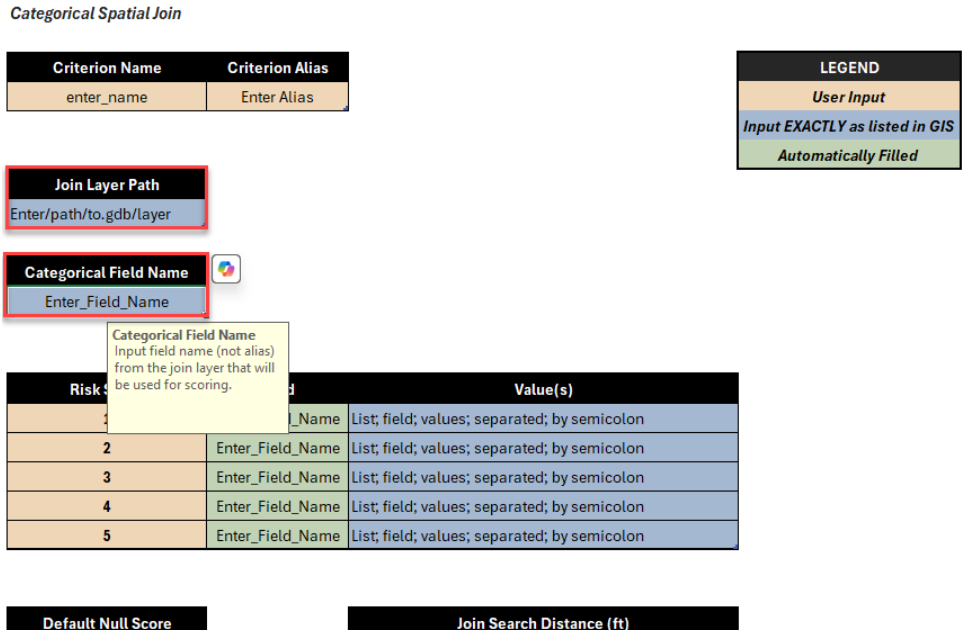
Default Null Score

Once the changes have been made to the Criterion Rubric spreadsheet it should be saved. Then, the user can run the **Run Criteria** and **Score Model** tools.

Updating Data Sources

As data sources are updated over time or if preprocessing occurs and a new data source needs to be used the user must update the criteria rubrics. Changes to the data source can easily be made by updating the Join Layer/Table Path and the associated field names. These are shown in the example below, highlighted in **red**:

Figure 14: Update risk layer path and field name(s)



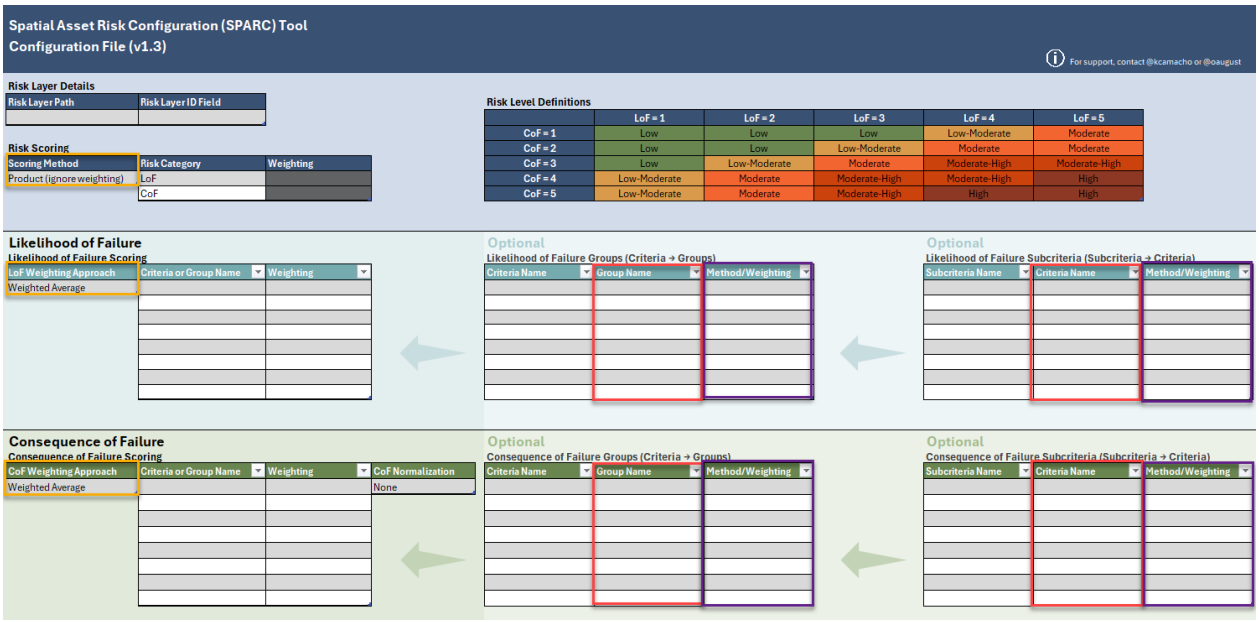
Once the changes have been made to the criteria rubric spreadsheet it should be saved. Then, the user can run the **Run Criteria** and **Score Model** tools.

Updating Weightings & Scoring Methodology

The most common updates once criteria scoring adjustments are complete, will be to LOF, COF, and Risk scoring methodology and weightings. These updates can be made by adjusting the Configuration File.

In the configuration file, the user can create or adjust subcriteria and criteria groups shown in **red**. Alternatively, the criteria scoring method/weightings can be updated using the dropdown options (highest, mean, or priority) or manually enter a weight value as shown in **purple**. Finally, the user can also update the risk scoring method and LOF/COF weighting approach shown in **yellow**.

Figure 15: Update Configuration File



Once the Configuration File has been saved, the user can navigate to the **Score Model** tool in the ArcGIS Pro toolbox and rerun LOF, COF, and/or Risk Score depending on the changes that were made.

Developing Scoring Scenarios

This section describes how the user can create an alternative scoring methodology or weighting scenario and compare the results. There are two options if the user would like to create and compare multiple scoring scenarios.

1. **For simple weighting comparisons:** First, the user can simply make the scoring changes as described in the section above and save the updated Configuration File. Then, the user can duplicate the Risk Table in GIS and rename it to indicate that the results will reflect the new scenario. Finally, the user can then rerun the **Score Model** tool making sure to store the results in the newly created Risk Table. The original scoring will be saved in the original Risk Table and the new scoring will be reflected in the new Risk Table. Users can join one or both tables to their Risk Layer, to visualize and compare the results.

2. **For major scoring methodology comparisons**: First, the user can create a copy of the Configuration File and rename it to indicate that it will reflect the new scoring methodology. Then, in the new Configuration File the user can make the scoring methodology changes as described above and save the updated Configuration File. Next, the user can duplicate the Risk Table in GIS and rename the table to indicate these results will reflect the new scenario. Finally, the user can then rerun the **Score Model** tool making sure to input the new Configuration File and store the results in the newly created Risk Table. The original scoring will be saved in the original

Risk Table and the new scoring will be reflected in the new Risk Table. Users can join one or both tables to their Risk Layer, to visualize and compare the results.

Model QAQC & Documentation

Thorough quality assurance and quality control (QAQC) are key to ensuring that the correct GIS layers are being used, scoring is being performed as expected, and there are no erroneous results being produced. To perform QAQC on results from a SPARC model, the user can begin by following these steps:

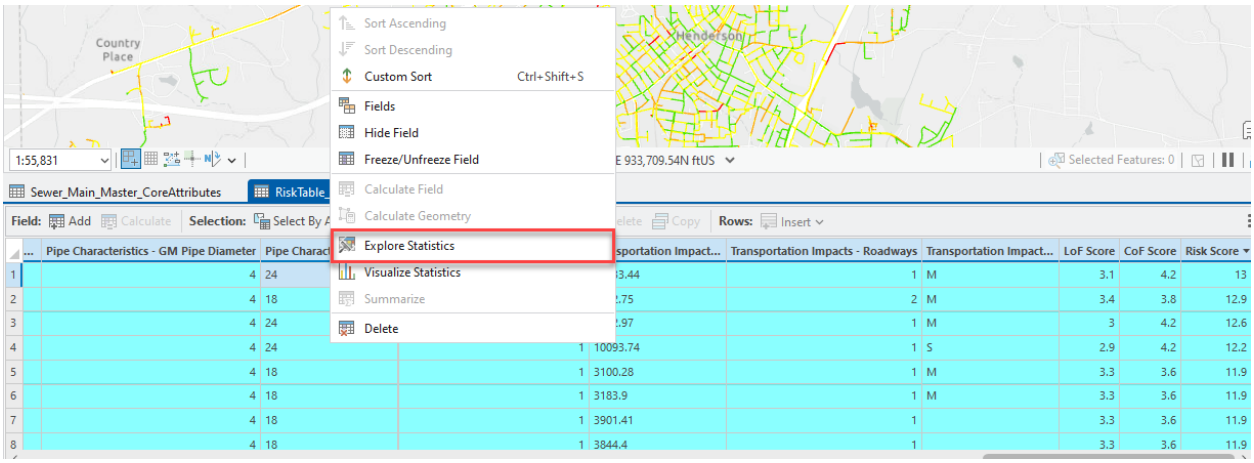
- Review Configuration File
    - Review Risk Layer file path and ID field.
    - Review Risk Level definitions.
    - Review Risk, LOF, and COF scoring methodology, criteria groups, and method/weights.
    - Review/confirm COF Normalization methodology.

- Review Criteria Rubrics:

    - Run the **Summarize Model Configuration** tool to export the GIS layers and tables and scoring rubrics used for each criterion. Review the data sources and scoring logic for each criterion to ensure their accuracy.

- Review Results:
    - Join the Risk Table results to the Risk Layer. Use Symbology to visualize the scores geospatially. Overlay reference layers such as waterbodies and roads to ensure the scoring is performing as intended.
    - Select the score fields in the Risk Table, then choose 'Explore Statistics' to review the distribution and statistics of results for each criterion, grouping, LOF, COF, and risk.

Figure 16: Explore statistics to QAQC results within GIS

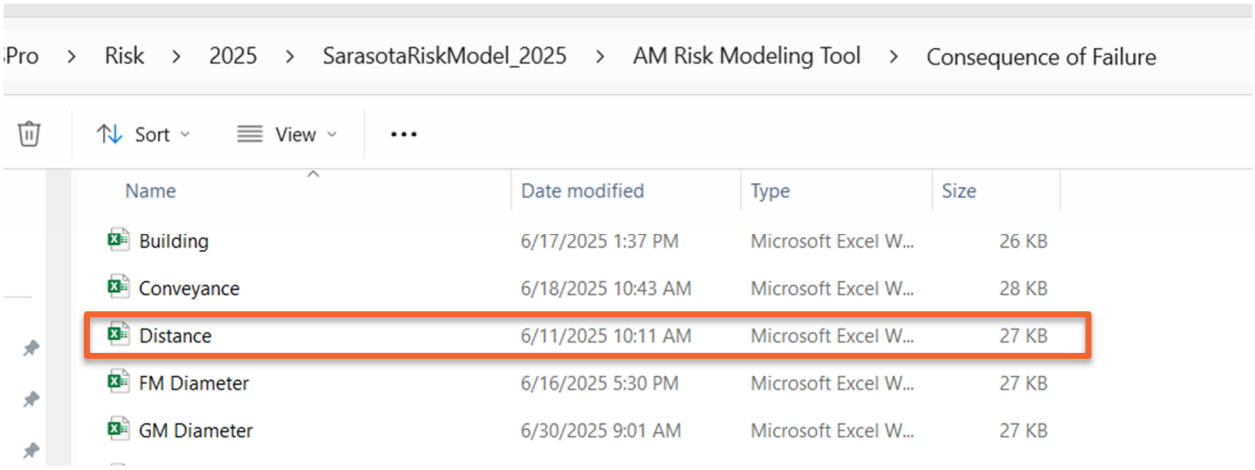


Troubleshooting Common Issues

Below details several common issues that can arise when operating the tool and the recommended solution.

- Null Asset IDs
    - Problem: risk layer has one or more null values in the asset ID column. Each row must have a unique asset ID for the tool to operate.
    - Solution: assign null asset IDs a permanent asset ID or create a new ID field with unique IDs for risk modeling.
- Criteria Rubric Locations
    - Problem: when criteria rubric templates are placed in the LOF or COF folder, they will be processed by the toolbox tools even if they are not included in the configuration file. This will cause the tool to produce an error if the criteria are not populated with name and alias.
    - Solution: ensure that only the rubrics being used for the risk assessment are in the LOF and COF folders and that no extra files are in those folders.

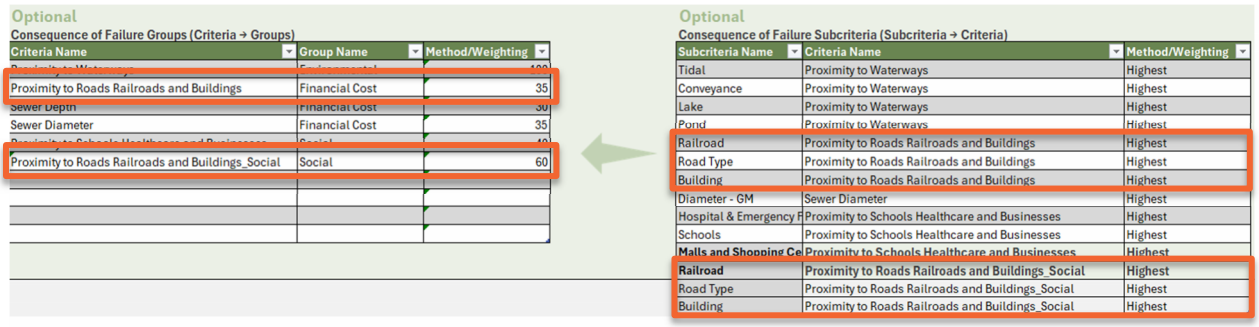
Figure 17: Remove unpopulated Criteria Templates from LOF and COF folders



- Version Incompatibilities
    - Problem: using old criteria templates with a new version of the toolbox will cause the tool to produce an error.
    - Solution: start with a new toolbox, copy and paste criteria from other runs at your own risk.

- Repeating Subcriteria
    - Problem: when subcriteria/criteria are being used for more than one criteria/group under the same name, the tool will produce an error.
    - Solution: if subcriteria are being used more than once, then they should be listed in the Configuration file as many times as they are being used and should be assigned a unique subcriteria/criteria for each use. In the example below, railroad, road type, and building criteria were all being used for both the social and financial cost criteria groups. Because the criteria name cannot repeat, one set of these criteria was renamed with "_Social".

Figure 18: Rename criteria so that there are no duplicates



Optional

Consequence of Failure Groups (Criteria → Groups)

Criteria Name	Group Name	Method/Weighting
Proximity to Roads Railroads and Buildings	Financial Cost	35
Sewer Depth	Financial Cost	30
Sewer Diameter	Financial Cost	35
Proximity to Roads Railroads and Buildings_Social	Social	60

Optional

Consequence of Failure Subcriteria (Subcriteria → Criteria)

Subcriteria Name	Criteria Name	Method/Weighting
Tidal	Proximity to Waterways	Highest
Conveyance	Proximity to Waterways	Highest
Lake	Proximity to Waterways	Highest
Pond	Proximity to Waterways	Highest
Railroad	Proximity to Roads Railroads and Buildings	Highest
Road Type	Proximity to Roads Railroads and Buildings	Highest
Building	Proximity to Roads Railroads and Buildings	Highest
Diameter - GM	Sewer Diameter	Highest
Hospital & Emergency F	Proximity to Schools Healthcare and Businesses	Highest
Schools	Proximity to Schools Healthcare and Businesses	Highest
Malls and Shopping Ce	Proximity to Schools Healthcare and Businesses	Highest
Railroad	Proximity to Roads Railroads and Buildings_Social	Highest
Road Type	Proximity to Roads Railroads and Buildings_Social	Highest
Building	Proximity to Roads Railroads and Buildings_Social	Highest

Advanced Examples

The following examples highlight more complex use cases that have emerged over the course of SPARC's lifespan. Reviewing these scenarios will offer insight into the tool's capabilities and internal logic.

Use Case 1: Collapsing Many Data Sources and Filters into One Criterion

In this example, the user wanted to combine several factors into one Soil criterion for Likelihood of Failure scoring. As can be seen from the figure below, soil corrosivity is calculated in a highly specific manner using four material types and four environmental corrosion layers (shown in white). For most materials, there was one criterion needed, but asbestos cement required three separate criteria to be merged into one 30% Soil Corrosivity score.

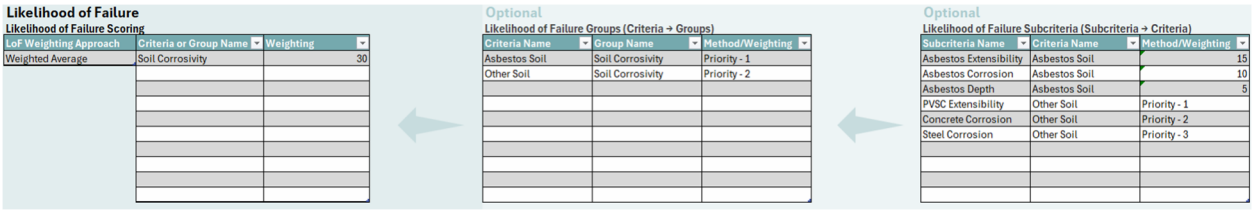
Figure 19: Soil section in planned risk scoring matrix.

Soil: 30%					
If material=PVC:	If material=Concrete:	If material=Steel, Iron:	If material=Asbestos Cement:	If material=Asbestos Cement:	If material=Asbestos Cement:
30%	30%	30%	15%	10%	5%
Linear Extensibility	Corrosion of Concrete	Corrosion of Steel	Linear Extensibility2	Corrosion of Concrete2	Depth to Groundwater
Very High, >=9%	High	High	Very High, >=9%	High	High
High, [6-9%)	-	-	High, [6-9%)	-	-
Moderate, [3-6%)	Moderate	Moderate	Moderate, [3-6%)	Moderate	Moderate
-	-	-	-	-	-
Low, <3%	Low	Low	Low, <3%	Low	Low

Solution Rubric Configuration

The solution for this situation was to create six Filtered Categorical Join Criteria, one for each of the material/environmental combinations shown above. Using subcriteria and groups, these were combined into a single Soil Corrosivity score.

Figure 20: Screenshot of Risk Model Configuration with soil criteria only.



Grouping and Scoring

As seen above, the asbestos criteria were treated as subcriteria and combined into a single "Asbestos Soil" criterion. The scores were combined using the 15/10/5 weighting designated in the original table. The

other soils were grouped together using the Priority grouping method, which – when the default score in the configuration rubrics is left blank – merges the individual material scores into a single output column. See the tables below for a closer look at how these groupings play out in the Risk Table. Once the subcriteria were combined, they could then be lumped into a single Soil Corrosivity criterion using criteria grouping.

Table 5: Risk Table with the six soil criteria already scored. The first five records are shown.

Asset ID	Material	Asbestos Extensibility	Asbestos Corrosion	Asbestos Depth	PVSC Extensibility	Concrete Corrosion	Steel Corrosion
abc-123	asb	3	5	2	NULL	NULL	NULL
abc-124	asb	1	1	3	NULL	NULL	NULL
abc-125	pvc	NULL	NULL	NULL	5	NULL	NULL
abc-126	concrete	NULL	NULL	NULL	NULL	4	NULL
abc-127	steel	NULL	NULL	NULL	NULL	NULL	2

Table 6: Risk Table with the soil criteria grouped into Asbestos Soil and Other Soil groups.

Asset ID	Material	Asbestos Soil	Other Soil
abc-123	asb	3.5	NULL
abc-124	asb	1.3	NULL
abc-125	pvc	NULL	5
abc-126	concrete	NULL	4
abc-127	steel	NULL	2

Table 7: Final soil corrosivity criterion that will be used for LOF scoring.

Asset ID	Material	Soil Corrosivity
abc-123	asb	3.5
abc-124	asb	1.3
abc-125	pcv	5
abc-126	concrete	4
abc-127	steel	2

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