Water Distribution System Integrity Study

Huber Heights, Ohio

Public Water System OH5703612

February 2023

Prepared by

BURGESS & NIPLE

Architects ■ Engineers ■ Planners

Water Distribution System Integrity Study

The City of Huber Heights, Ohio

Public Water System Identification No. OH5703612

Drafted October 2022
Finalized February 2023

BURGESS & NIPLE

TABLE OF CONTENTS

TABLE OF CONTENTS ii
1. INTRODUCTION 1
1.1. Methodology 3
2. DISTRIBUTION SYSTEM CHARACTERIZATION 5
2.1. Active Watermains 5
2.1.1. Asset Characteristics 6
2.1.2. Active Watermain Data - Quality Control 7
2.2. Abandoned Watermains 10
2.3. Service Connections 12
2.4. Valves 12
3. WATERMAIN CONDITION AND PERFORMANCE 14
3.1. Watermain Break Data 14
3.1.1. Break Data Quality Control 16
3.2. Historical Break Rate Analysis 17
3.2.1. Data Validation 17
3.2.2. Systemwide Break Analysis 18
3.2.3. Performance of Cast Iron (CI) 21
3.2.4. Performance of Ductile Iron (DI) 22
3.2.5. Performance of Prestressed Concrete Pipe (PCCP) 24
3.2.6. Impact of Soils on Historical Breaks 25
3.3. Prediction of Future Breaks 29
4. IMPACTS OF OPERATIONAL CHANGES 33
4.1. Pipe Bedding Changes 33
4.2. Increased Pressure North of I-70 35
4.3. Decommissioning of Needmore Road WTP / Commissioning of Rip Rap Road WTP Improvements 38
5. CONSEQUENCES OF WATERMAIN FAILURE 42
5.1. Watermain Criticality / Consequence of Failure (COF) Scoring 42
5.1.1. Diameter 42
5.1.2. Adjacency Factors 44
5.1.3. Critical Customers 49
6. WATERMAIN RISK 56
6.1. Risk Management Strategies 56
7. REPLACEMENT PLANNING RESULTS 61
7.1. Baseline Replacement Scenario 62
7.2. Modified Baseline Replacement Scenario – Evenly Distributed Investment 64
7.3. Replacement Scenario – $4.5 Million Investment Level 66
7.4. Replacement Scenario – 150-Year Cycle ($2.2 Million Investment) 67

7.5. Replacement Scenario – Multi-Level Investment 68
8. DISTRIBUTION SYSTEM HYDRAULICS 70
8.1. Population Projection 70
8.2. Demand Rate and Projected Future Demands 71
8.3. Plant Capacity 71
8.4. Distribution System Capacity 72
9. RECOMMENDATIONS 73
9.1. Capital Improvements Plan 73
9.1.1. Impact of 2019-2020 Operational Changes 74
9.1.2. Inflation, Supply Chain, and the Labor Market 74
9.1.3. Performance of Existing Ductile Iron Watermains 74
9.1.4. Alternative Material Selection 74
9.2. Corrosion Protection 75
9.3. Physical Assessment of Pipe Deterioration 76
9.4. Continued Pipe and Break Data Management Processes 77
9.5. Water Master Plan 77
9.6. Emergency Preparedness Plan – Functional or Full-Scale Exercise(s) 78
9.7. Asset Management Plan Updates 79

List of Figures

Figure 1-1. Distribution System Break Rate by Year 1
Figure 1-2. Location Plan 2
Figure 2-1. Water Distribution System Site Map 5
Figure 2-2. Total Length of Watermain Installed by Year (Currently Active Pipe Only) 6
Figure 2-3. Length of Water Main by Size 7
Figure 2-4. Abandoned Watermain Locations 11
Figure 2-5. Average Annual Break Rate of Abandoned (ABN) Pipe and Active (ACT) Pipe 12
Figure 3-1. Distribution System Break Rate by Year 14
Figure 3-2. Historical (January 2010- July 2022) Water Main Breaks by Location 15
Figure 3-3. Systemwide Break Rate versus Age *(Nb=number; mi=miles; yr=year)* 19
Figure 3-4. Length of Pipe by Age 19
Figure 3-5. Average Annual Break Rate and Average Age of CI, DI, and PCCP 20
Figure 3-6. Systemwide Break Rate versus Diameter 21
Figure 3-7. Average Yearly Break Rate and Length by Age of CI Pipe 21
Figure 3-8. CI Break Rate by Diameter 22
Figure 3-9. Average Yearly Break Rate and Length by Age of DI Pipe 23
Figure 3-10. DI Break Rate by Diameter 23
Figure 3-11. Average Yearly Break Rate and Length by the Year of Installation of PCCP Pipe 24
Figure 3-12. PCCP Break Rate by Diameter 25
Figure 3-13. Soil Type Map for Northeast Montgomery County 26
Figure 3-14. Risk of Soil Corrosion for Concrete (Montgomery County only) 27
Figure 3-15. Risk of Soil Corrosion for Steel (Montgomery County only) 27
Figure 3-16. Break Rate Based on the Combination of Material and Soil Corrosivity 28
Figure 3-17. Break Rate and Number of Breaks versus Time (No Replacement) 30
Figure 3-18. Current Probability of Pipe Breaks 31
Figure 3-19. Current Predicted Break Rate 32
Figure 4-1. Average Annual Break Rate of DI Pipe Based on Year of Installation 33
Figure 4-2. Aging Curve for DI Pipe Built Through 1985 34
Figure 4-3. Aging Curve for Post-1985 DI Pipe 34
Figure 4-4. Cast Iron Aging Curve 35
Figure 4-5. Number of Breaks North of I-70 by Month 37
Figure 4-6. Location of Watermain Breaks Before May 1, 2019 39
Figure 4-7. Location of Watermain Breaks After May 1, 2019 40
Figure 5-1. Water Criticality Scores Based on Diameter 43
Figure 5-2. Water Criticality Scores Based on Proximity to Roads 46
Figure 5-3. Water Criticality Scores Based on Proximity to Water Bodies 47
Figure 5-4. Water Criticality Scores Based on Proximity to Structures 48
Figure 5-5. Location of Critical Customers 50

Figure 5-6. Criticality Score Based on Potential Service Impacts to Critical Customers................ 53
Figure 5-7. Criticality Based on Adjacency to Critical Consumption... 54
Figure 5-8. Total Criticality Scores.. 55
Figure 6-1. Maximum Acceptable Break Rate Based on COF.. 56
Figure 6-2. Theoretical Monetized Triple-Bottom Line Consequence of Pipe Failure................... 58
Figure 6-3. 50-Year Risk Scores by Pipe.. 59
Figure 6-4. Estimated Benefit to Cost Ratio by Pipe.. 60
Figure 7-1. Replacement Cost and Length by Year – Baseline Scenario (Not Optimized)............ 62
Figure 7-2. Annual Breaks and Risk – Baseline Scenario (Not Optimized)..................................... 63
Figure 7-3. Replacement Cost and Length by Year – Modified Baseline Scenario......................... 64
Figure 7-4. Annual Breaks and Risk – Modified Baseline (Even Investment)................................. 65
Figure 7-5. Annual Breaks and Risk – $4.5 Million Annual Investment.. 66
Figure 7-6. Annual Breaks and Risk – $2.2 Million Annual Investment.. 67
Figure 7-7. Replacement Cost and Length by Year – Multi-Level Investment............................... 68
Figure 7-8. Annual Breaks, Break Rate, and Risk – Multi-Level Investment.................................. 69
Figure 8-1. Population Forecast.. 70

List of Tables

Table 2-1. Length of Active Watermain by Material ... 7
Table 2-2. Duplicate Pipe IDs in the Intermediate GIS Data Set ... 9
Table 2-3. Pipes with Anomalous Pipe Material ... 9
Table 2-4: Abandoned Watermain Summary by Installation Year ... 10
Table 3-1. Duplicate Break ID Corrections ... 16
Table 3-2. Breaks with Same PipeID and Date of Break, but Different Break ID ... 17
Table 3-3. Number of Breaks (Jan 2010 - Apr 2019) and Total Pipe Length by Material ... 18
Table 3-4. Length of Pipe by Age Range ... 18
Table 3-5. Length of PCCP and Breaks by Diameter ... 24
Table 4-1. Number of Breaks by Year ... 37
Table 5-1. Criticality Based on Diameter ... 44
Table 5-2. Criticality Based on Roadway Adjacency Factors ... 44
Table 5-3. Criticality Based on Adjacency Factors (Non-Roadway) ... 45
Table 5-4. Criticality Based on Adjacency to Roads ... 45
Table 5-5. Criticality Based on Adjacency to Water Bodies ... 45
Table 5-6. Criticality Based on Adjacency to Structures ... 45
Table 5-7. Critical Customer List ... 49
Table 5-8. Hydraulic Criticality Factors and Scoring ... 51
Table 5-9. Criticality Based on Potential Service Impacts to Critical Customers ... 51
Table 5-10. Criticality Based on Adjacency to Critical Consumption ... 52
Table 5-11. Total Criticality Scores ... 52
Table 6-1. MABR versus COF ... 57
Table 7-1. AWWA Annual Break Rate (breaks/100 miles) Benchmarking Data ... 61
Table 7-2. Pipe Replacement Unit Costs (per foot) by Diameter ... 61
Table 7-3. Average Annual Replacement Cost v. Replacement Cycle ... 62
Table 7-4. Multi-Level Investment Framework ... 69
Table 8-1. Future Water Demand Ranges ... 71
Table 9-1. Multi-Level Replacement Strategy ... 73

1. INTRODUCTION

The City of Huber Heights water distribution system experienced a sudden increase in its watermain break rate beginning in 2019 (see **Figure 1-1**). For the 9 years prior, the average number of breaks per year was just over 45. The 156 breaks in 2020 was nearly 3.5 times that average, and the 118 breaks in 2021 was 2.6 times that average. The purpose of this study was to determine the causes of the spike in breaks; determine if the cause(s) will persist; and evaluate alternatives to control the future break rate to acceptable levels.

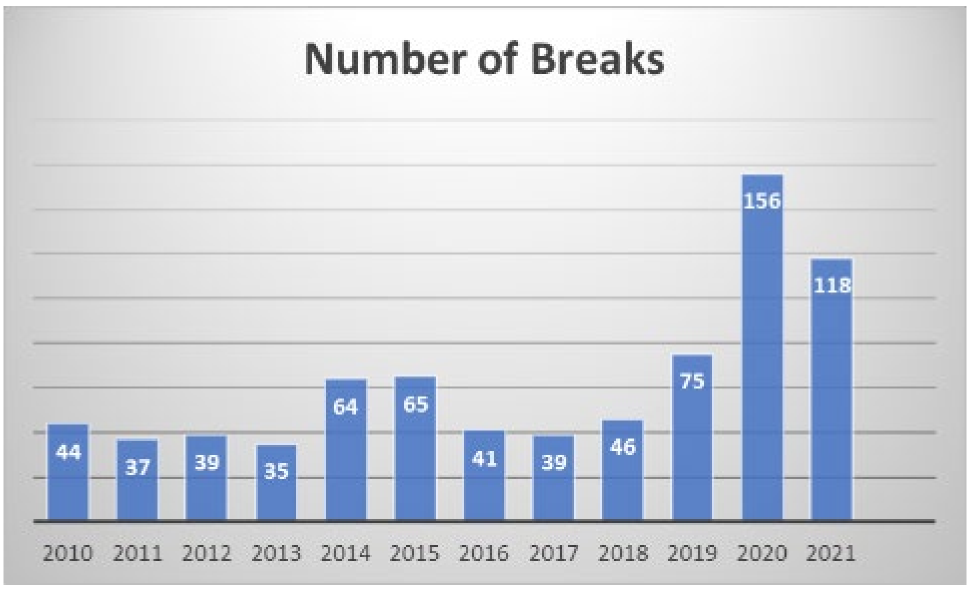


Figure 1-1. Distribution System Break Rate by Year

Prior to the spike in breaks, the average annual break rate was approximately 22 breaks per 100 miles per year. Many major cities in the US experience a break rate of less than 20 breaks per 100 miles per year, and the AWWA Partnership for Safe Water Distribution System Program's 2018 goal for a fully optimized distribution system is 15 breaks per 100 miles per year. Even before the spike in breaks, the City was in a position to potentially benefit from targeted, proactive watermain replacements, and did some proactive replacements in 2019 and 2020. This study will analyze alternative investment levels to control the break rate to varying degrees.

This study provides a roadmap to address the risks of aging watermains in the Huber Heights water distribution system (see **Figure 1-2** Location Plan) through proactive replacements. Under normal circumstances, there are challenges with developing a replacement plan that identifies the right replacements at the right time for infrastructure that is hidden from view and extremely costly to physically inspect.

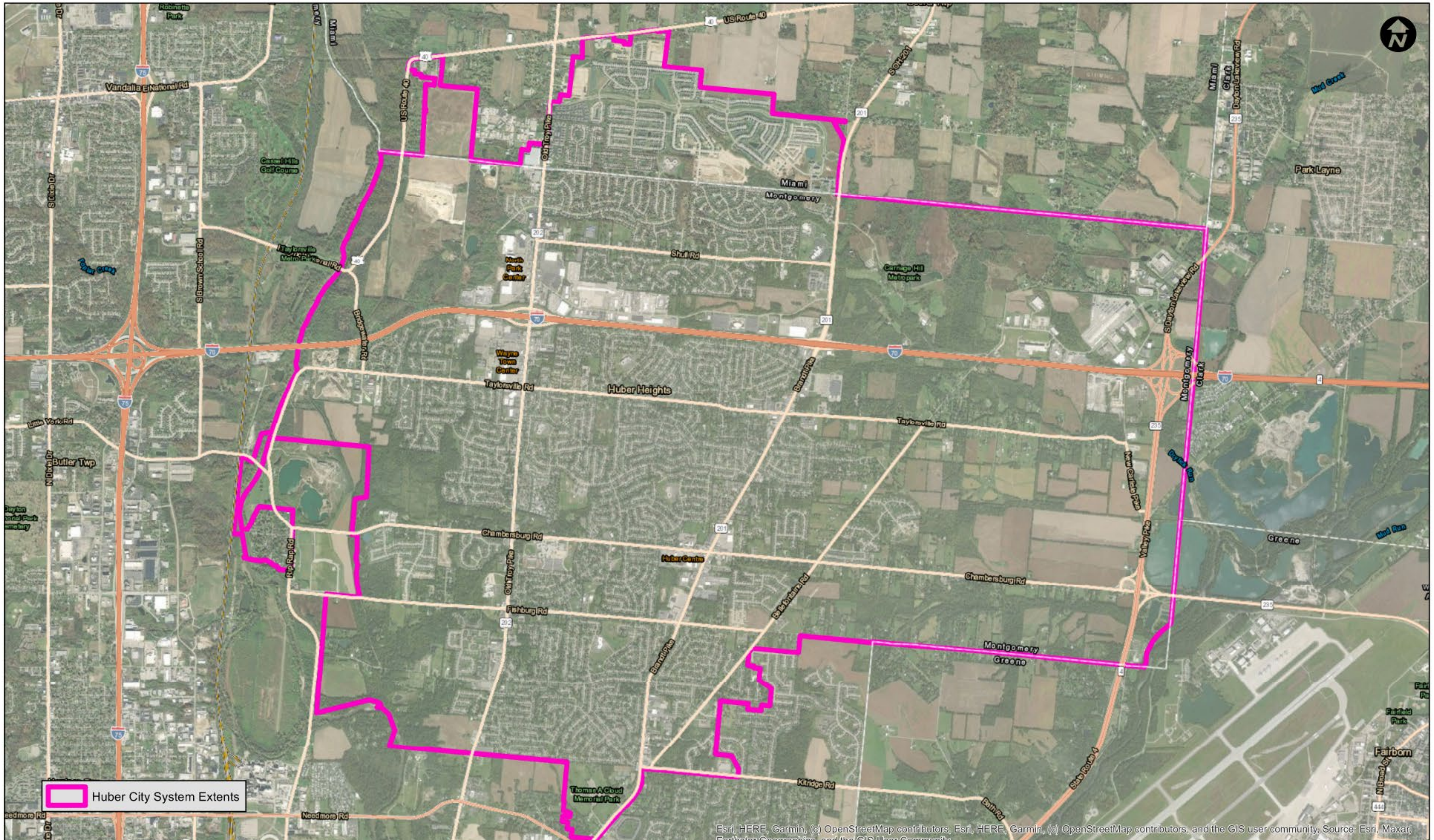


Figure 1-2. Location Plan

Adding to the complexity of this analysis are multiple recent changes to how the distribution system was operated:

1. Commissioning of three new booster stations that increased pressures in the distribution system north of I-70 by 20 psi (from approximately 40 psi to 60 psi)
2. Abandonment of the Needmore Road Water Treatment Plant that changed both pumping operations and water quality
3. Upgrades to the Rip Rap Road Water Treatment Plant that changed both pumping operations and water quality

To evaluate the impacts of those operational changes, B&N employed the use of the most sophisticated, accurate watermain break prediction software available (infraSOFT). This software, along with other analysis methods sought to determine whether the causes of the spike in breaks would persist, allowing for the subsequent right-sizing of alternative solutions.

This project used asset attribute data for watermains and their associated break history to determine where the highest levels of risk exposure associated with watermain breaks exist and includes a plan to cost-effectively mitigate those risks.

1.1.Methodology

Break rate is strongly tied to watermain attributes under normal circumstances, so the project began by examining the Huber Heights GIS to determine the comprehensiveness of available data. The three most significant watermain parameters involved in predicting watermain performance in any water system under normal operating conditions include age (installation date), material, and size (as an indicator of wall thickness). Initial asset attribute data from GIS for both diameter and material was 100-percent populated. Approximately 2.5-percent of the system (113 pipes) had an unpopulated installation year. Data cleanup efforts by the City supported by B&N led to the population of all installation year data.

Data quality issues were also identified using the infraSOFT platform, including missing asset identifiers (i.e., asset IDs, which were subsequently assigned as part of this project), duplicate break IDs for several watermain breaks, and in few cases suspect pipe material (e.g., cast iron pipe installed after 1977, when ductile iron was predominant.). The pipe data and quality control issues are described in **Section 2**.

Evidence has shown that using age alone as a replacement criterion is counter-productive and can lead to gross miscalculations in the remaining useful life of pipes. Therefore, using actual break data from the City was a focal point of this project. Building the replacement plan included examining 12 years of empirical pipe break data (2010-2021 inclusive) for Huber Heights's pipes. The City has maintained a comprehensive break database dating back to January 2010. Breaks were assigned to pipes through an asset ID to allow the performance of each pipe within a pipe class, and overall pipe classes, to be evaluated.

The use of local, empirical break data allows for prediction of future pipe failures that more accurately reflects local conditions. In addition to examining the system as a whole, pipes with different installation dates, diameters, and materials break at different rates. Identifying poor performing subgroups, or "cohorts", is important to developing an effective replacement plan. As part of this project, B&N used pipe and break data to predict future performance for each pipe based on an analysis of both each pipe itself and similar pipes in its cohort. As an example, data from the oldest 10-inch, cast iron watermains can be used to predict the future break rate of younger 10-inch, cast iron watermain. This methodology is summarized in **Section 3**.

Because of the changes in system operations (booster stations and treatment facilities), the break rate was examined in various sections of the distribution system, such as the area north of I-70 which was impacted by an increase in operating pressure beginning in late May 2019. The impact of each operational change was examined to the extent possible, and findings are presented in **Section 4**.

The consequence of failure (COF) of pipes is also a factor in developing alternative mitigation alternatives. Pipes that have a relatively low repair cost and impact on the community can sustain a higher break rate than pipes with more consequential impacts. COF was determined in two ways:

- Using the City's GIS, consequences were estimated based on the proximity of pipes to other spatial features such as roads (traffic impacts), water bodies (difficulty of repair), and other structures (property damage).
- Using the City's hydraulic model, additional consequences involving loss of service to customers were estimated by determining the hydraulic impacts of failure for each pipe.

The consequence of failure methodology is presented in **Section 5**.

The combination of a pipes probability of failure (POF) and COF determine the City's risk exposure associated with each pipe, and prioritization is given to replacing pipes that will have the largest potential reduction in risk exposure. Risk data is described in **Section 6**.

Because high risk pipes can be interspersed with lower-risk pipes, the process of project bundling (determining appropriate "packets" of adjacent pipes to replace as part of a capital project) requires some analysis, with the ultimate determination based on the ratio of a project's benefit (overall risk reduction) to its overall cost. The methodology for utilizing risk data to prioritize replacements is discussed in **Section 7**.

Recommendations from this report should be coordinated with the City's finance department (for funding opportunities) and roadway and other utility departments to determine if there are economies of scale by sequencing projects such that roadway and other utility work coincide with watermain replacements. Final recommendations are made in **Section 8**.

2. DISTRIBUTION SYSTEM CHARACTERIZATION

2.1. Active Watermains

GIS records include 209 miles of active watermains. Descriptions of active watermain assets based on GIS data are included below. **Figure 2-1** shows a map of the water distribution system as of July 2022.

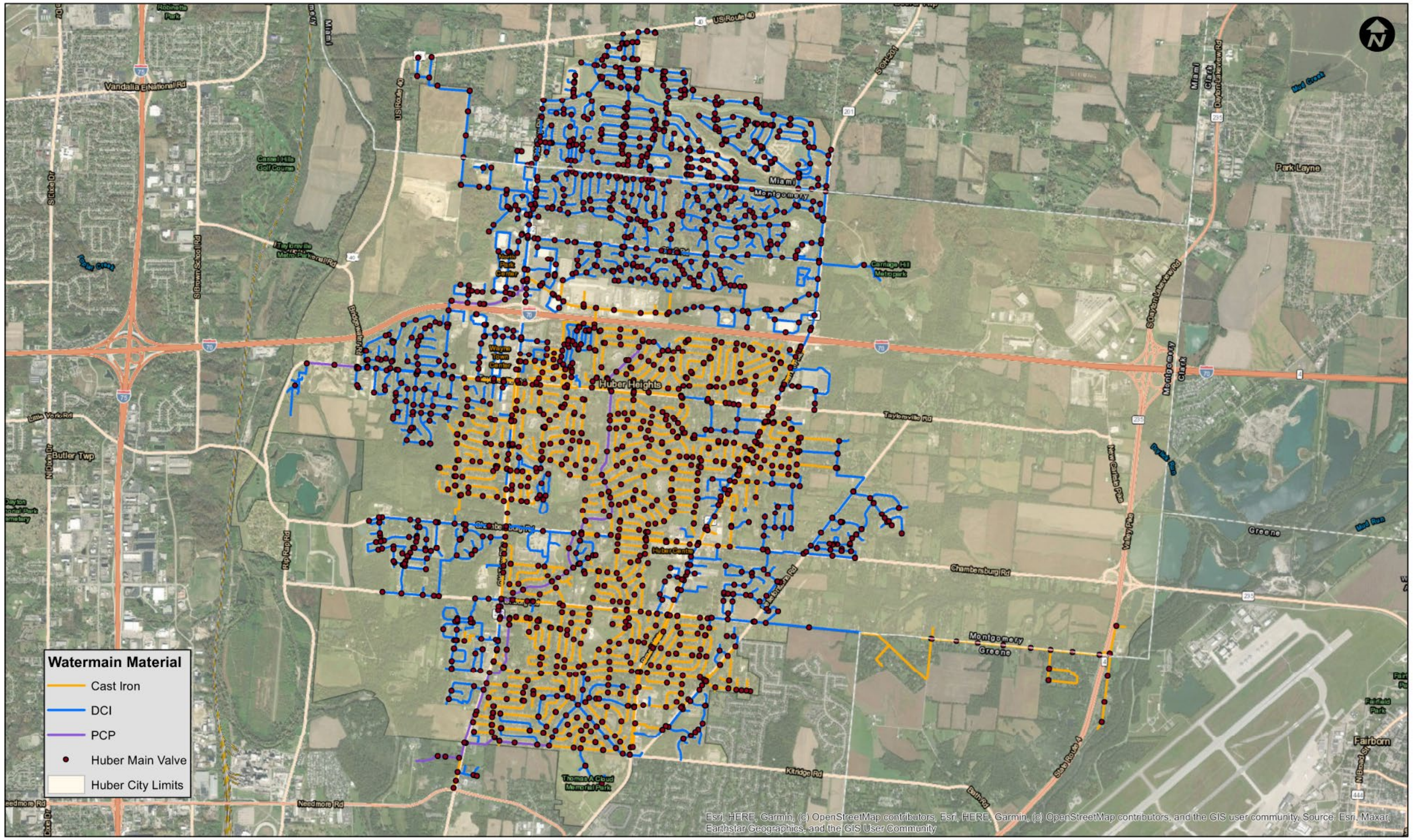


Figure 2-1. Water Distribution System Site Map

2.1.1. Asset Characteristics

The three most significant asset characteristics involved in predicting future pipe performance are age / date of installation, size (diameter), and material. The data associated with those parameters is discussed below. Overall, the City of Huber Heights has maintained its GIS records at a very high level of data comprehensiveness and quality, allowing for detailed analysis.

Installation dates were populated for 97.5 percent of pipes in the initial data set. Early in the project, the City researched records for the 2.5-percent (113 pipes) without an install date to determine an actual or assumed install year. There is a high degree of confidence in most install dates except for 1977 ductile iron (DI) pipe – if field records showed ductile iron pipe without an installation year, 1977 was assigned because (a) more recently installed DI pipes are more likely to have better record data and (b) ductile iron pipe was the default material by about 1977. **Figure 2-2** shows the historical growth in watermain length by year (excluding abandoned pipe data).

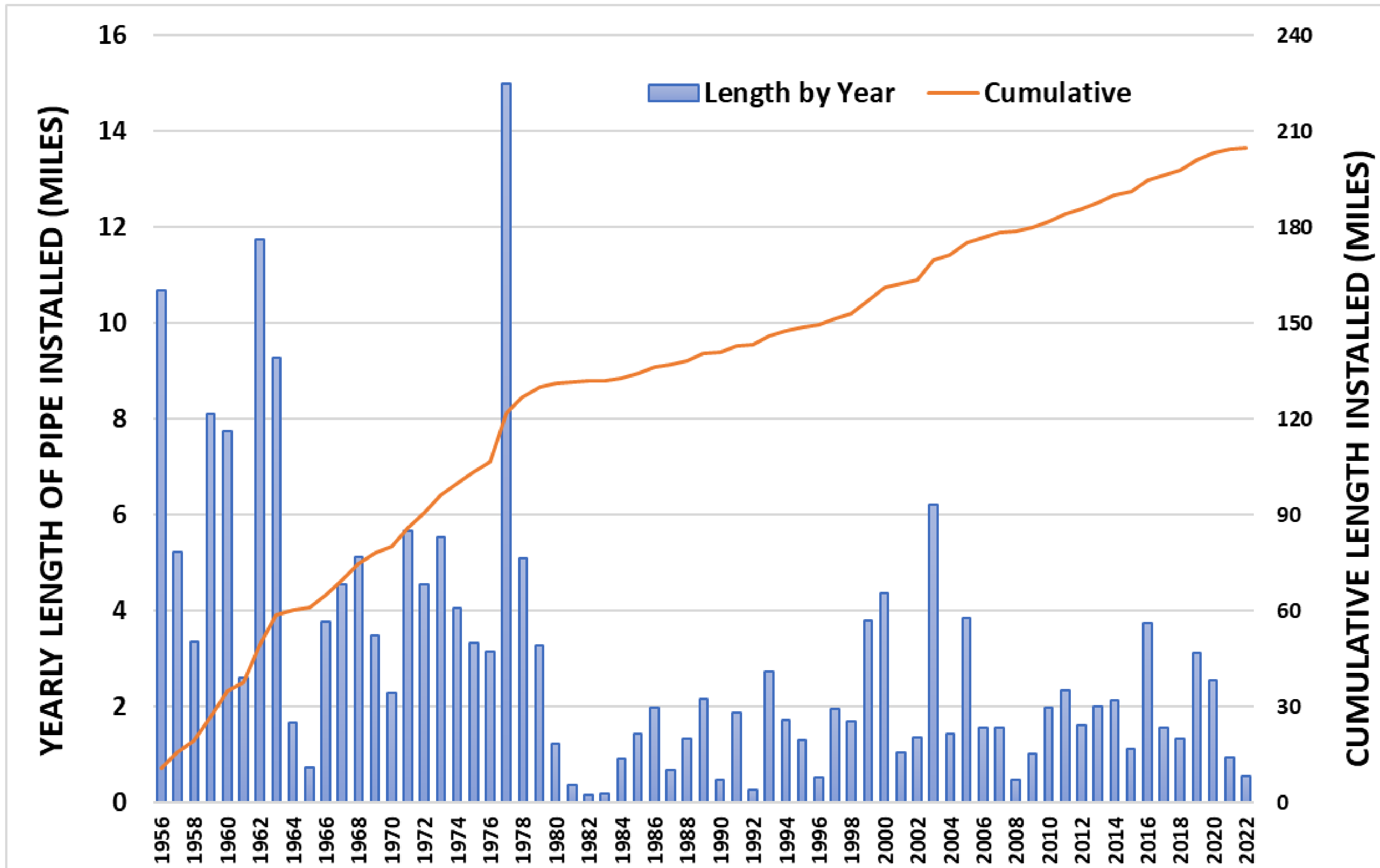


Figure 2-2. Total Length of Watermain Installed by Year (Currently Active Pipe Only)

Material was populated for all pipes in the initial GIS data set. **Table 2-1** summarizes the breakdown of active watermains by material.

Table 2-1. Length of Active Watermain by Material

Material	Length (miles)	Percentage of total Length (%)
Cast Iron (CI)	91.89	44.0
Ductile Iron (DI or DCI)	111.23	53.3
Prestressed Concrete Cylinder Pipe (PCCP, sometimes PCP)	5.72	2.7

This table is based on the GIS analysis of active watermains following quality control changes discussed below

Pipe size was also populated in the initial GIS data set for every pipe. Pipe size ranges from 2-inches to 24-inches, as shown in **Figure 2-3**.

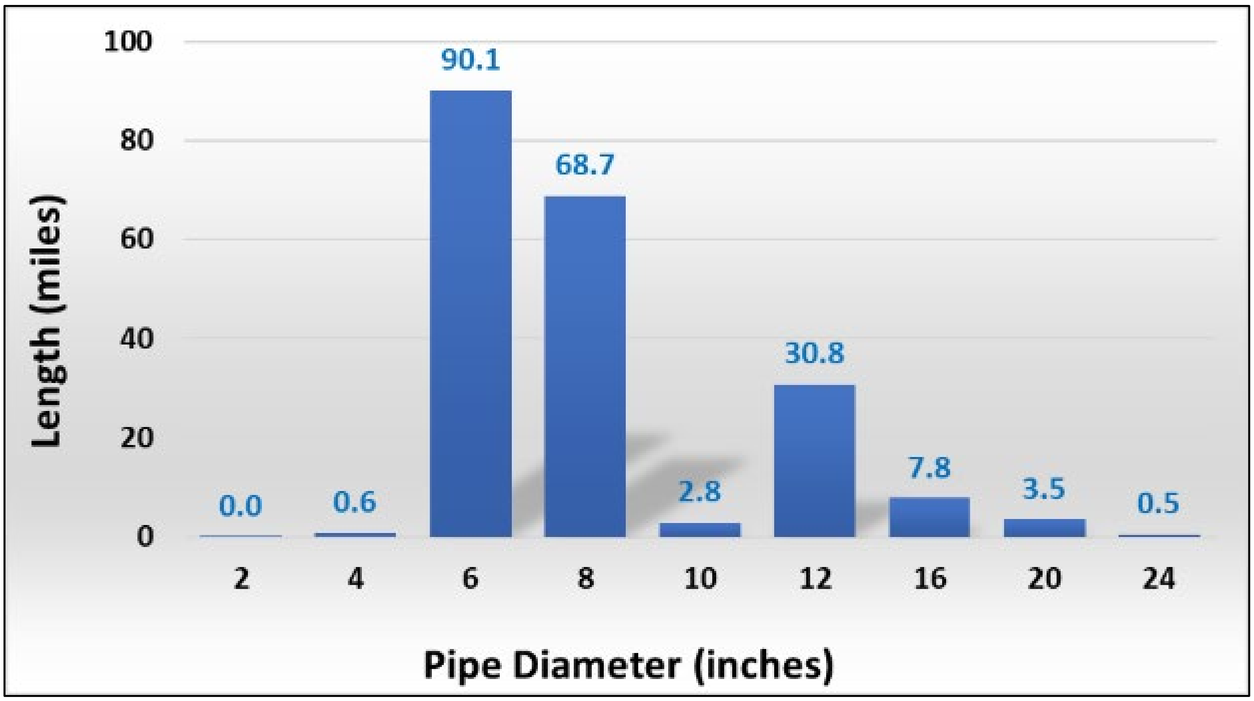


Figure 2-3. Length of Water Main by Size

2.1.2. Active Watermain Data - Quality Control

A quality control check of the watermain source data provided by the City was conducted to help assure the quality of the eventual output data. Examples of quality control measures included identifying pipes (active and abandoned) that had issues related to:

- Pipe / Asset IDs
    - Duplicate asset IDs
    - Assets without IDs
- Install Dates
    - Some agencies use a default value for pipes with unknown install dates (*in the case of Huber Heights, 1977 was used for DI pipe without an install date as discussed above*). Any anomalous install dates are flagged.
    - For abandoned pipe, installation dates that do not precede dates of abandonment are flagged for investigation.
- Diameter
    - Some agencies use default values that are obviously incorrect to allow users to be alerted to missing data.
    - Pipes under 3-inches in diameter are excluded from analysis as they tend to be service connections
- Length
    - Some agencies use a negative length for "orphaned" pipes, though this has become very rare with well-developed GIS systems. Pipes with lengths of less than 2 feet were flagged for this project.

Quality control measures identified the following issues with the initial GIS data set:

Missing Date of Installation (DOI)

Of the 4,562 total pipes provided in the latest GIS data (including 4,501 active GIS pipes and 51 abandoned GIS pipes), 113 pipes did not initially include install dates, representing about 2.5-percent of all pipes. Pipes with no installation date were reviewed by the City. Upon reviewing their internal GIS, as-built documents, and surrounding pipes, the City inserted installation dates for all 113 pipes, allowing all of these pipes to be included in the break analysis. The list of pipes without installation dates in the initial data set are shown in **Appendix A**.

Missing Pipe ID

At the beginning of the project, the project team identified that the City's GIS did not have a static asset ID assigned to each pipe. The City assigned unique asset IDs to each pipe as a result of this requirement, and the IDs are permanently updated in the City's GIS database.

Duplicate Pipe ID

A set of 8 pairs of pipes were identified in intermediate data sets with duplicate IDs (see **Table 2-2**). These duplicates were resolved by the City and updated in the City's GIS records.

Table 2-2. Duplicate Pipe IDs in the Intermediate GIS Data Set					
ID	Issues	Installation Date	Material	Length	Diameter
WM00944	DUPL Pipe ID, same Life Status	2000-12-31	DCI	361.3	8
WM00944	DUPL Pipe ID, same Life Status	2000-12-31	DCI	470.9	8
WM02896	DUPL Pipe ID, same Life Status	1988-12-31	DCI	82.1	16
WM02896	DUPL Pipe ID, same Life Status	2002-12-31	DCI	117.5	16
WM03607	DUPL Pipe ID, same Life Status	1967-12-31	Cast Iron	358.4	8
WM03607	DUPL Pipe ID, same Life Status	1969-12-31	Cast Iron	464.3	8
WM03924	DUPL Pipe ID, same Life Status	1988-12-31	DCI	257.6	8
WM03924	DUPL Pipe ID, same Life Status	1975-12-31	DCI	6.7	8
WM04031	DUPL Pipe ID, same Life Status	1979-12-31	DCI	524.5	8
WM04031	DUPL Pipe ID, same Life Status	1975-12-31	DCI	663.4	8
WM04085	DUPL Pipe ID, same Life Status	1963-12-31	PCCP	498.6	20
WM04085	DUPL Pipe ID, same Life Status	1959-12-31	PCCP	7.0	20
WM04207	DUPL Pipe ID, same Life Status	1978-12-31	DCI	443.9	8
WM04207	DUPL Pipe ID, same Life Status	1989-12-31	DCI	923.8	8
WM04443	DUPL Pipe ID, same Life Status	1991-12-31	DCI	316.9	8
WM04443	DUPL Pipe ID, same Life Status	1991-12-31	DCI	124.6	8

Material

One anomaly with material data was the apparent installation of cast iron pipe beyond 1977. **Table 2-3** shows 10 pipes installed in 1984 and after with cast iron listed as the material in the initial GIS data set. The material for these pipes was changed to ductile iron.

Table 2-3. Pipes with Anomalous Pipe Material				
ID	Year of Installation	Anomalous Material	Length (ft.)	Diameter
WM02569	2001	Cast Iron	379.5	8
WM03672	1999	Cast Iron	370.1	8
WM03802	1984	Cast Iron	601.3	12
WM02570	2001	Cast Iron	459.7	8
WM02568	2001	Cast Iron	463.7	8
WM04651	2011	Cast Iron	4.8	12
WM02571	2001	Cast Iron	448.7	8
WM02567	2001	Cast Iron	542.7	8
WM02241	2001	Cast Iron	1.7	8
WM02566	2001	Cast Iron	543.1	8

2.2. Abandoned Watermains

Including abandoned watermains in the analysis of pipe break rates is very important as it provides more informed predictions of future pipe longevity of active pipe, particularly with understanding of how the break rate for different pipe cohorts accelerates near the end of their useful lives. Based on available data provided by the City, **Table 2-4** summarizes the breakdown of abandoned watermain attributes. A map of abandoned pipes is shown in **Figure 2-4**. Watermain abandonments were predominantly cast iron (92.1-percent) with some ductile iron (DI) replacement (7.9-percent). A more detailed description of abandoned watermains can be found in **Appendix B**.

Table 2-4: Abandoned Watermain Summary by Installation Year

Install Year	Replacement Year	Material	Diameter (inches)	Length (miles)	Cumulative Length (miles)	Cumulative Percentage
1956	2010	CI	6	0.63	0.63	16.0
1956	2011	CI	6 to 12	1.60	2.23	56.6
1956	2016	CI	6 to 8	0.70	2.93	74.5
1959	2020	CI	6	0.69	3.62	92.1
1974	2022	DI	12	0.04	3.66	93.0
1989	2007	DI	8	0.06	3.72	94.6
2005	2005	DI	8	0.06	3.78	96.1
2012	2019	DI	8	0.15	3.94	100.0

Figure 2-5 shows the average annual break rate of abandoned (ABN) pipes at the time they were abandoned (1.43 breaks per mile per year) versus the current average annual break rate of active (ACT) pipes (0.22 breaks per miles per year). This data indicates that at the time of abandonment, the abandoned pipes had an average annual break rate 6.5-times higher than the current average annual break rate of active pipe, and that Huber Heights has historically selected the right pipes to replace.

Missing Pipe ID

As was the case for active mains, the project team identified that abandoned pipes in the City's GIS did not have a static asset ID assigned to each pipe at the beginning of the project. The City assigned unique asset IDs to each abandoned pipe, and the IDs are permanently updated in the City's GIS database.

There were no other data quality issues associated with abandoned mains.

Figure 2-4. Abandoned Watermain Locations

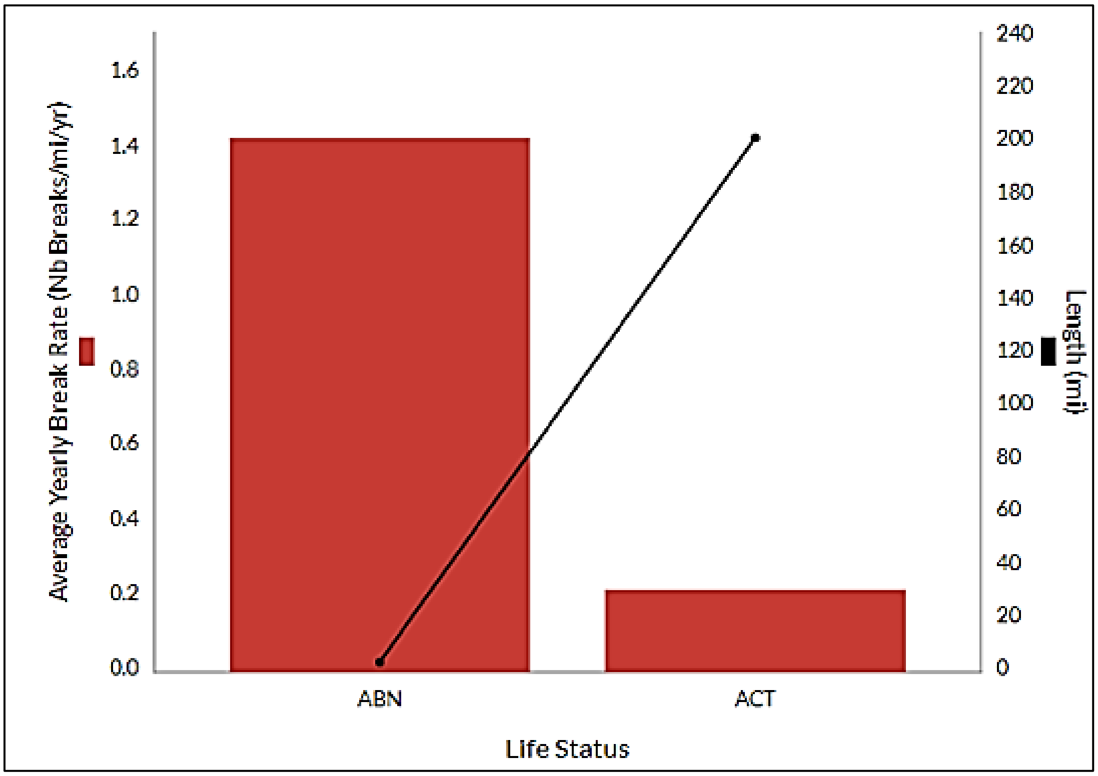


Figure 2-5. Average Annual Break Rate of Abandoned (ABN) Pipe and Active (ACT) Pipe

2.3. Service Connections

Based on discussions with B&N, the City separated service connections from mainline watermains in the GIS dataset provided for this study. Service laterals are not subject to alternative mitigation strategies. If any service laterals remain, they can be eliminated manually from the replacement plan through geospatial inspection. Pipes with a diameter of less than 3-inches were filtered out of the analysis for this reason.

2.4. Valves

Valves are installed on the pipes to enable staff to perform multiple functions, primarily to isolate segments of pipes for repair. They can be used to isolate portions of the distribution system to measure and detect leakage; control operating pressures between pressure districts; control the path of water to manage pressure and energy losses, manage water quality, and supply water to the appropriate areas during emergencies (e.g., firefighting); and can assist in locating underground pipe.

Part of this study utilized valve information to estimate the consequences of failure (COF) of pipes. Using the City's hydraulic model, the model is run by iteratively "breaking" one pipe at a time, closing the surrounding valves as they would be done in actuality to allow for the pipe to be safely repaired, and determining which customers are impacted while the valves are closed. This is done for every pipe in the system (**see Section 5** for results).

Having a comprehensive inventory of isolation valves in the GIS is crucial for this evaluation of COF. If valves are missing from the GIS representation of the system, COF would be overestimated because a larger number of customers would appear to be impacted (in the model compared to in reality) by pipe breaks. Overestimating the COF of a pipe would elevate the priority of that pipe for replacement.

Based on the analysis completed as part of this study, it appears that a comprehensive inventory of isolation valves is included in the GIS. No further research was recommended as part of this project.

3. WATERMAIN CONDITION AND PERFORMANCE

3.1. Watermain Break Data

The City provided watermain break rate from 2010 (inclusive) through mid-2022 to support this study (see **Figure 3-1** for break data for full years through 2021). There are 803 breaks in the break database, including breaks on active and abandoned mains. The location of historical breaks is shown in **Figure 3-2**.

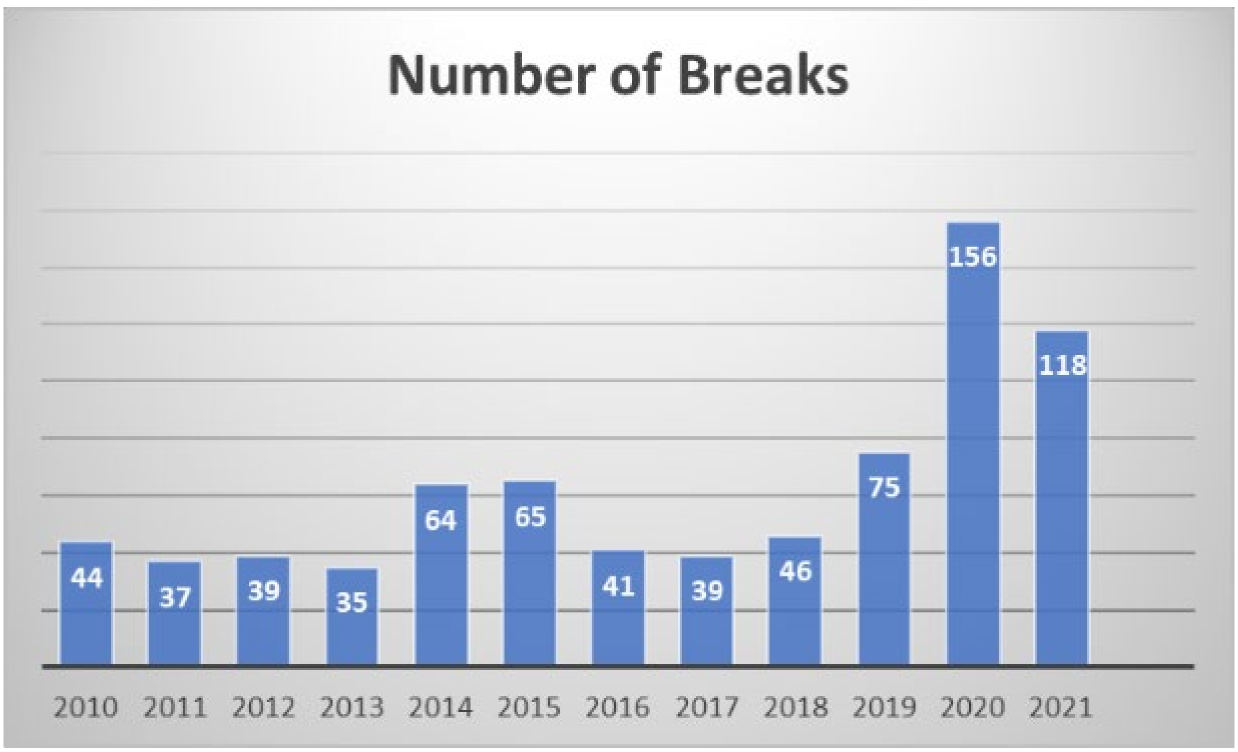


Figure 3-1. Distribution System Break Rate by Year

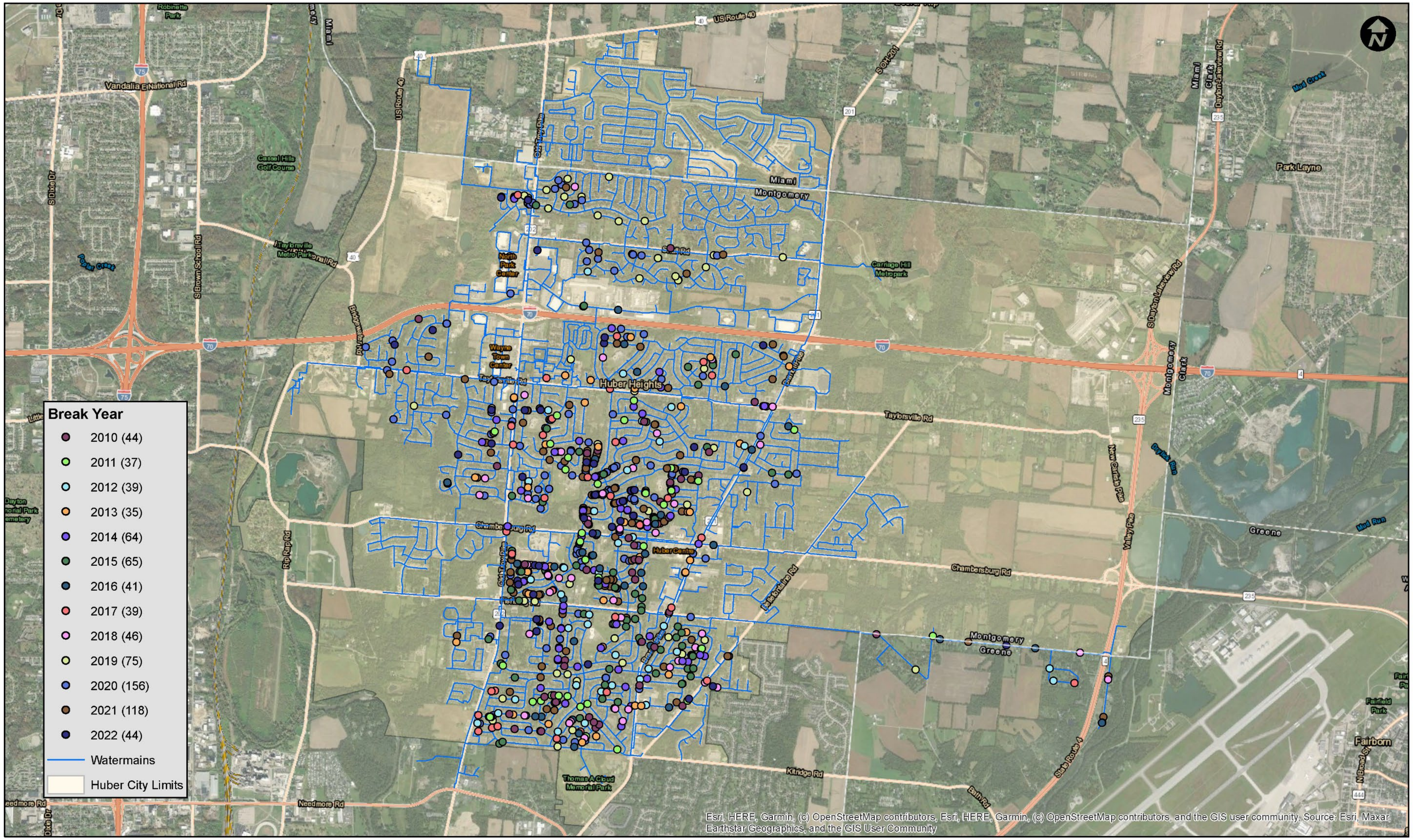


Figure 3-2. Historical (January 2010- July 2022) Water Main Breaks by Location

3.1.1. Break Data Quality Control

B&N applied quality control measures to the break database using the infraSOFT platform to assure the quality of final output. Built-in quality control measures identified issues related to:

- Breaks with no date
- Multiple breaks with the same break ID
- Duplicate entry of breaks (same pipe ID, same date of break, different break ID)
- Duplicate entry of breaks (same pipe ID, same date of break, same break ID)
- Date of break occurs after abandonment date (not an issue with this dataset as only active pipes were used)
- Date of break occurs before date of pipe installation
- No pipe ID associated with the break
- No break ID

Duplicate Break IDs

At the beginning of the project, B&N found four watermain break IDs that were duplicated. In each case, a sequentially adjacent ID number was unused. To resolve these duplicates, the changes in **Table 3-1** were made to break IDs and are now reflected in the City's GIS database:

Table 3-1. Duplicate Break ID Corrections

Duplicate Break ID	Address	New Break ID
520200004	6010 Channing Way	520200003
1220200001	6135 Sandbury	1220200002
920210002	6049 Hemingway	920210001
520210003	6931 Bascombe	520210004

Duplicate entry of breaks (same pipe ID, same date of break, different break ID)

Quality checks identified a potential issue with 4 sets of breaks that occurred on the same pipe on the same day, even though they had different break ID numbers. This is often a sign of duplicate entry of the same break, which could skew the analysis and prediction of future breaks if they are duplicates. These breaks (shown in **Table 3-2**) were discussed with City staff that determined these breaks were <u>not</u> the result of duplicate entry – these were actual breaks on different sections of the same pipe on the same day. Therefore, all eight of the breaks in Table 3-1 were included in the analysis.

Table 3-2. Breaks with Same PipeID and Date of Break, but Different Break ID			
Address of Break	**Break ID**	**Break Date**	**Pipe ID**
7039 Bascombe	720200013	2020-07-26	WM02313
7003 Bascombe	720200014	2020-07-26	WM02313
6026 Longford	820200010	2020-08-06	WM04401
Longford at Harshmanville	820200009	2020-08-06	WM04401
6127 Longford	820200024	2020-08-25	WM02308
6131 Longford	820200025	2020-08-25	WM02308
7051 Claybeck	820200026	2020-08-26	WM02315
7051 Claybeck	820200030	2020-08-26	WM02315
5704 Hinckley	102020004	2020-10-03	WM02300
5738 Hinkley	102020006	2020-10-03	WM02300

3.2. Historical Break Rate Analysis

This section presents the results of utilizing asset attribute data and historical watermain break data to predict future breaks.

3.2.1. Data Validation

Analysis of project break data is hindered by three events significantly impacted pipe break rates:

1. 2019: Prior to the commissioning of three booster stations to increase pressures north of I-70, gradual increases in operating pressures north of I-70 began in late May / early June, increasing breaks by a factor of 30 over the eight following months.
2. 2020: Upgrades to the Rip Rap Road Water Treatment Plant changed flow and pressures in some areas, and water quality (commissioning date May 1, 2020)
3. 2020: Abandonment of the Needmore Road Water Treatment Plant changed flow and pressures in some areas, and water quality (last water pumped on July 20, 2020)

Analysis presented in **Section 4** of this report indicates that:

- These changes were the causes of the spike in break rate beginning in 2019.
- The impacts of higher pressures north of I-70 appear to have significantly dissipated.
- While water quality issues associated with the commissioning of the Rip Rap Road Water Treatment Plant improvements were resolved in late 2021, the 44 overall breaks in the system through July 2022 is virtually equal to the average annual break rate prior to 2019, suggesting some continued impacts. More time is needed to make conclusion of the lasting impacts on overall break rate.

B&N recommends that prediction of future breaks (and the plan to mitigate them to an acceptable level) exclude those impacts until more data is captured over time. If watermain breaks continue at rates that significantly surpass the 2010-2018 break rates, the mitigation measures recommended in the study can and should be accelerated.

The data presented in this section utilizes break data from January 2010 through April 2019 (inclusive). Data from May 2019 and beyond is excluded.

3.2.2. Systemwide Break Analysis

Table 3-3 shows the number of breaks (from January 2010 through April 2019) and length of pipe associated with each material following the removal of smaller pipes.

Table 3-3. Number of Breaks (Jan 2010 - Apr 2019) and Total Pipe Length by Material			
Material	**Number of Breaks**	**Total Length of Pipe Material (miles)**	**Percent of Total Length**
CI	410	91.9	44.0
DI	19	111.2	53.3
PCCP	4	5.7	2.7
CI=Cast Iron; DI=Ductile Iron; PCCP=Prestressed Concrete Pipe			

Overall Break Rate versus Age (all materials). The data in **Figure 3-3** shows how the break rate of distribution system pipes increases with age, as expected. While watermains in the system experience a very low break rate through about 40 years of age, the break rate rises significantly after age 40.

This rapid increase in break rate is a concern because a significant portion (64 percent) of the distribution system is older than 40 years old (See **Table 3-4**). **Figure 3-4** shows the length of watermains in the system based on age (note the high length of DI pipe at age 45 is the result of assigning some DI pipes with unknown installation dates and install year of 1977).

Table 3-4. Length of Pipe by Age Range		
Age of Pipe	Length	Percentage of Overall Length
0-20 years	43 miles	21%
21-40 years	31 miles	15%
>40 years	132 miles	64%

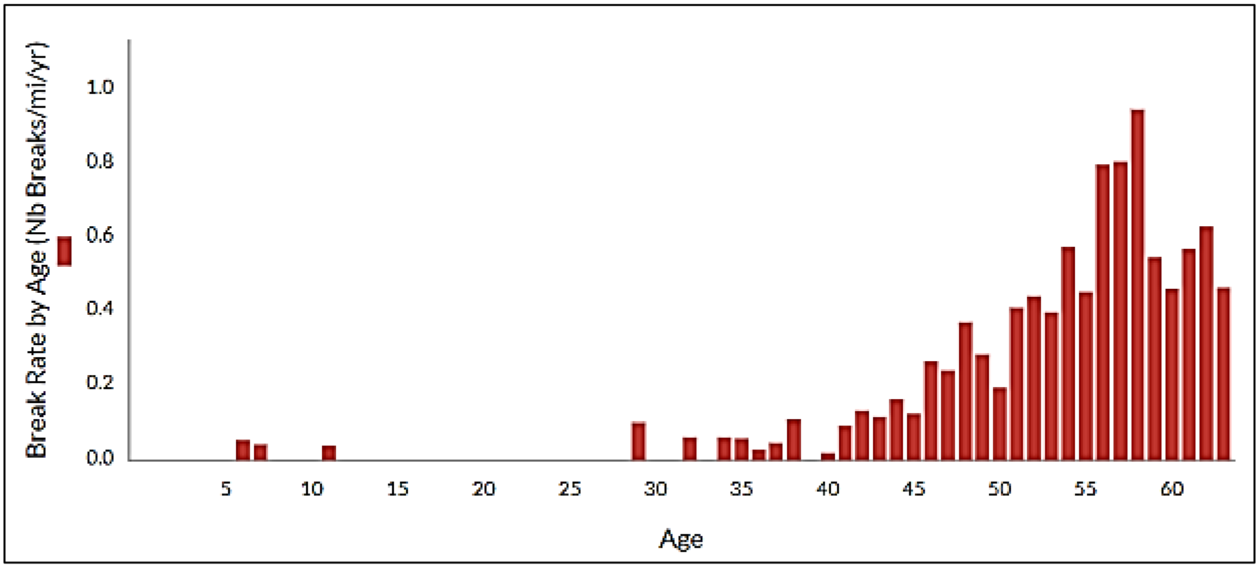


Figure 3-3. Systemwide Break Rate versus Age *(Nb=number; mi=miles; yr=year)*

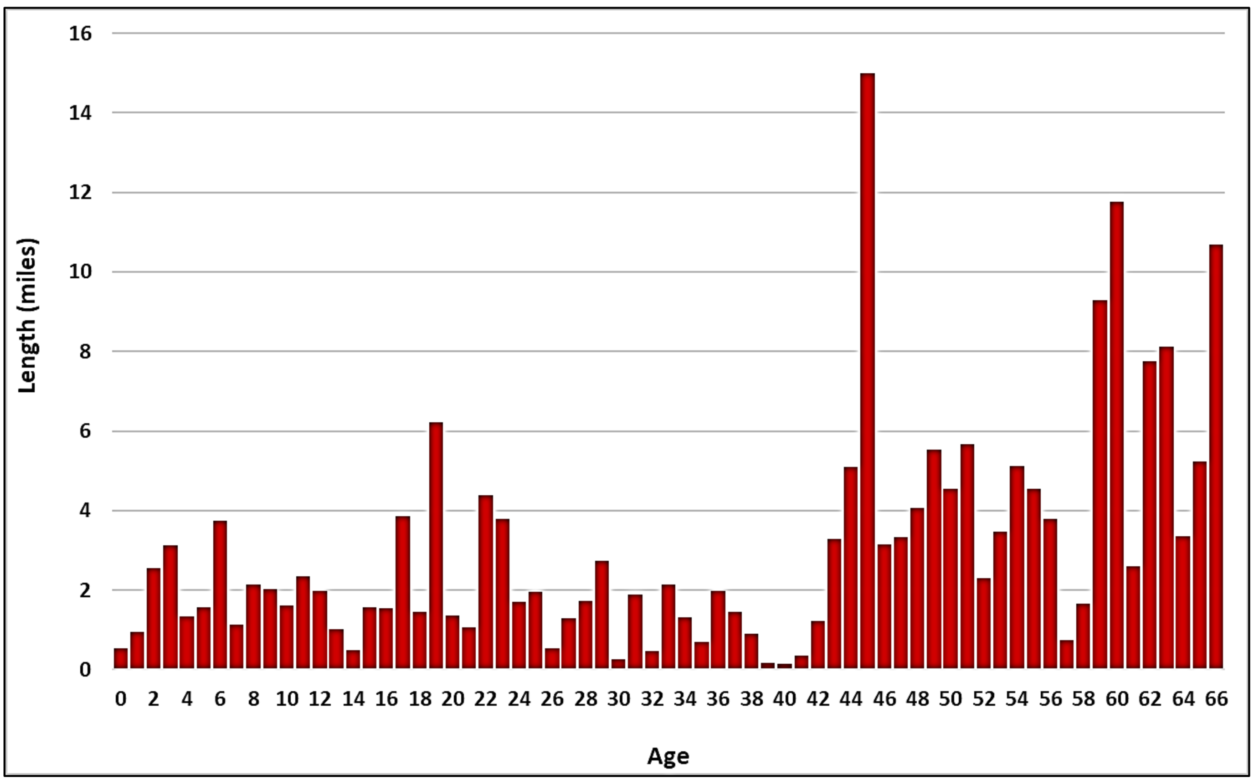


Figure 3-4. Length of Pipe by Age

Watermain break rate is dependent on more than age. Two other primary factors include material and diameter. **Figure 3-5** shows the relationship between break rate (red bars) and material, with cast iron showing a very high break rate (0.46 breaks per mile per year) and average age (black points on the figure) of 56 years. Ductile iron has a very low break rate (0.02 breaks per mile per year with an average age of 26 years). Despite its average age of 55 years, PCCP pipe has a relatively low break rate (0.07 breaks per mile per year), which is in line with longevity predictions of PCCP pipe in the Midwest (105 years), as published in the American Water Works Association (AWWA) Buried No Longer report.

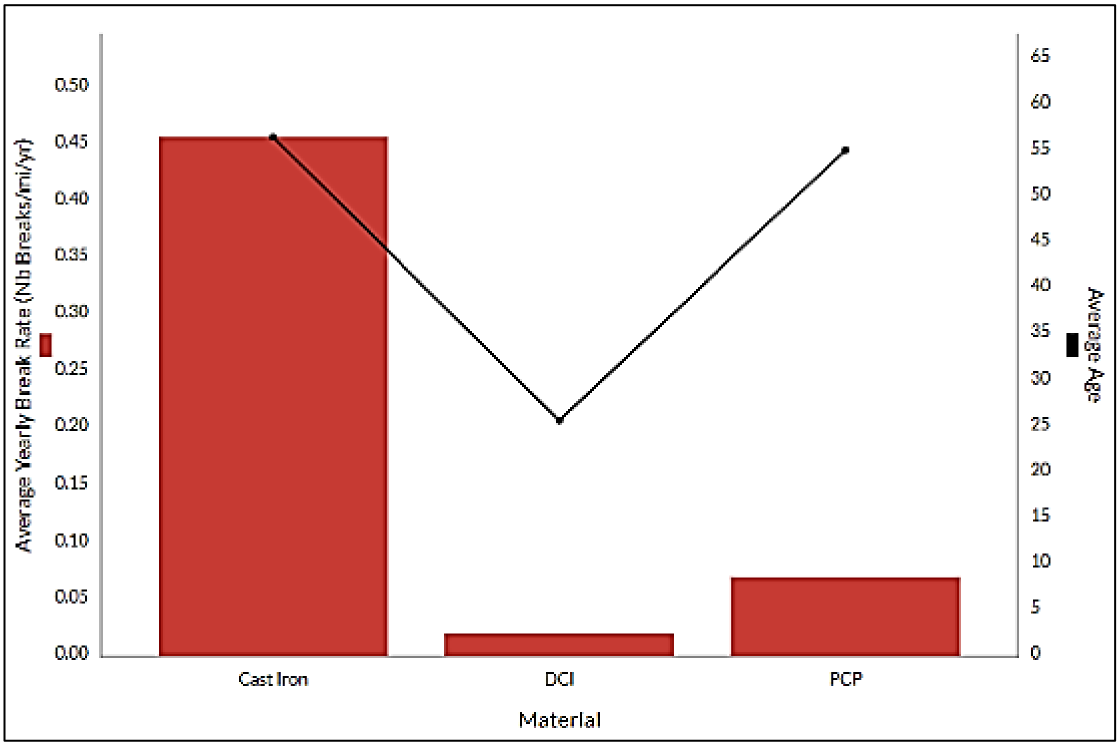


Figure 3-5. Average Annual Break Rate and Average Age of CI, DI, and PCCP

Figure 3-6 illustrates the relationship between break rate and pipe diameter. As expected, the break rate decreases as the diameter increases. This is generally because larger diameter pipes have greater wall thickness and take longer for deterioration to cause breaks. The two anomalous values in the chart can be largely explained: The lower than expected break rate for 8-inch pipes is due to the fact that most 8-inch pipe is (a) younger pipe (the average age of 8-inch pipe is 24 years old, as shown by the black points in the figure, compared to 52 years old for 6-inch pipe and 51 years old for 10-inch pipe; and (b) 87-percent of 8-inch pipe is ductile iron pipe, which is performing far better than cast iron – see Figure 3-5 above). The lower-than-expected break rate for 4-inch pipe has a different explanation related to statistical significance: only 1 break has occurred on 4-inch pipe; there are only 0.6 miles of 4-inch pipe in GIS. One additional break on 4-inch pipe would double its break rate to a more expected value. It is possible not all breaks on 4-inch pipe are recorded as they may be private service connections.

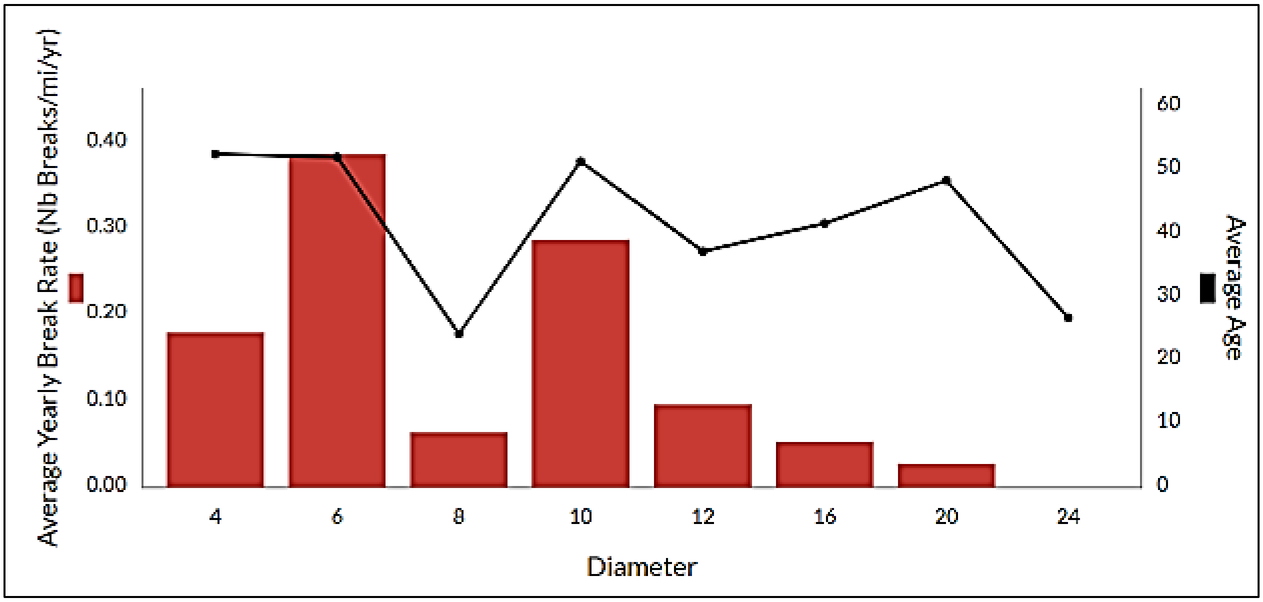


Figure 3-6. Systemwide Break Rate versus Diameter

The next three subsections describe break performance based on pipe material.

3.2.3. Performance of Cast Iron (CI)

Figure 3-7 shows the relationship between the break rate for CI versus age. For CI pipe older than 50 years old, the break rate is significantly higher than the systemwide average break rate of 0.22 breaks per mile per year.

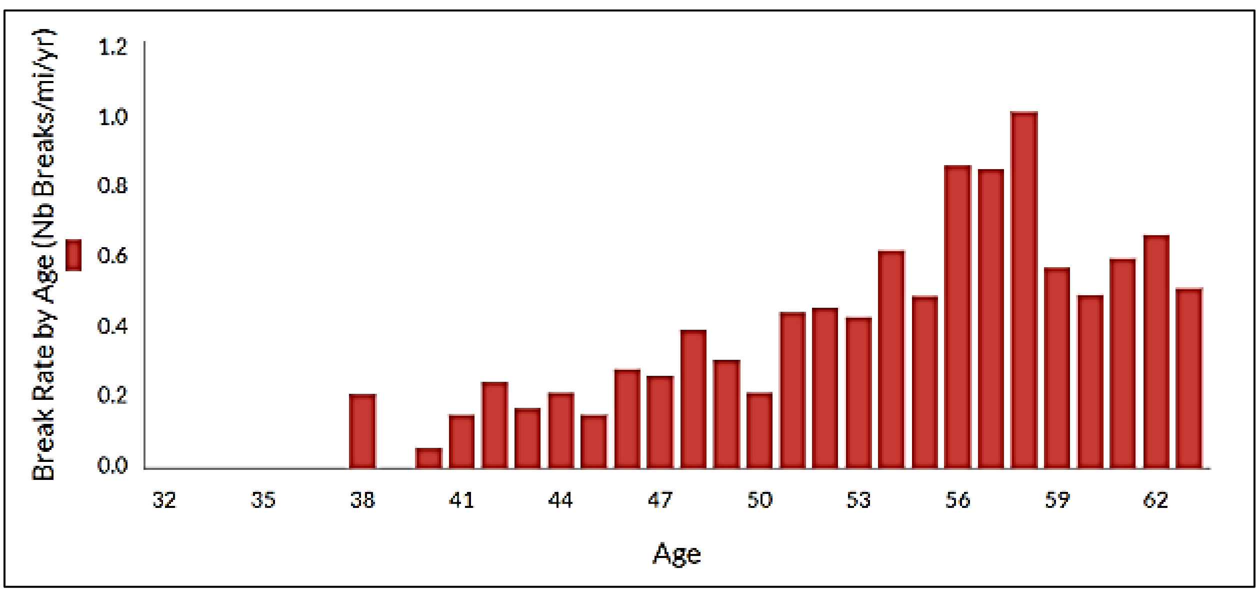


Figure 3-7. Average Yearly Break Rate and Length by Age of CI Pipe

(*Note: because the* *break* *database goes only as far back as 2010, and because there is no cast iron present in the system with an installation data after 1978, all cast iron pipe was at least 32 years old when break data begins, hence why the age in Figure 3-7 starts at 32 years.)*

Figure 3-8 shows the relationship between the break rate for CI versus diameter. The general trend in break rate is downward as diameter increases, which is the expectation. The low break rate for 4-inch diameter is based on having only 1 break and a relatively small relative length (0.5 miles).

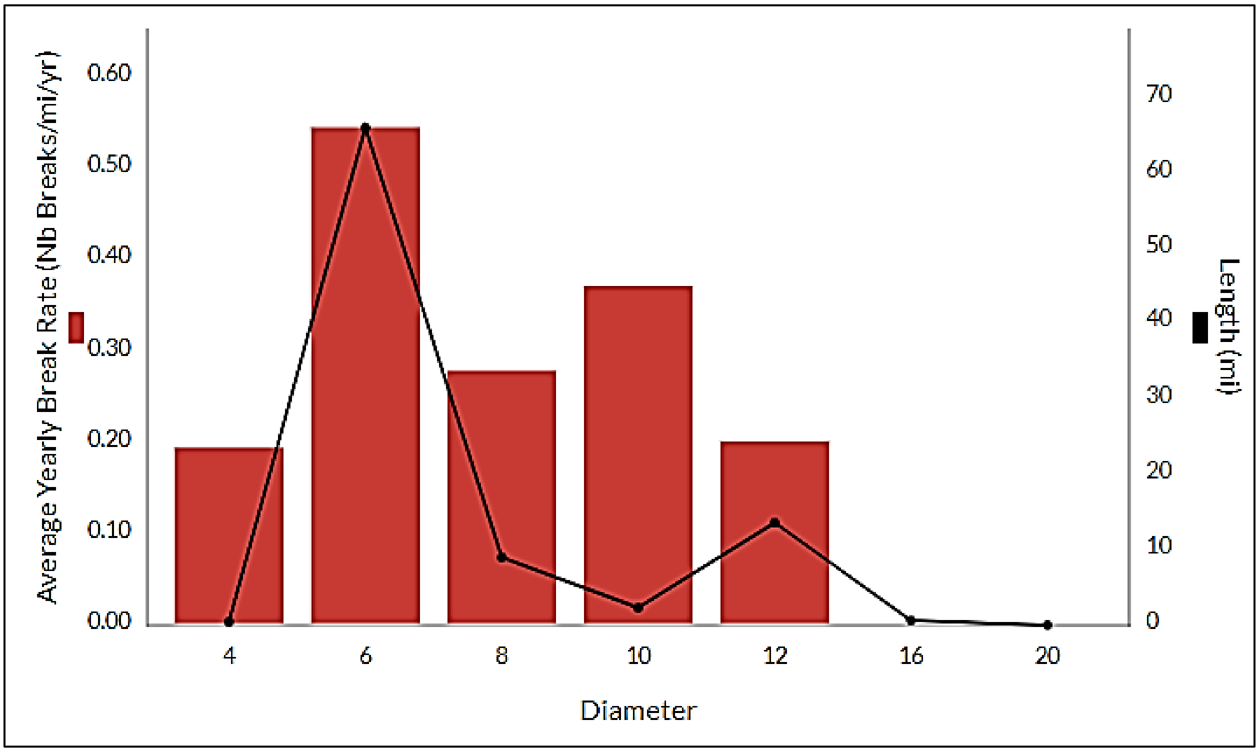


Figure 3-8. CI Break Rate by Diameter

3.2.4. Performance of Ductile Iron (DI)

Figure 3-9 shows the relationship between the break rate for DI versus age. Because there have been a small number of cumulative breaks on DI pipe, the data appears scattered. However, the general trend of fewer breaks at earlier ages versus more frequent breaks as age increases is expected.

Figure 3-10 shows the relationship between the break rate for DI versus diameter. The general trend downward is expected, and the lack of a break rate for 10-inch pipe is related to the very small amount of 10-inch DI in the system (0.6 miles).

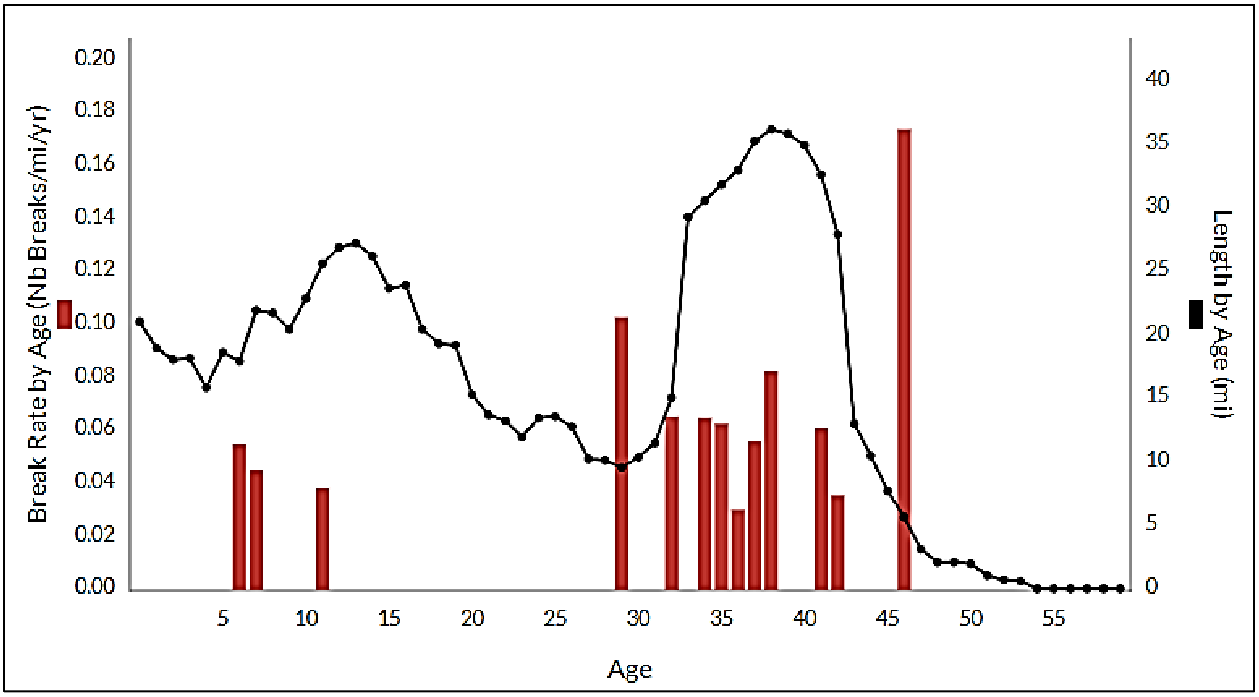


Figure 3-9. Average Yearly Break Rate and Length by Age of DI Pipe

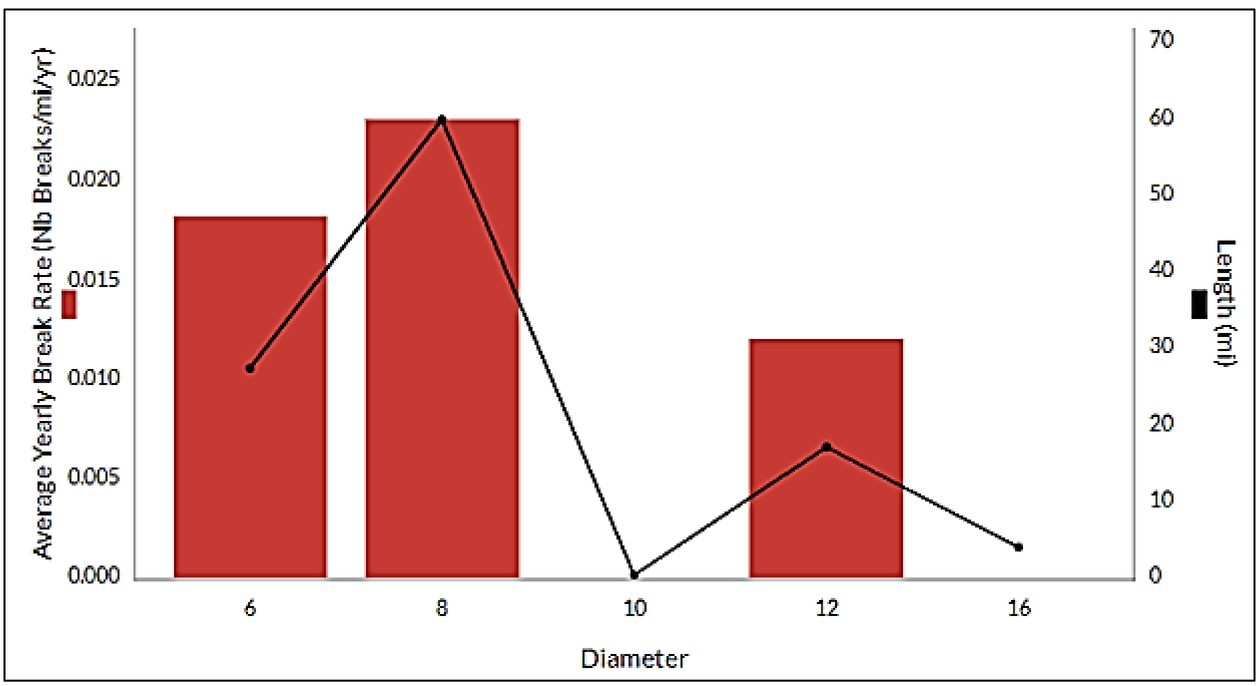


Figure 3-10. DI Break Rate by Diameter

3.2.5. Performance of Prestressed Concrete Pipe (PCCP)

About 2.7-percent of the distribution system (5.73 miles) is PCCP, and most PCCP (92%) is either 16 or 20 inches in diameter (See **Table 3-5**). Of the 5.73 miles of active PCCP pipe, 4.75 miles were constructed between 1956 and 1963, while 0.98 miles of 20- and 24-inch PCCP was constructed in 1991 as part of the Taylorsville Wildcat project.

Only 4 breaks have been recorded on PCCP pipe, all of which occurred on older, 16-inch PCCP (See **Figure 3-12**). **Figure 3-11** shows that the break rate for each vintage of pipe is below the system average break rate of 0.22 breaks per mile per year.

Table 3-5. Length of PCCP and Breaks by Diameter			
Diameter	Length	Percent of Overall Length	Historical Breaks
6	0.0004	0.01%	0
8	0	n/a	n/a
10	0.11	1.86%	0
12	0	n/a	n/a
16	2.9	50.61%	4
20	2.4	41.34%	0
24	0.4	6.18%	0

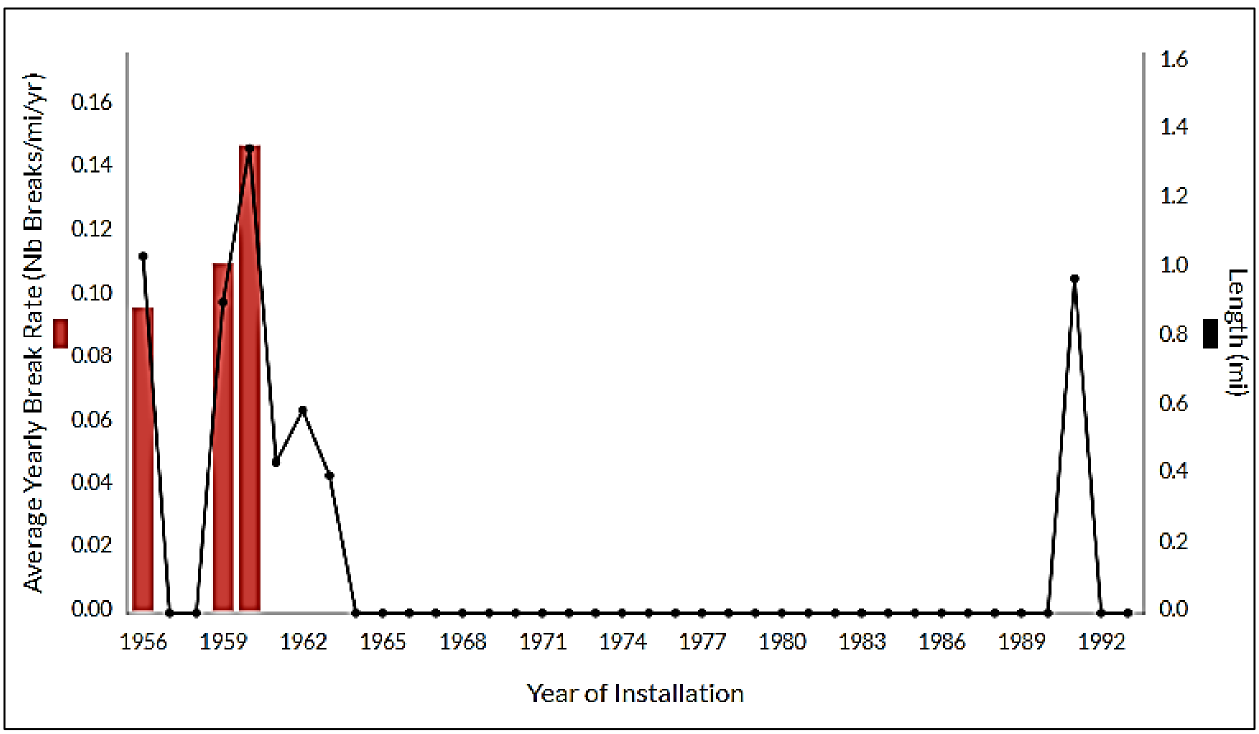


Figure 3-11. Average Yearly Break Rate and Length by the Year of Installation of PCCP Pipe

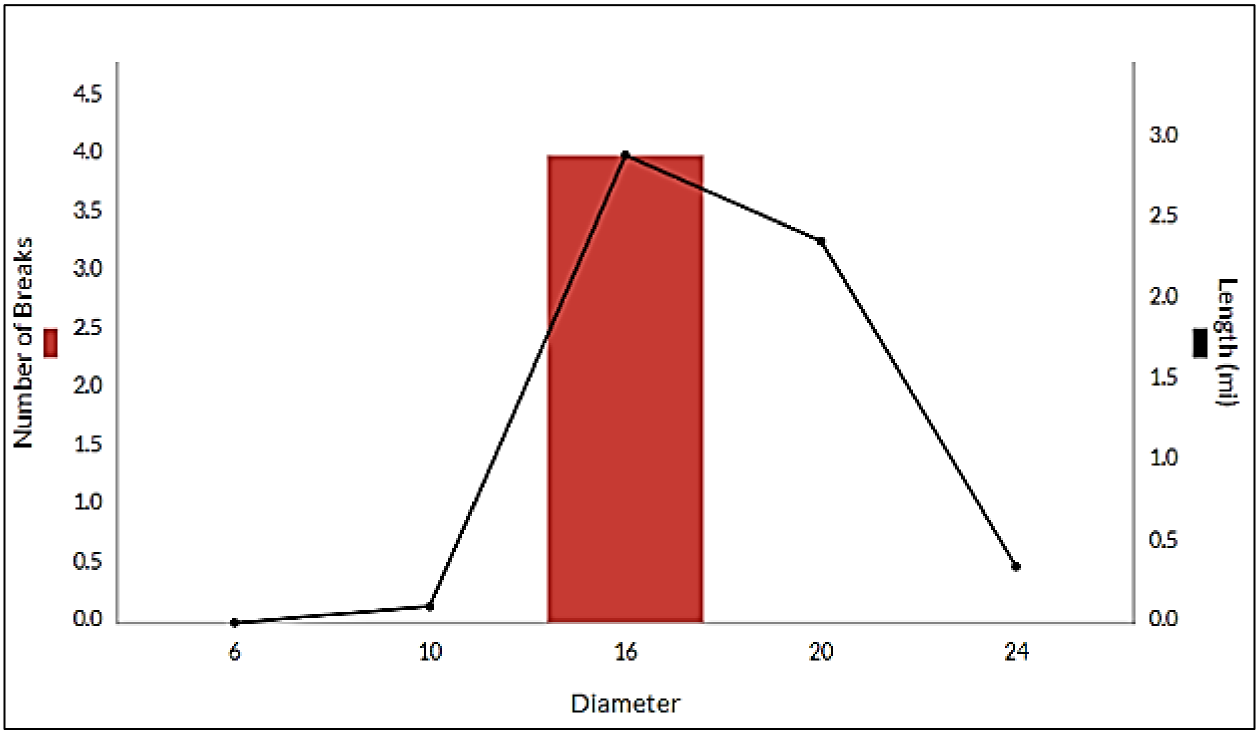


Figure 3-12. PCCP Break Rate by Diameter

Despite it relatively high average age (55 years), the relatively low number of breaks on PCCP pipe is consistent with industry average values, which assign a relatively long useful life for PCCP pipe (105 years, according to the AWWA Publication "Buried No Longer"). It is also believed to be consistent with an analysis of soil properties in Huber Heights, which show concrete corrosivity in soils of either "low" or "moderate" on a scale of low, moderate, and high (see below for further discussion).

3.2.6. Impact of Soils on Historical Breaks

B&N utilized the US Department of Agriculture - Natural Resources Conservation Service soil survey database to access information about the corrosiveness of native soils in Huber Heights. This database was updated in September 2022. An example of the soil type data for Huber Heights within Montgomery County is shown in **Figure 3-13**. While the soil types shown in this figure are not legible as shown, it is the subsequent maps that illustrate the properties of those soils that are relevant to this study.

Figure 3-13. Soil Type Map for Northeast Montgomery County

The soil database assesses the "risk of corrosion to concrete" in a single parameter that pertains to potential soil-induced electrochemical or chemical action that corrodes or weakens concrete. The rate of corrosion of concrete is based mainly on the sulfate and sodium content, texture, moisture content, and acidity of the soil. The risk of corrosion is expressed as "low," "moderate," or "high" in the database. There are no areas that are highly corrosive to PCCP in Huber Heights (see **Figure 3-14**).

The soil database also assesses the "risk of corrosion to steel" in a single parameter that pertains to potential soil-induced electrochemical or chemical action that corrodes or weakens uncoated steel. The rate of corrosion of uncoated steel is related to such factors as soil moisture, particle-size distribution, acidity, and electrical conductivity of the soil. The risk of corrosion is expressed as "low," "moderate," or "high". While iron can develop a patina to inhibit corrosion of the metal's integrity, potentially giving it better corrosion resistance than steel, the failure morphology for steel and iron watermains is similar ("Control of External Corrosion of Iron and Steel Watermains", R.A. Gummow, 2004). This parameter is, therefore, applicable to iron pipes. For Huber Heights, soils are either highly or moderately corrosive to metal (See **Figure 3-15**). There are not soils in Huber Heights that have low corrosion for steel.

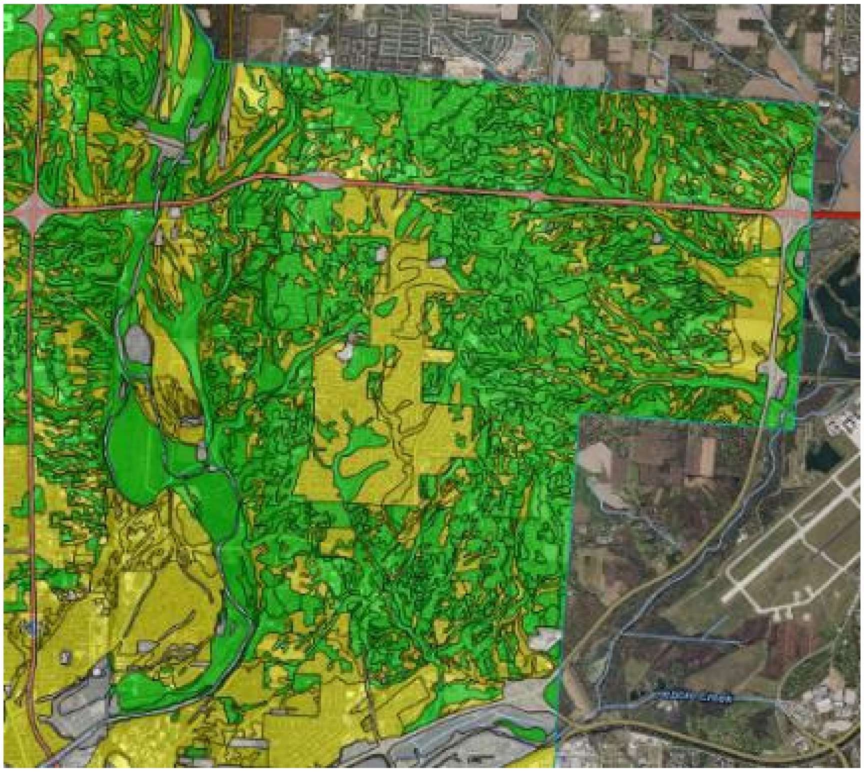


Figure 3-14. Risk of Soil Corrosion for Concrete (Montgomery County only)

(Green = Low Corrosivity for Concrete; Yellow = Moderate Corrosivity for Concrete)

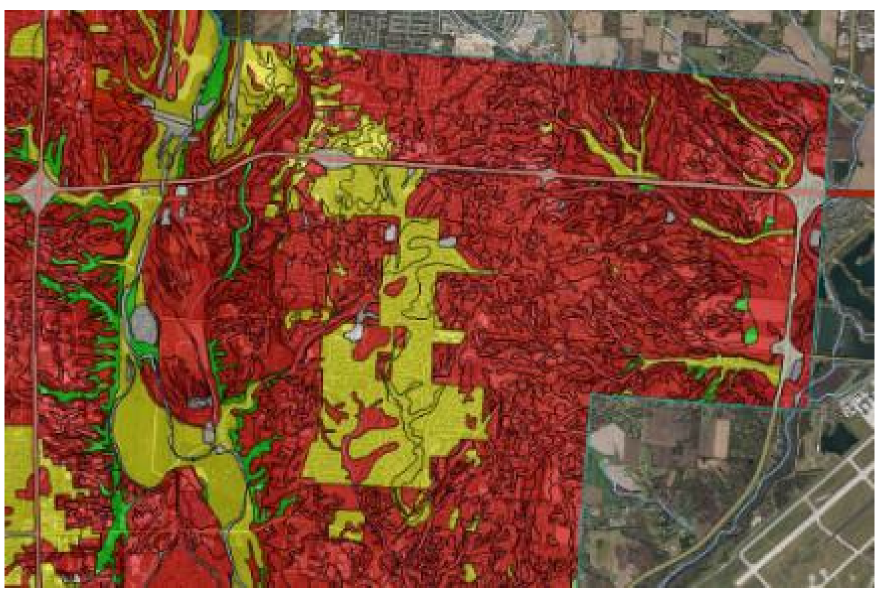


Figure 3-15. Risk of Soil Corrosion for Steel (Montgomery County only)

(Yellow = Moderate Corrosivity for Steel; Red = High Corrosivity for Steel)

For this analysis, the break rate of prestressed concrete cylinder pipe (PCP or PCCP) in moderately corrosive soil is compared to PCP in low corrosive soil. For the purposes of the comparison (shown in **Figure 3-16**), for PCP pipe, "bad" = moderately corrosive and "good" = low corrosive soil.

Additionally, the break rate of CI and DI pipe in highly corrosive soil (shown as "bad" in **Figure 3-16**) is compared to CI and DI pipe in moderately corrosive soil (shown as "good"). There are no low-corrosive soils for metal pipe in the entire service area.

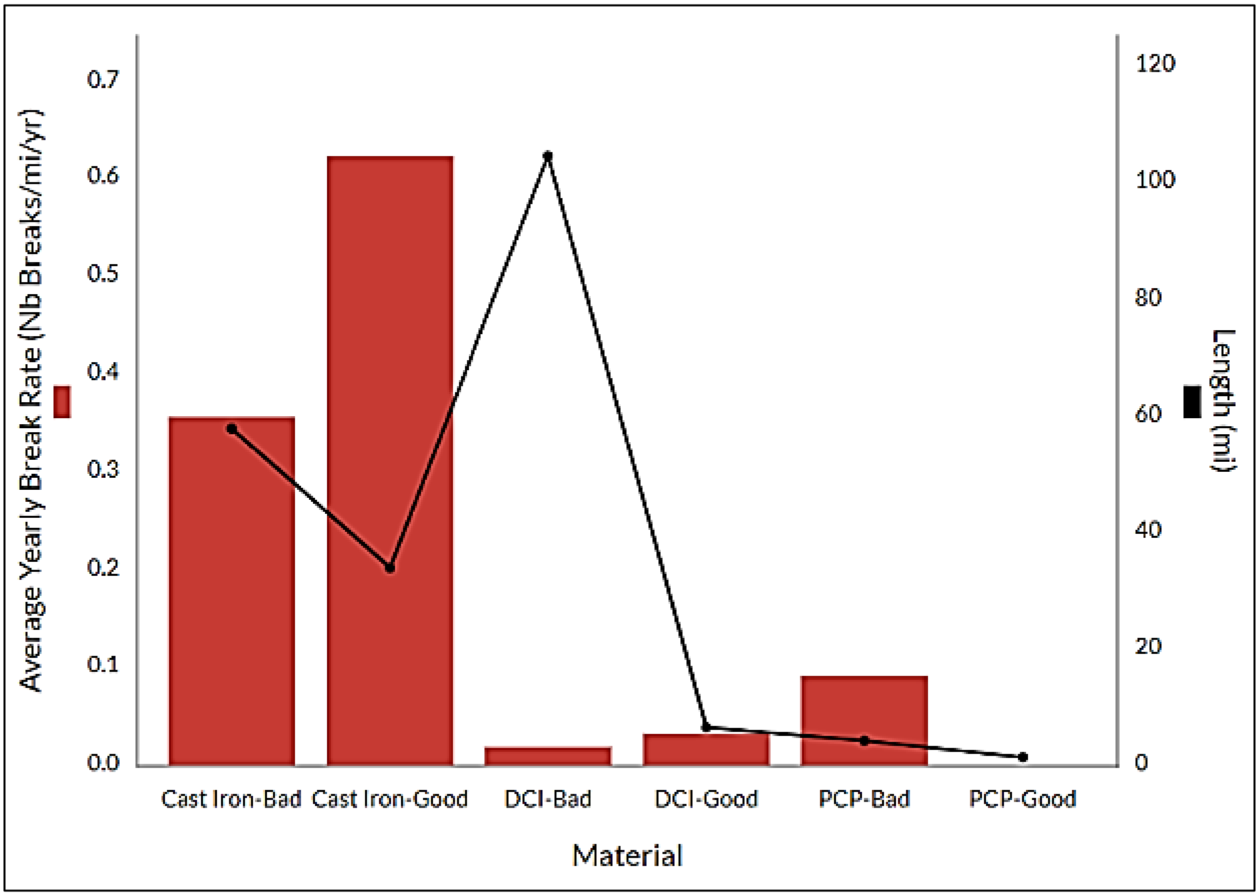


Figure 3-16. Break Rate Based on the Combination of Material and Soil Corrosivity

For PCP, all breaks occurred on pipes in "bad soil" – in this case moderately corrosive soils versus "good soil" with low corrosivity.

However, for CI and DI pipes, there is an inverse correlation between soil corrosivity and the break rate. There are possible explanations for the inverse relationship:

- If pipes in highly corrosive soils were replaced in the past but those replacements are not reflected in the abandoned mains data used for this project, the remaining pipes in highly corrosive soils could appear to have a better-than-expected break rate, and/or

- Because all native soils in the study area are at least moderately corrosive to metal (there are no low-corrosive soils for metal), all pipes are deteriorating at an accelerated rate that is not distinguishable.
- Because backfilling procedures were updated in the early 1980s and pipes were no longer backfilled with native soil, but rather engineered soil backfill after that, the native soil would not impact on post-1980 pipe break rates. This would apply almost exclusively to ductile iron as no cast iron pipe was installed after 1980.

Because no meaningful correlation could be found between corrosivity for steel and CI and DI pipe, soil corrosivity was not used as a factor in the prediction of future breaks for metal pipe.

3.3. Prediction of Future Breaks

Using the historical break data and information on pipe attributes, predictions of the probability of future breaks for each individual pipe were made using infraSOFT. infraSOFT uses a machine learning algorithm to correlate the data for breaks, pipes, and soils to make predictions of future performance.

Predictions are based on break data from January 2010 through April 2019 only, excluding the rise in break rate beginning in May 2019, as discussed in **Section 4** of this report. This methodology assumes that the causes of the rise in break rate have been addressed (based on available information) and that the break rate should subside. It is too early to definitively conclude if the break rate will subside entirely to pre-2019 levels on its own. Even if the break rate in 2023 and beyond is higher than pre-2019, it is unlikely to approach 2019-2022 levels, so using 2019-2022 data is not appropriate regardless.

The predicted systemwide break rate, assuming no proactive pipe replacement occurs, and assuming the causes of the 2019-2022 rise in breaks are fully addressed, is shown in **Figure 3-17**. The data shows that the number of breaks in the system would more than triple over the next 15 years (by 2037) compared to the 2010-2019 average of approximately 45 breaks per year. *Note: this figure does not account for line replacements after 2019*.

A map of the predicted breaks in 2023 is shown in **Figure 3-18**. This figure shows the estimated number of breaks on a pipe asset, and because longer pipes will have a higher likelihood of failure than shorter pipes with the same break rate, longer pipes in general will have higher predicted break numbers. For that reason, pipes are also examined based on their predicted break rate, shown in **Figure 3-19**.

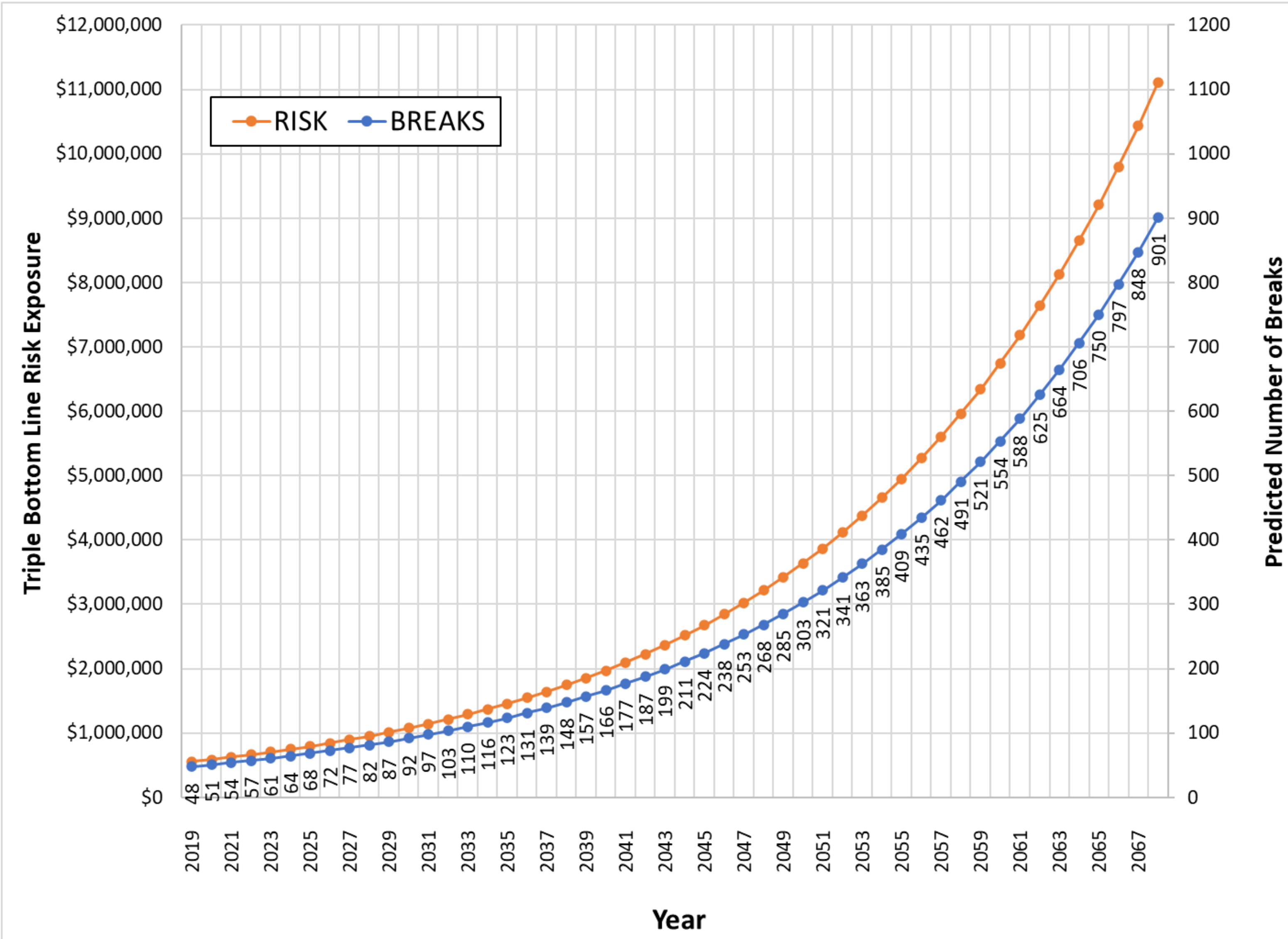


Figure 3-17. Break Rate and Number of Breaks versus Time (No Replacement)

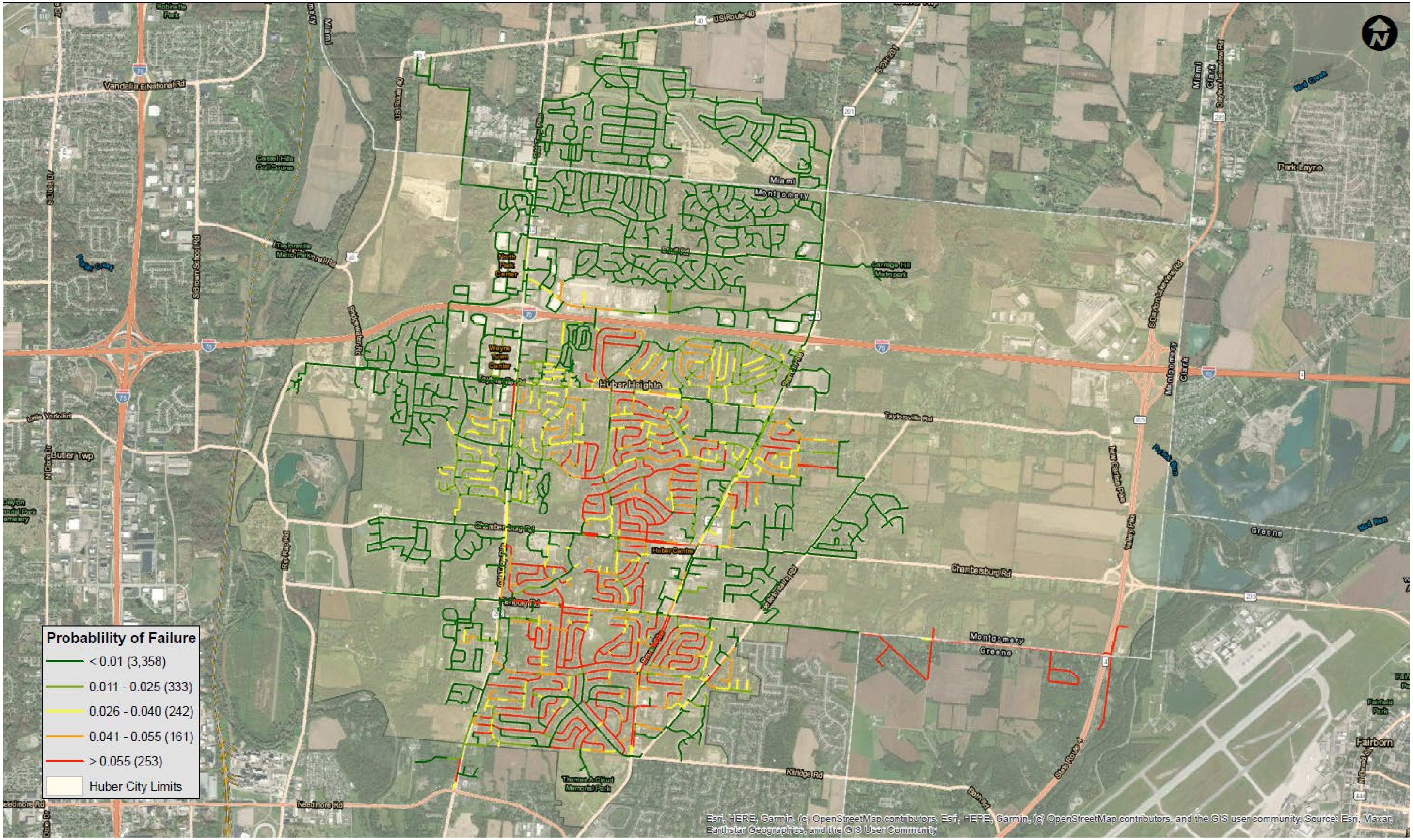


Figure 3-18. Current Probability of Pipe Breaks

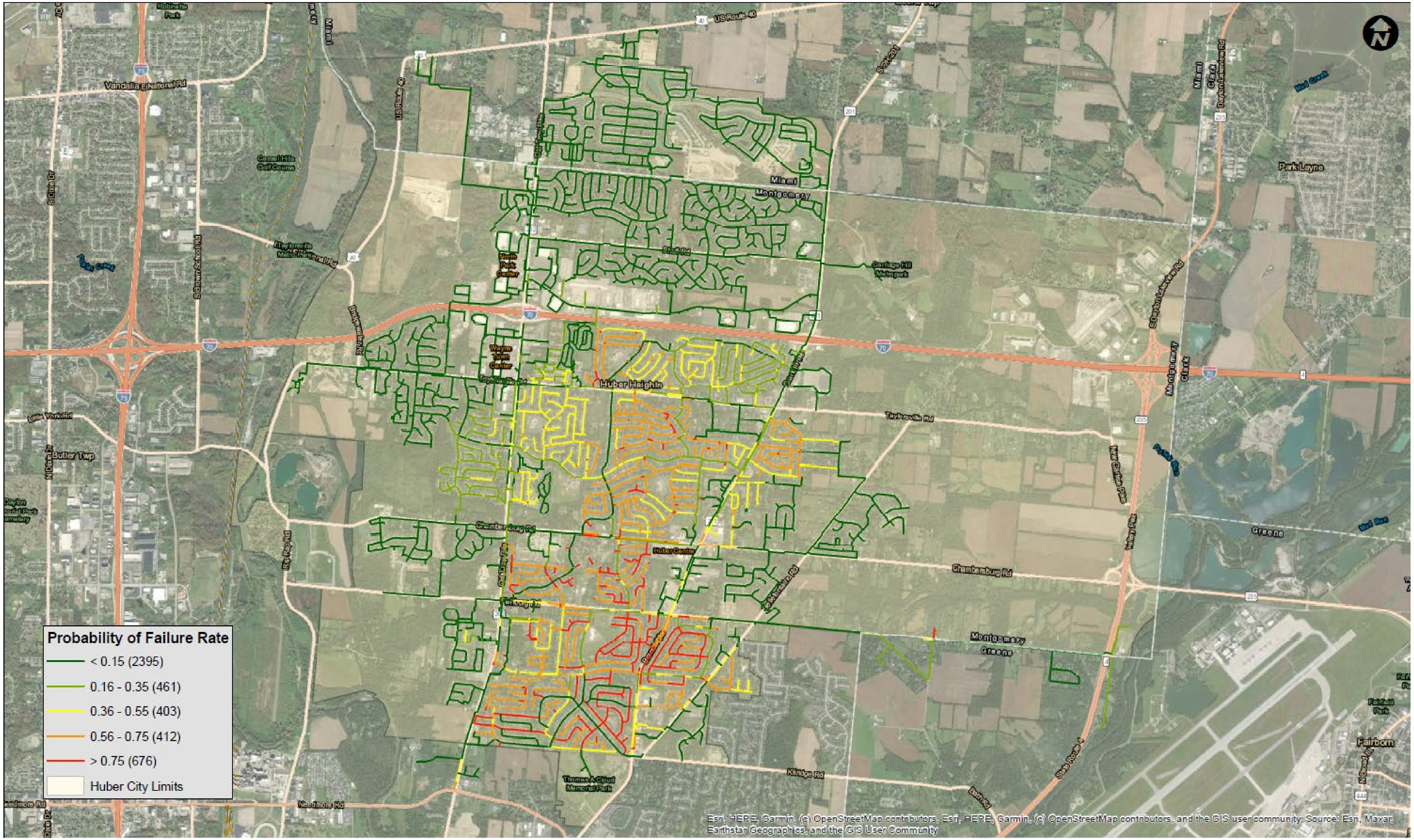


Figure 3-19. Current Predicted Break Rate

4. IMPACTS OF OPERATIONAL CHANGES

The impacts of operating practice changes on breaks are discussed in this section:

- Changes to pipe bedding material
- Increase in pressure north of I-70
- Commissioning of upgrades to Rip Rap Road Water Treatment Plant (RRR WTP) and decommissioning of the Needmore Road Treatment Plant

4.1.Pipe Bedding Changes

The analysis of the impacts of changes to pipe bedding practices around 1985 is hindered in that pipe constructed after 1985 is virtually all ductile iron pipe, and all cast iron pipe was built before 1980. Differences in break rates before and after 1985 could be associated with the different performance of materials rather than (or in addition to) backfill.

Examining DI pipe only, **Figure 4-1** shows that the break rate of DI pipe installed after 1985 is extremely low. This supports the potential conclusion that pipe bedding changes have had beneficial results. However, (a) pipe installed after 1985 is relatively young and breaks are not expected in significant quantities, and (b) even DI pipe installed between 1975 and 1985 exhibited a relatively low break rate.

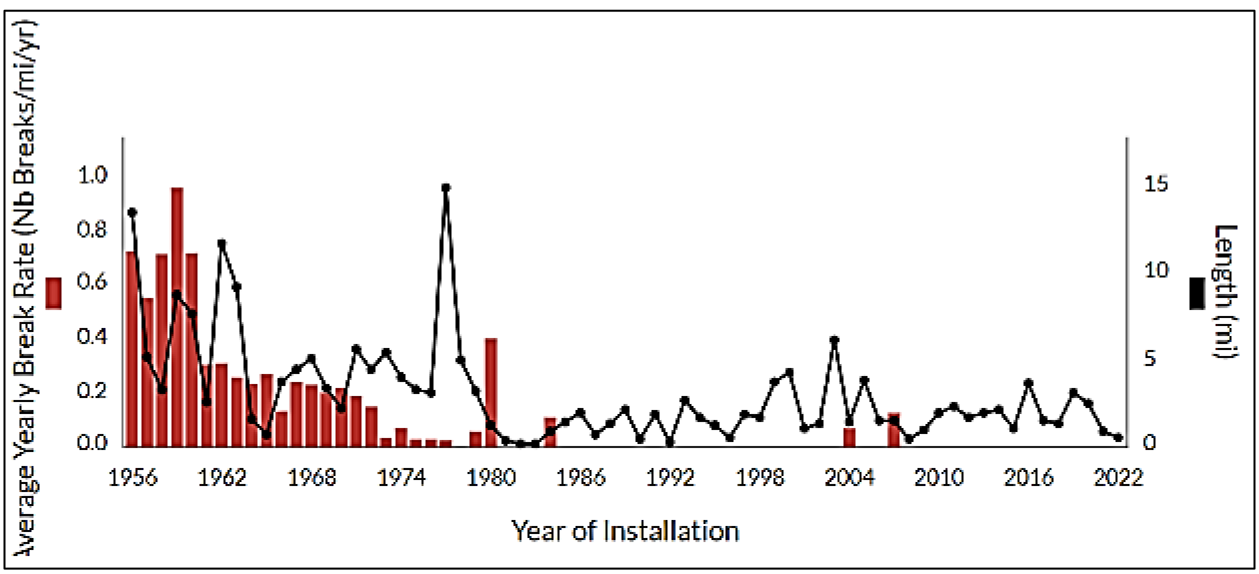


Figure 4-1. Average Annual Break Rate of DI Pipe Based on Year of Installation

DI Pipe was separated into two cohorts: DI installed through 1985 and DI installed in 1986 and after. Their aging curves (which shows break rate versus age) for each cohort are shown below in **Figures 4-2 and 4-3**. The two most significant number to examine in each aging curve figure are the annual rate of increase of breaks in the top right corner (1.0709 and 1.0743) and the break rate at age 50 for each cohort in the bottom left corner (0.108 and 0.107). These number are nearly identical and suggest the break rate between cohorts (and therefore the impacts of new backfill procedures in 1985) are indeterminate with the data currently available.

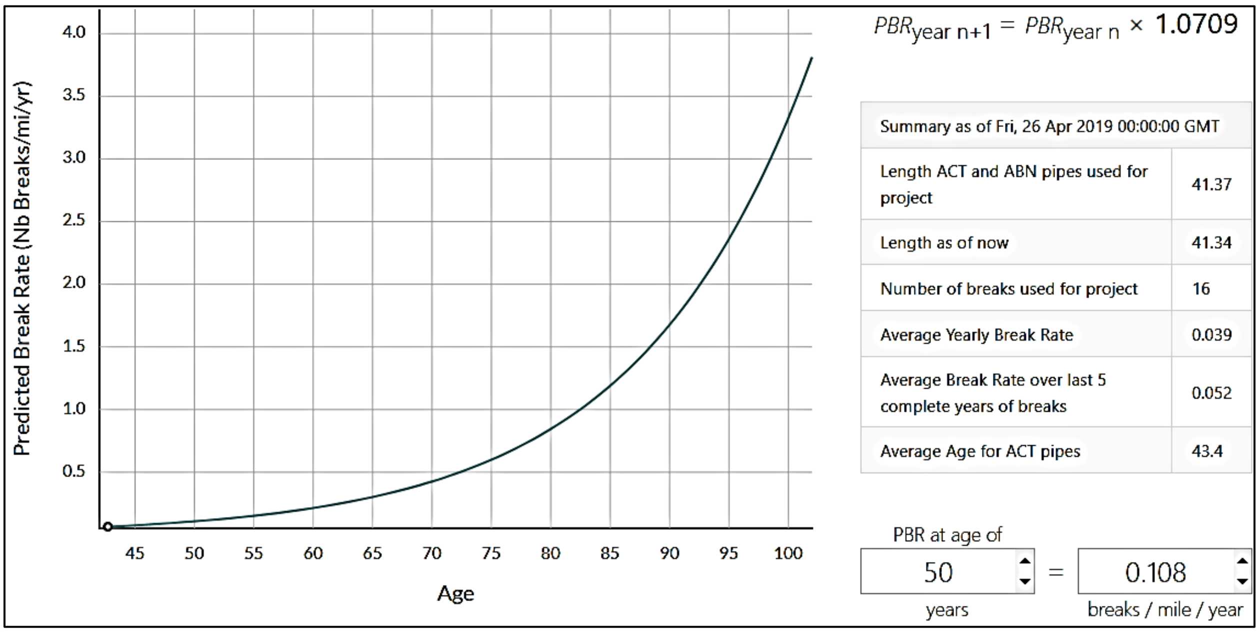


Figure 4-2. Aging Curve for DI Pipe Built Through 1985

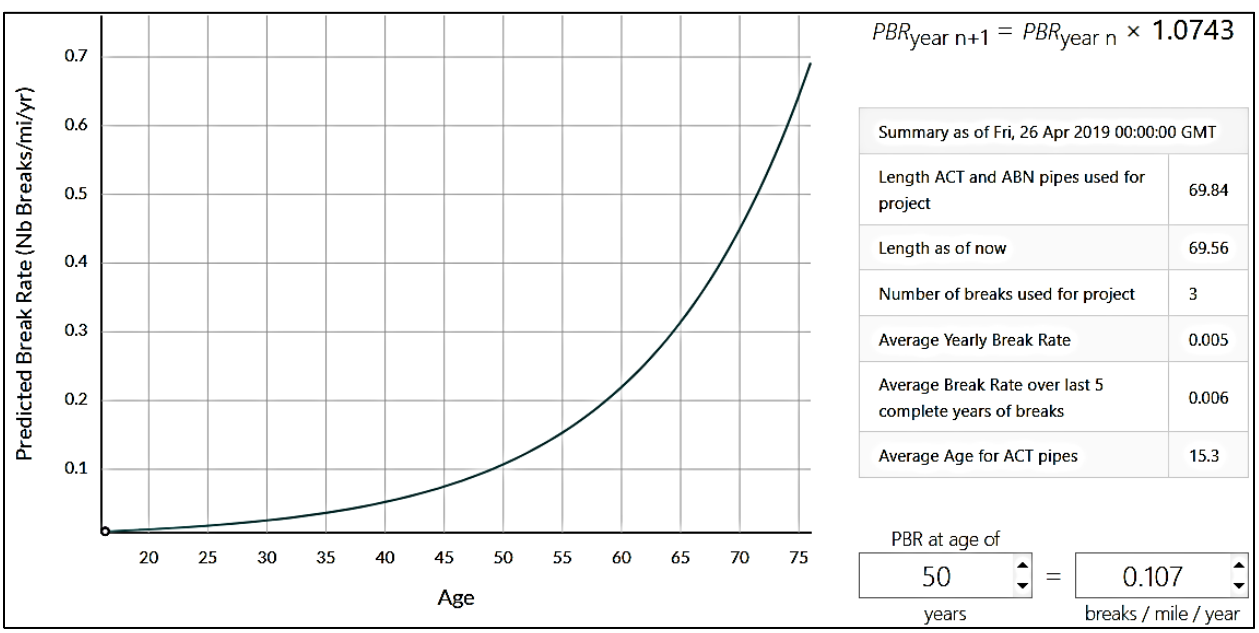


Figure 4-3. Aging Curve for Post-1985 DI Pipe

This does not mean that backfilling has not had a beneficial result. The break rate for DI pipe is so low through early 2019 that any difference in the impacts of backfilling may take more time to emerge.

However, the cast iron (CI) aging curve in **Figure 4-4** shows a CI break rate at age 50 is 0.377, over 3.5 times higher for CI than for DI. While different materials are expected to behave differently, this difference in break rate between these two materials is greater than expected and may be a result of all CI being installed in native soil prior to changes in backfilling procedures. The differences in break rate between CI and DI pipe are captured in future break predictions.

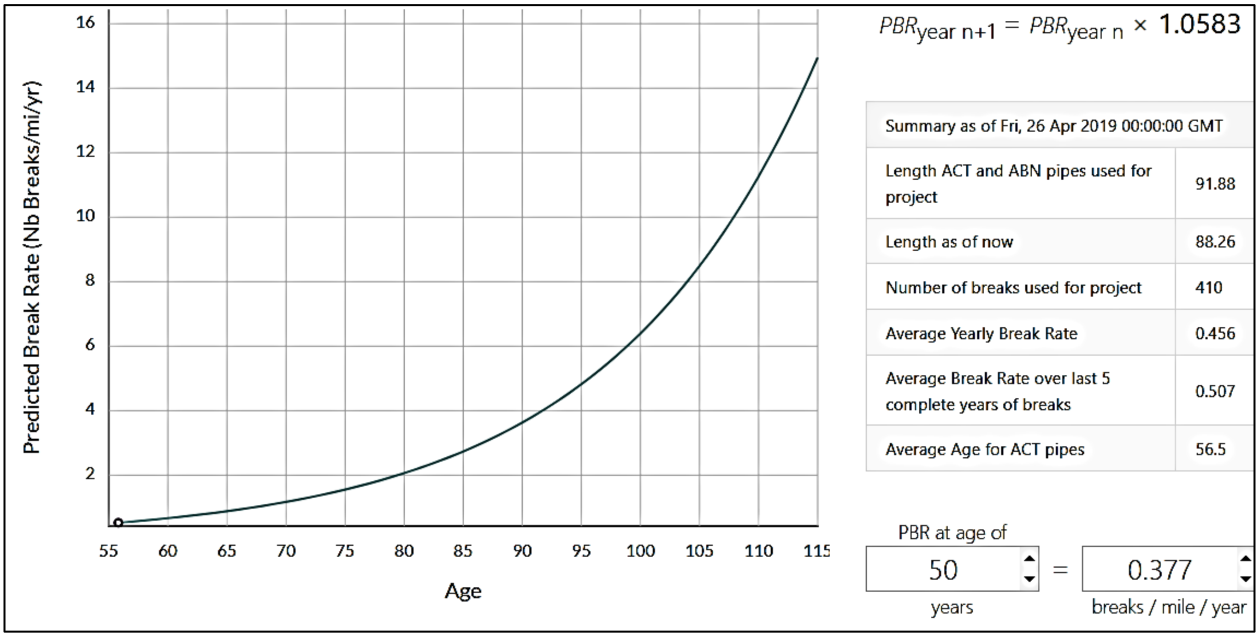


Figure 4-4. Cast Iron Aging Curve

4.2. Increased Pressure North of I-70

The boosting of pressures from 40 psi to 60 psi north of I-70 was expected to increase breaks for two reasons:

- Increased water pressure places more strain on the pipes. Though the pipes in the distribution system are rated for such pressures, they also degrade over time due to corrosion, and higher pressures can lead to slightly higher break rates, even if the pressures are within design tolerances.
- **Changes** in pressure, even when within design tolerances, often leads to a <u>temporary</u> increase in break rate. This temporary increase in break rate was predicted by the Huber Heights City Engineer, B&N, and has been observed by other parties. Several studies in the early 2000s showed that frequent variations in pressure are associated with higher frequency of new breaks and leaks.

To investigate the impacts of booster pressure north of I-70, the annual average number of breaks beginning in 2010 were tabulated for both the entire system and for only the area north of I-70 (see **Table 4-1**).

For the entire system, the average number of breaks before pressures were increased in mid-2019 was just under 46. The annual average number of breaks prior to mid-2019 for the area north of I-70 was about 1.3. For the final 8 months in 2019 when pressures were increased, there were 26 breaks north of I-70, an increase in the break rate for those 8 months of over 30 times the normal break rate. Before pressures were boosted, there had not been consecutive months with breaks, and the number of breaks in any given month was either 1 or 2 (see **Figure 4-5**). After the increase in pressure, 7 of 8 months in 2019 had breaks (with as many as 7 breaks in one month) and there were six consecutive months in 2020 with breaks.

Because water pressure north of I-70 was boosted, overall water usage was expected to increase slightly. It is possible that pressures in the transmission mains that convey water to those booster stations (south of I-70) would see a shift in flow and pressures for this reason. However, the analysis does not support a significant increase in the break rate south of I-70, while the break rate north of I-70 increased 30-fold. For 2019, the expected number of breaks for the system was 46, but there were 75; the number of breaks north of I-70 in 2019 was 26 (25 more than in an average year). If the 25 unexpected breaks north of I-70 are excluded, the number of systemwide breaks is reduced 50, very close to the expected 46. For this reason, it appears the impacts of increasing pressure to the north of I-70 are confined to the area north of I-70.

It also appears from the data that the most significant impacts of increasing pressures north of I-70 were largely temporary, as predicted. The 5 breaks north of I-70 in 2021 and 2 breaks through July 2022, while higher than pre-2019 levels, are also far lower than the number of breaks in 2019 (26 breaks) and 2020 (19 breaks). This suggests that the system north of I-70 has “settled” into the new normal operating pressures. The break rate north of I-70 may remain slightly higher than pre-2019 levels, but more observation and data is needed to determine the degree.

An additional conclusion is that the increased systemwide break rate in 2020 and 2021 was not due to the change in pressures north of I-70, which appears to have settled down by the winter of 2019-2020 (see **Figure 4-5**). This suggests a second cause of the increased break rate since 2020 (see **Section 4.3** below).

Table 4-1. Number of Breaks by Year														
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022*	Average 2010-2018:
Overall System Breaks	44	37	39	35	64	65	41	39	46	75	156	118	44*	45.6
Breaks North of I-70	1	0	2	0	1	4	1	2	1	26	19	5	2*	1.3
* Breaks in 2022 are through July 2022														

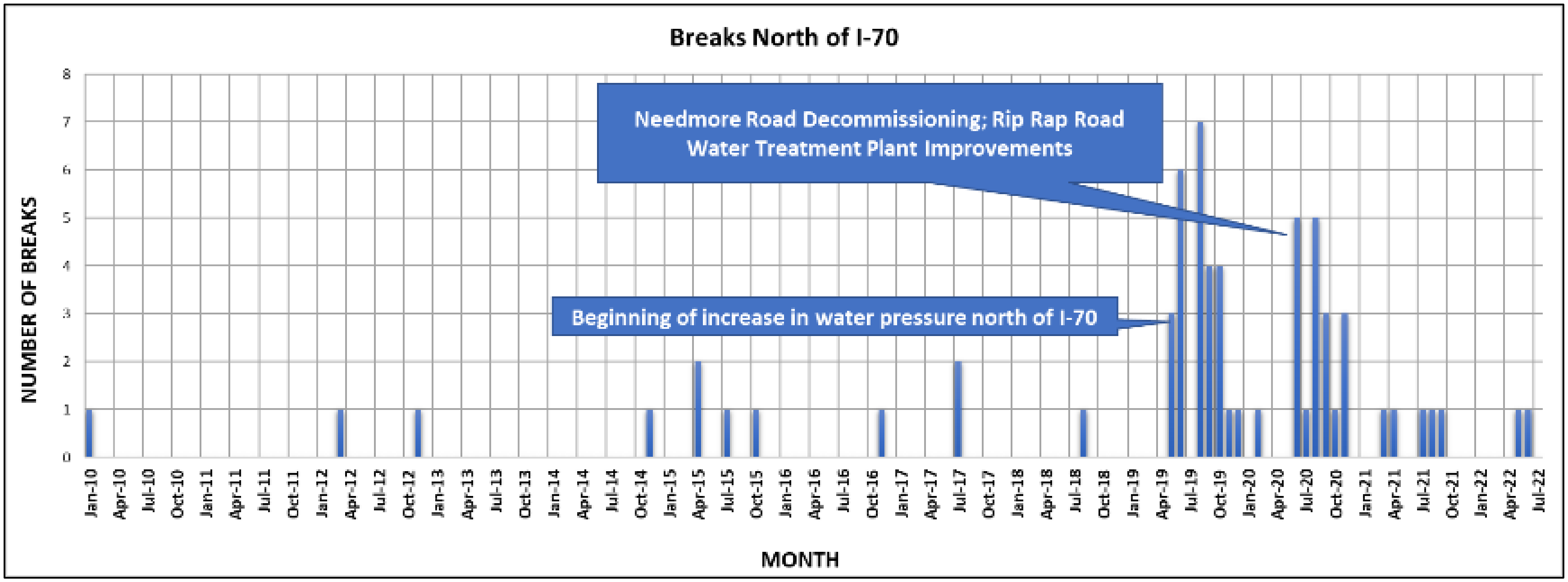


Figure 4-5. Number of Breaks North of I-70 by Month

4.3. Decommissioning of Needmore Road WTP / Commissioning of Rip Rap Road WTP Improvements

While the increase in break rate in 2019 was attributed to the increase in pressures north of I-70, the increase in break rate in 2020 and 2021 is not. The 2020 and 2021 spike appears to be attributable to the changes in flows, pressures, and water quality in the system caused by the commissioning of Rip Rap Road WTP softening improvements and the decommissioning of the Needmore Road Water Treatment Plant (WTP). The data shown in Table 4-1 and Figure 4-5 shows in 2020, when the number of breaks north of I-70 began to decrease (from 25 to 19), the overall number of systemwide breaks soared to 156. In 2021, when the number of breaks north of I-70 decreased again to only 5, the overall number of systemwide breaks remained very high at 118.

The expected number of breaks south of I-70 in a given year was 44 based on pre-2019 data. In 2020, even if all 19 of the breaks north of I-70 were attributed to boosted pressures, the number of breaks south of I-70 would be 137, over 3 times higher than expected. In 2021, even if all 5 of the breaks north of I-70 were attributed to boosted pressures, the number of breaks south of I-70 would be 113, over 2.5 times higher than expected.

The location of breaks before May 1, 2019 (9 years and 4 months of data) and after May 1, 2019 (2 years and 2 months of data) are shown respectively in **Figures 4-6 and 4-7**. Breaks prior to May 1, 2019 appear to be concentrated in the central and southern portions of the distribution system (south of Taylorsville Road). Aside from the breaks north of I-70, breaks after May 1, 2019 are also predominantly located in the central and southern portions, with a slightly higher concentration of breaks south of Taylorsville and north of Fishburg Road.

The spike in breaks after May 1, 2019 are distributed in nature. It is not clear whether the cause of the breaks is more closely associated with (a) the change in flow directions (water no longer transmitted from the Needmore Road facility; instead, all flow is now treated and distributed from the Rip Rap Road facility); (b) changes in pressure throughout the system, and/or (c) changes in water quality in the finished water through November 2021.

As part of the softening process at the Rip Rap Road facility, hardness in softened water is reduced significantly, and prior to finished water leaving the plant, chemicals are injected to stabilize hardness and pH in the finished water. From May 2020 until November 2021 (18 months), adjustments were ongoing, and pH levels were not optimized with periodic high pH slugs. They have since stabilized, and staff anecdotally reported reduced breaks thereafter.

Because the break rate is still higher than pre-2019 levels (44 breaks in 2022 through July, as opposed to 45 breaks for an average 2010-2019 year), further investigation is warranted if the break rate does not continue to decrease in 2022 and 2023. Note that the break prediction model predicted 57 breaks in 2022 based on January 2010 – April 2019 data.

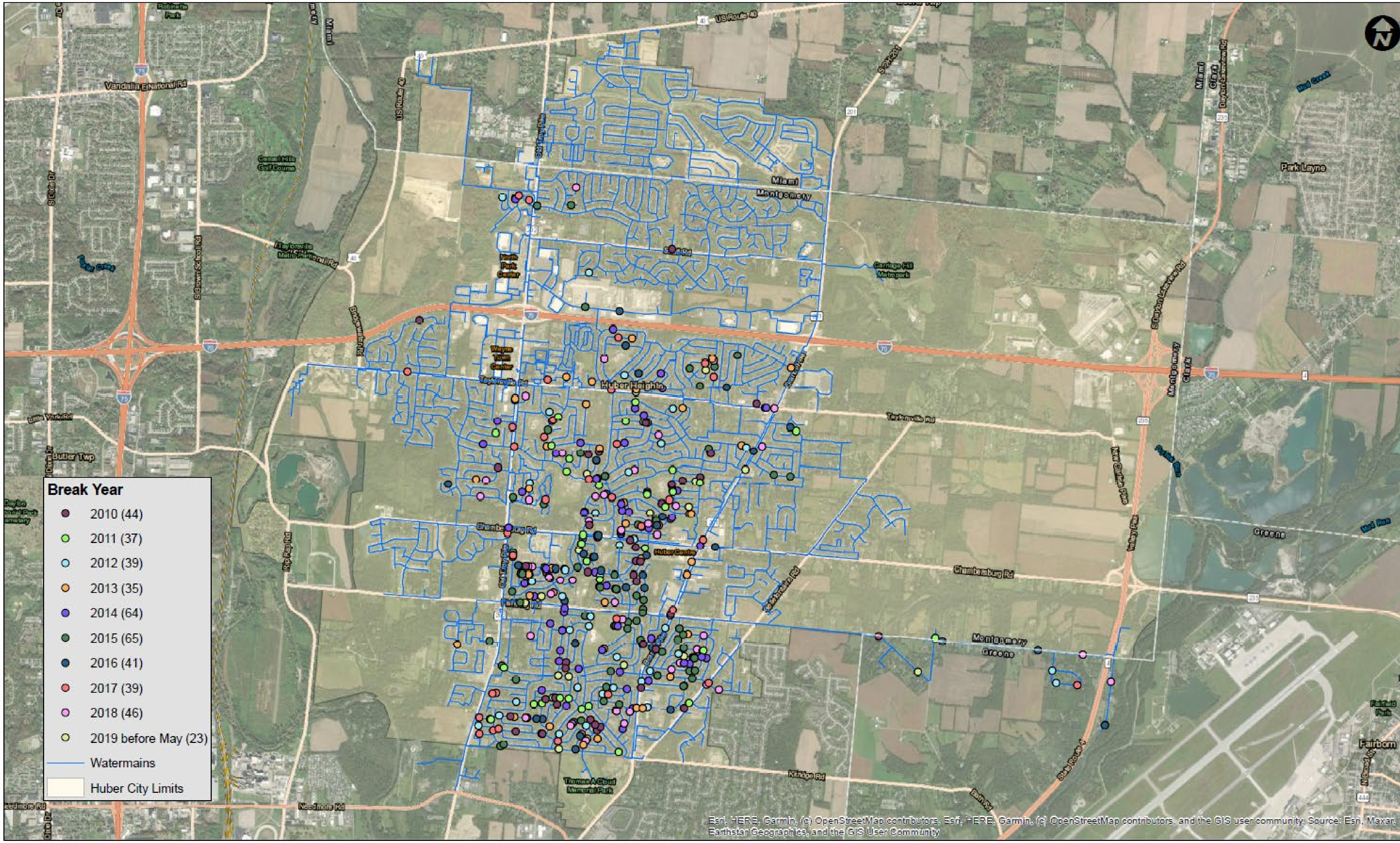


Figure 4-6. Location of Watermain Breaks Before May 1, 2019

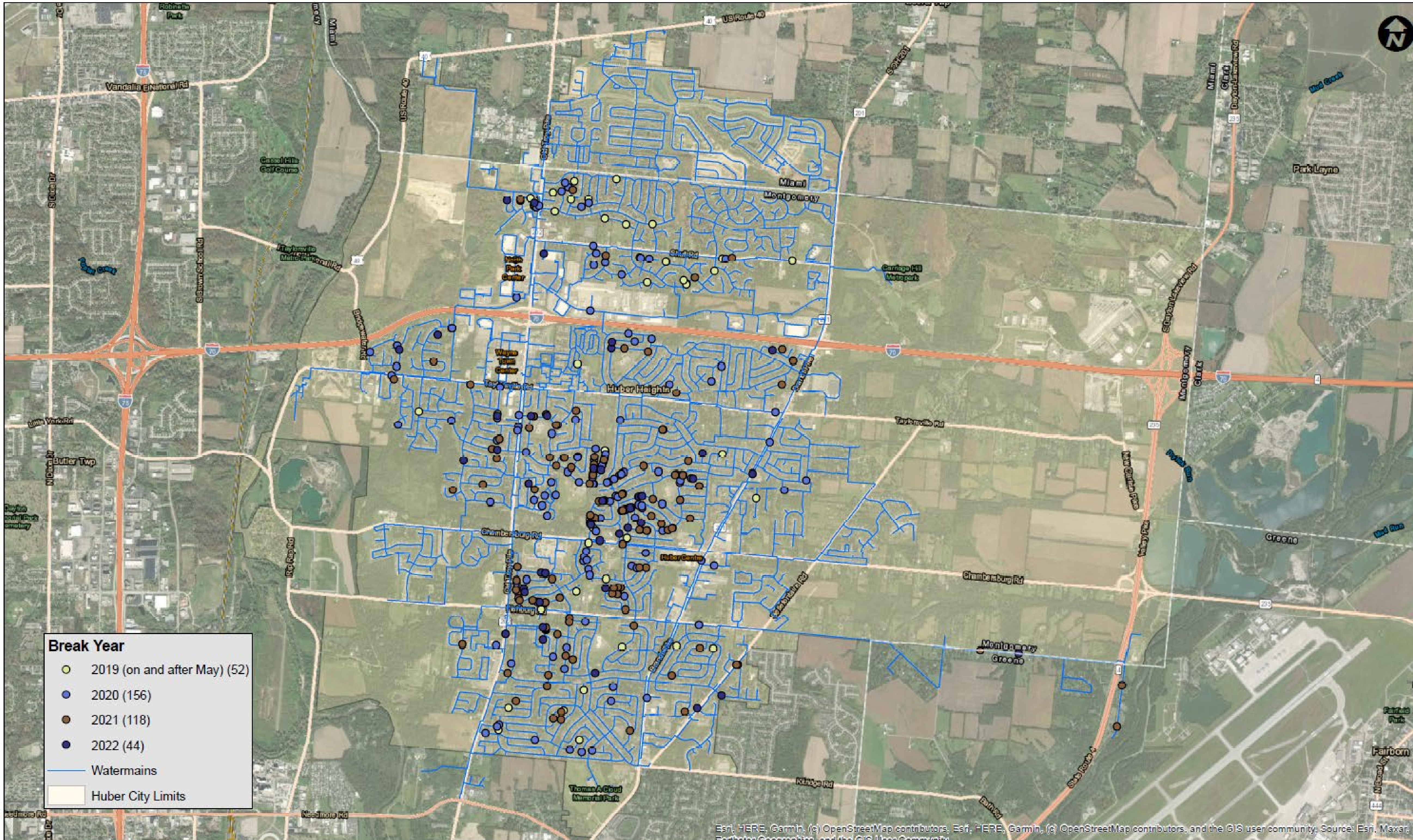


Figure 4-7. Location of Watermain Breaks After May 1, 2019

Because the breaks after May 1, 2022 are not localized, and because they are predominantly on older cast iron pipe, an initial conclusion is that break are the result of a combination of factors: external corrosion of metal pipe (cast iron generally is more susceptible than ductile iron) due to moderately and highly corrosive soils and the flow, pressure, and water quality changes that occurred in 2020 through 2021. If this is the case, pipes that were already corroded were susceptible to breaks when the operational changes took place, and they broke somewhat prematurely. This may indicate that because operations have been stabilized (pumping and treatment), the break rate will continue to decrease in 2023 as the weakest pipes have already broken and been repaired while initially stronger pipes remain in service.

5. CONSEQUENCES OF WATERMAIN FAILURE

Coupling consequence of failure data with the likelihood of failure data presented in **Section 3** allows for an assessment of the risk posed by an asset or asset system. Risk is the primary factor used for prioritizing replacements.

Risk = Likelihood of Failure (LOF) x Consequence of Failure (COF)

Consequence data can be broken into three sub-components: financial costs, social costs, and environmental costs. Financial costs are well documented by many utilities and generally include the direct cost of pipe replacement, including excavation, materials, site restoration, depreciation on vehicles, and labor. Environmental costs associated with watermain breaks are generally insignificant in comparison and would generally only be a factor near a highly sensitive waterway. Social costs can vary greatly from (a) relatively low if the water system is looped and pressure is maintained, allowing the repair to be planned to minimize impacts) to (b) highly consequential if the break results in traffic disruption, property damage, an unplanned outage to a critical customer, or other impacts.

This section the estimation of the consequences of watermain failures. COF data will be combined with the probability of failure data discussed in previous sections to generate an overall estimation of the risk associated with each pipe in **Section 6**.

5.1. Watermain Criticality / Consequence of Failure (COF) Scoring

Criticality scoring for each pipe is measured on a scale of 1 (least critical) to 5 (most critical) across a variety of parameters that are indicative of the impacts of watermain failures. Criteria include:

- Pipe Diameter
- Adjacency Factors (pipes that intersect or are near waterbodies, roads, and structures)
- Critical Customers

5.1.1. Diameter

Pipe diameter is a measure of both the cost to replace the pipe and the indirect impact on customers (higher diameter pipes generally service more customers). Watermain criticality scores based on diameters are shown in **Table 5-1** and illustrated in **Figure 5-1**.

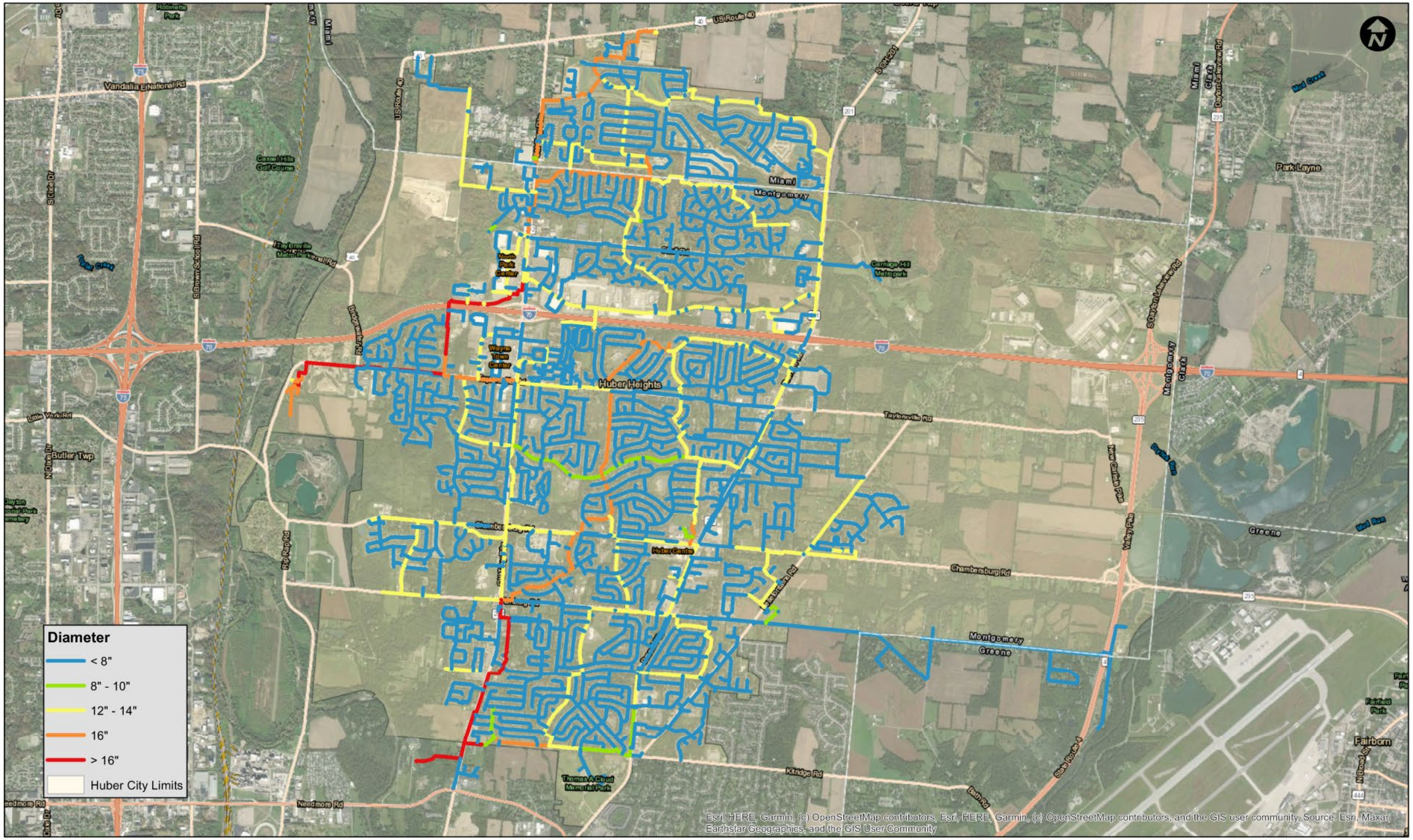


Figure 5-1. Water Criticality Scores Based on Diameter

Table 5-1. Criticality Based on Diameter			
Score	Diameter (inches)	Length (miles)	Percent of System
1	< 7″	90.7	44.3
2	8″ – 10″	71.6	34.9
3	12″	30.8	15.0
4	16″	7.8	3.8
5	> 16″	4.0	2.0

5.1.2. Adjacency Factors

Adjacency factors were assessed using GIS data obtained from the City and other sources (Montgomery County, Miami County, ODOT). Shapefiles that represented geospatial locations of water bodies, structures, and various road types relative to the water distribution system were utilized. (Railway shapefiles were requested, but no active railways intersect with the study area). Each watermain was assigned criticality scoring based on intersection or adjacency to those features as shown in **Table 5-2** and **Table 5-3**.

Table 5-2. Criticality Based on Roadway Adjacency Factors					
Score:	**5**	**4**	**3**	**2**	**1**
Road Class					
Interstates FCLASS 01, 11, 12, and 63*	Intersecting or within buffer of (12′*[LANES]+24′) /2	Within secondary buffer (12′* [LANES]+24′)/2+50′	NA	NA	NA
Principal Arterials FCLASS 02 and 14**	NA	Intersecting or w/in buffer (10′x([LANES]+1)) /2 + 10′	NA	NA	NA
Minor Arterials FCLASS 06 and 16***	NA	NA	Intersecting or w/in buffer (10′x([LANES]+1)) /2 + 10′	NA	NA
Collectors and Public transit FCLASS 07, 08, 17, and 99***				Intersecting or w/in buffer (10′x([LANES]+1))/ 2 + 10′	
Local FCLASS 09 and 19	NA	NA	NA	NA	NA

* For score = 5: Assume 12′ lane width and two 12′ shoulders for each segment. Repairs will require lane closures. Limited access highway makes construction vehicle access more difficult. For score = 4: Additional secondary 50′ buffer. Work anticipated to be outside of pavement but impacts could still affect traffic (pavement flooding and construction traffic).
** Assume 10′ lane width plus 1 turn lane for pavement width, plus additional 10′ buffer. Work within buffer would impact traffic.
*** Assume same buffer criteria as for principal arterials, however lower traffic volumes result in less impact.
**** Functional class information sourced from ODOT TIMS.

Table 5-3. Criticality Based on Adjacency Factors (Non-Roadway)		
Score	**Adjacency to:**	
	Water Bodies	**Structures**
1	n/a	n/a
2	n/a	n/a
3	Within 200 feet	Within 100 feet
4	Within 50 feet	Within 25 feet
5	Intersecting	Intersecting

Watermain criticality scoring based on adjacency to roads is summarized in **Table 5-4** and shown in **Figure 5-2**.

Table 5-4. Criticality Based on Adjacency to Roads			
Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
0	3,836	165.3	80.7
2	241	13.7	6.7
3	272	18.5	9.0
4	79	5.3	2.6
5	22	2.1	1.0

Watermain criticality scoring based on adjacency to water bodies is summarized in **Table 5-5** and shown in **Figure 5-3**.

Table 5-5. Criticality Based on Adjacency to Water Bodies			
Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
0	3,913	165.8	80.9
3	414	25.0	12.2
4	83	7.8	3.8
5	40	6.3	3.1

Watermain criticality scoring based on adjacency to structures is summarized in **Table 5-6** and shown in **Figure 5-4**.

Table 5-6. Criticality Based on Adjacency to Structures			
Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
0	299	17.2	8.4
3	3,569	147.6	72.0
4	568	38.9	19.0
5	14	1.2	0.6

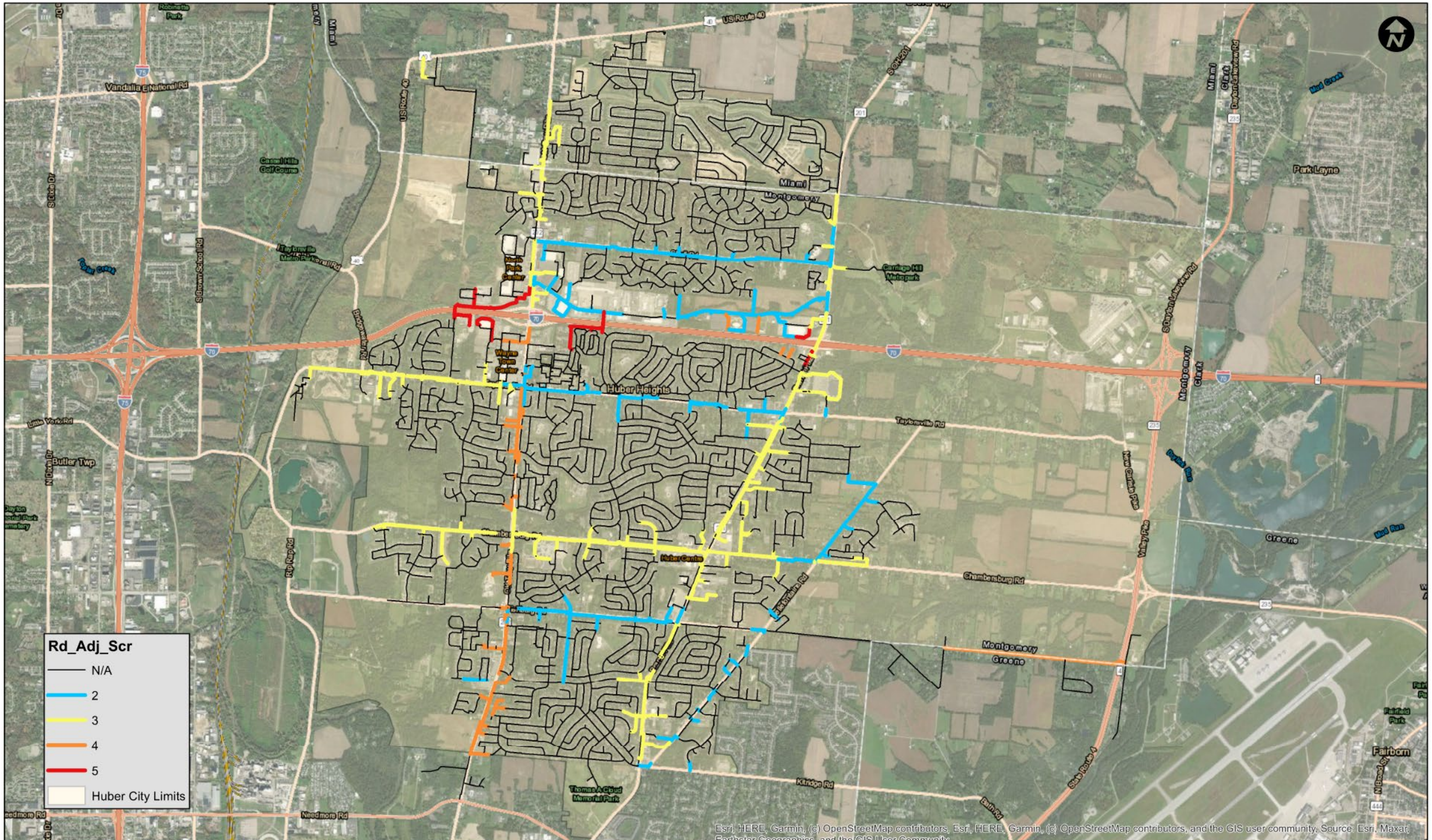


Figure 5-2. Water Criticality Scores Based on Proximity to Roads

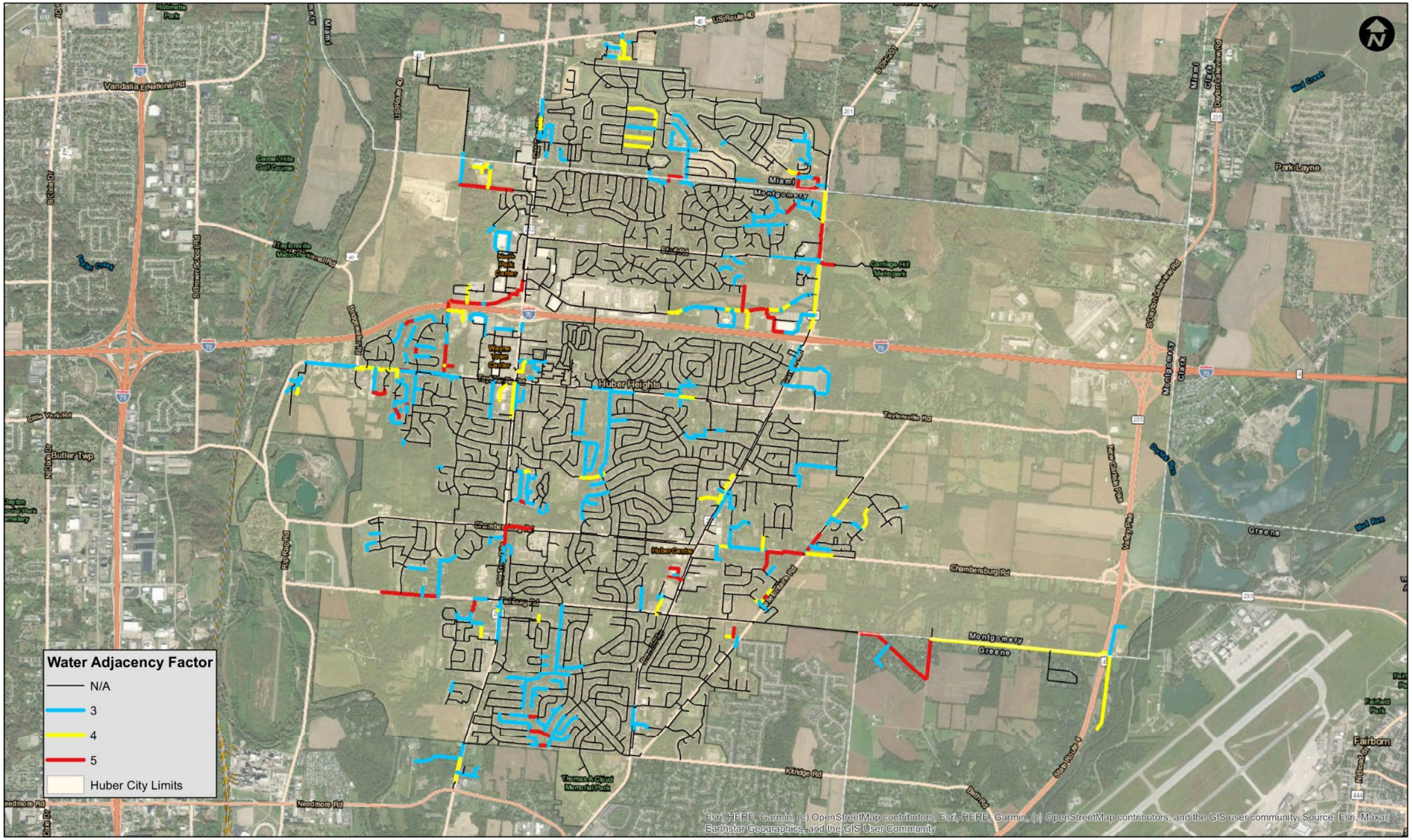


Figure 5-3. Water Criticality Scores Based on Proximity to Water Bodies

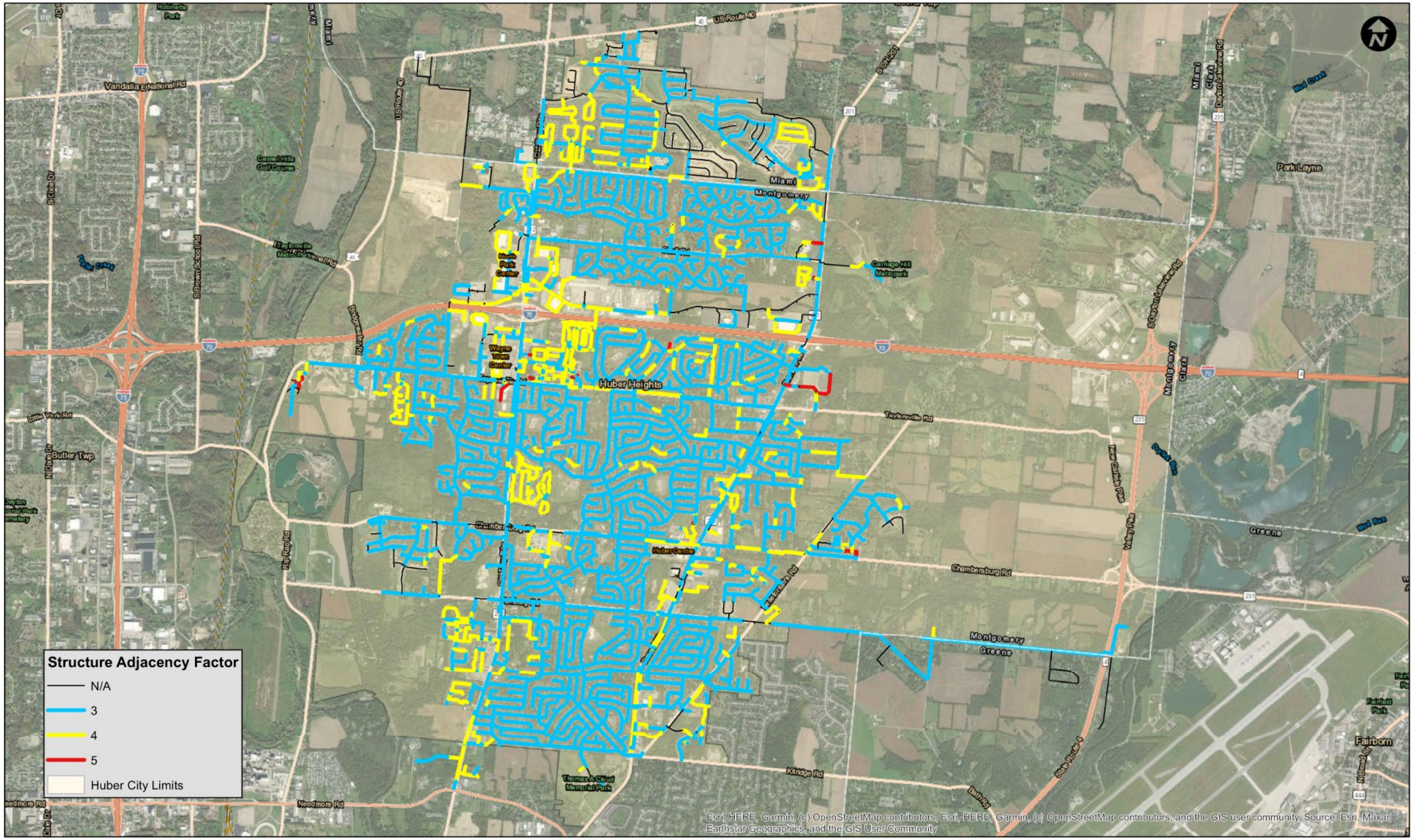


Figure 5-4. Water Criticality Scores Based on Proximity to Structures

5.1.3. Critical Customers

Watermains that intersect with critical customers' property and serve critical customers were traced back in all directions to the first set of isolation valves and then out to the second set of isolation valves. Pipes past two isolation valves are expected to have sufficient cross connections to not warrant an increased criticality, but these were inspected manually in GIS to confirm and adjust. The critical customer list provided by the City is shown in **Table 5-7,** and critical customer locations are shown in **Figure 5-5**.

Table 5-7. Critical Customer List

Type	Name	Address
Large User	Flying Ace Express Car Wash	5570 Merily Way
Nursing Home	Landing Of Huber Heights	6200 Bellefontaine Rd
Large User	Aquatic Center	8625 Brandt Pike
Large User	Parkview Apt Master Meter	2200 Cooley Lane
Large User	Mount Hood/Mt Carmel Master Meter	8189 Mount Carmel St
Large User	Spin Light Carwash	6705 Brandt Pk
Nursing Home	Laurels Nursing Home	5440 Charlesgate Rd
Grocer	Meijer Inc. Site #241a	7150 Executive Blvd
Large User	Mt Hood/Mt Everest/Mt Aetna Master Meter	8031 Mount Everest St
Restaurant	Texas Roadhouse Restaurant	5611 Merily Way
Medical Facility	Huber Health Center	8701 Old Troy Pike
Medical Facility	Fresenius Medical Care	7251 Shull Rd
Kidney Dialysis Patient	Davita	7769 Old Country Ct
Nursing Home	Danbury Senior Living	8001 Red Buckeye Dr
Kidney Dialysis Patient	Davyon Eubanks	6468 Shull Rd
School	Huber Heights Public Schools Admin	5950 Longford Rd
School	Huber Heights Baptist	7730 Taylorsville Rd
School	Kittyhawk School	5758 Harshmanville Rd
School	Monticello Elementary	6523 Alter Rd
School	Rushmore Elementary	7701 Berchman Dr
School	St. Peter School	6185 Chambersburg Rd
School	Weisenborn Intermediate	6061 Old Troy Pike
School	Titus Elementary	7450 Taylorsville Rd
School	Valley Forge	7199 Troy Manor
School	Wayne High School	5400 Chambersburg Rd
School	Studebaker Admin	5950 Longford Rd

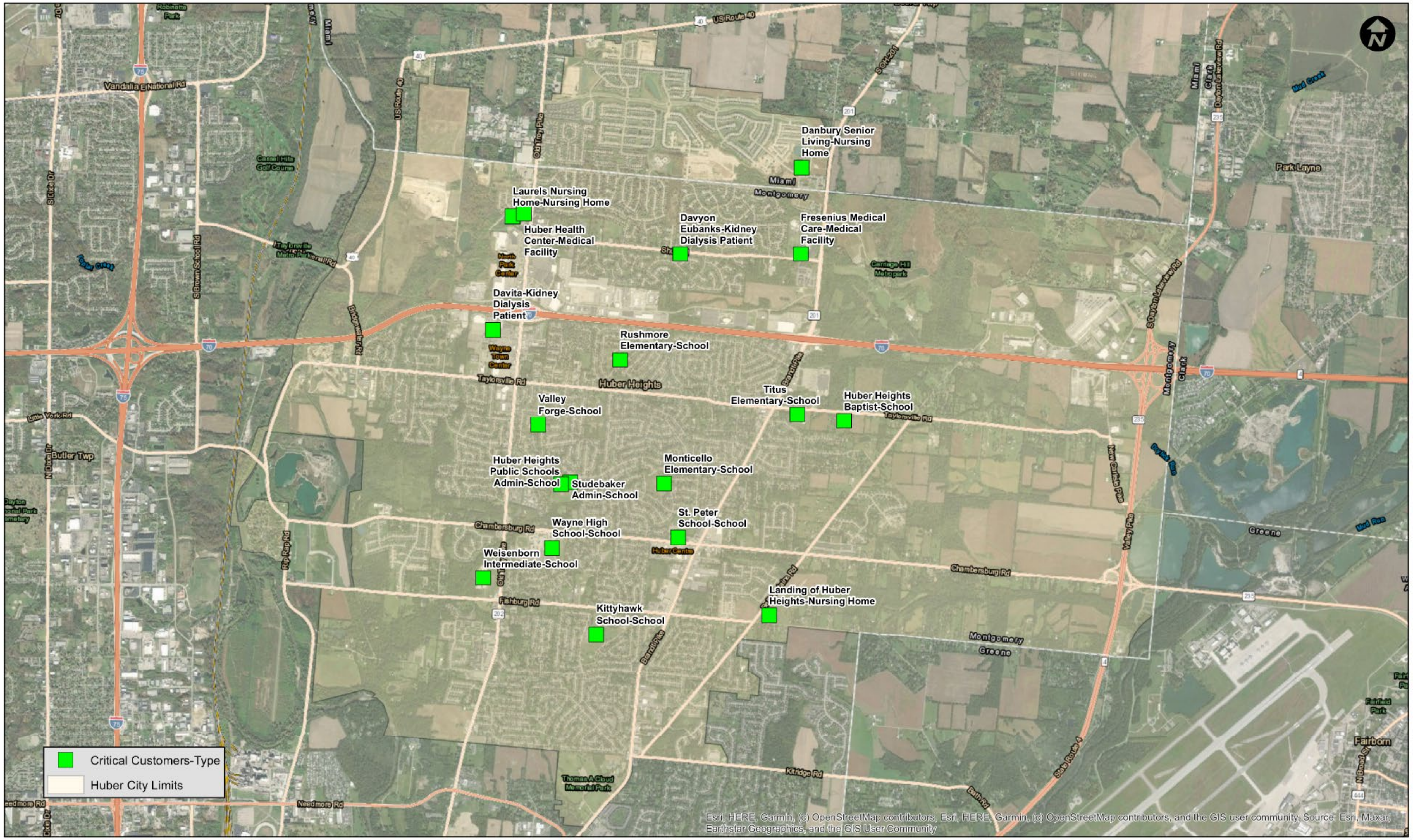


Figure 5-5. Location of Critical Customers

To measure the impacts of potential loss of service in the event of a watermain break and associated repair to customers, including critical customers, the City's hydraulic model (updated in 2022) was utilized. Using pre-existing functionality in WaterGEMS, a break was simulated in the hydraulic model on every watermain in the system (one at a time, iteratively throughout the system). For each simulated pipe break, the valves needed to isolation that pipe are closed, and the model is run. The resulting hydraulic impacts such as pressure drops and customers without water were determined. Hydraulic impacts could entail (a) loss of service to a critical customer, (b) partial or total loss to customers, measured in 100-cubic-feet (CCF) of consumption loss, and/or (c) an unbalanced model run, which indicates hydraulic consequences so severe that the model fails – this typically occurs on transmission mains.

A hydraulic criticality score was assigned to every watermain using this technique. **Table 5-8** summarizes the factors that contribute to hydraulic criticality and how they are scored.

Table 5-8. Hydraulic Criticality Factors and Scoring

Criteria	**1**	**2**	**3**	**4**	**5**
Critical Customers	< 100 residential	100 - 500 residential	School OR > 500 residential	2 schools OR 1 assisted living/nursing home/prison	Hospitals/dialysis centers OR: 3+ schools OR: 1 assisted living/ nursing home/prison PLUS any other critical customer
Consumption Loss (Monthly average in CCF)	< 1,000	1,000 - 3,999	4,000 - 7,499	7,500 - 10,000	>10,000
Unbalanced Model					Yes

Criticality scoring based on <u>potential service impacts to critical customers</u> is summarized in **Table 5-9** and shown in **Figure 5-6**.

Table 5-9. Criticality Based on Potential Service Impacts to Critical Customers

Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
1	3,739	173.3	84.6
2	537	23.1	11.3
3	81	4.8	2.3
4	32	1.4	0.7
5	61	2.3	1.1

Criticality scoring based on adjacency to critical consumption is summarized in **Table 5-10** and shown in **Figure 5-7.**

Table 5-10. Criticality Based on Adjacency to Critical Consumption			
Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
1	3,897	176.7	86.3
2	489	25.1	12.3
3	64	3.0	1.5

Total criticality scores (the summation of scoring for all criticality parameters on all pipes) are summarized in **Table 5-11** and shown in **Figure 5-8**.

Table 5-11. Total Criticality Scores			
Score	**Number of Assets**	**Total Length (miles)**	**Percent of System**
1-4	96	6.6	3.2
5-8	2,954	118.4	57.8
9-12	1,176	59.3	28.9
13-16	189	16.7	8.1
17+	35	4.0	1.9

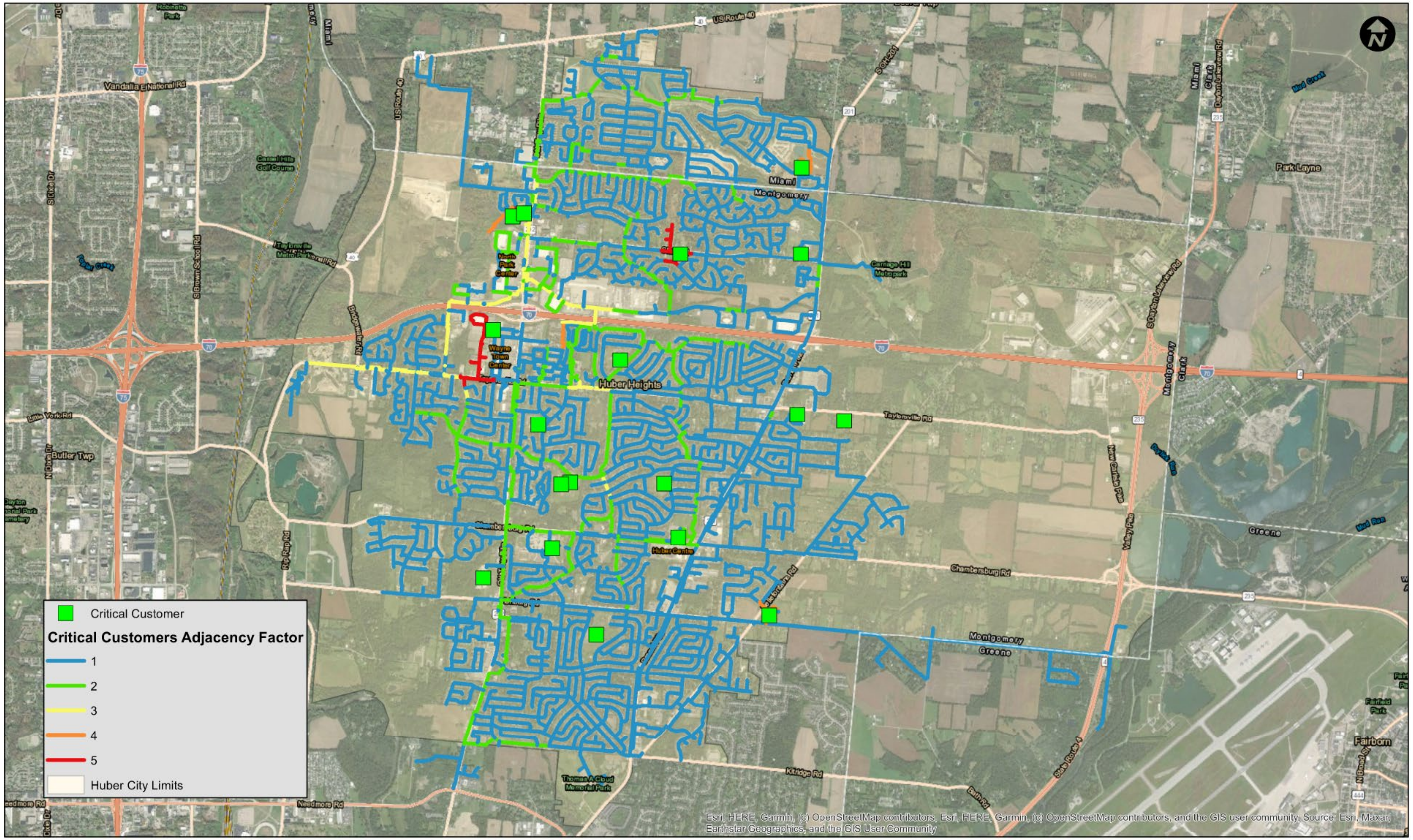


Figure 5-6. Criticality Score Based on Potential Service Impacts to Critical Customers

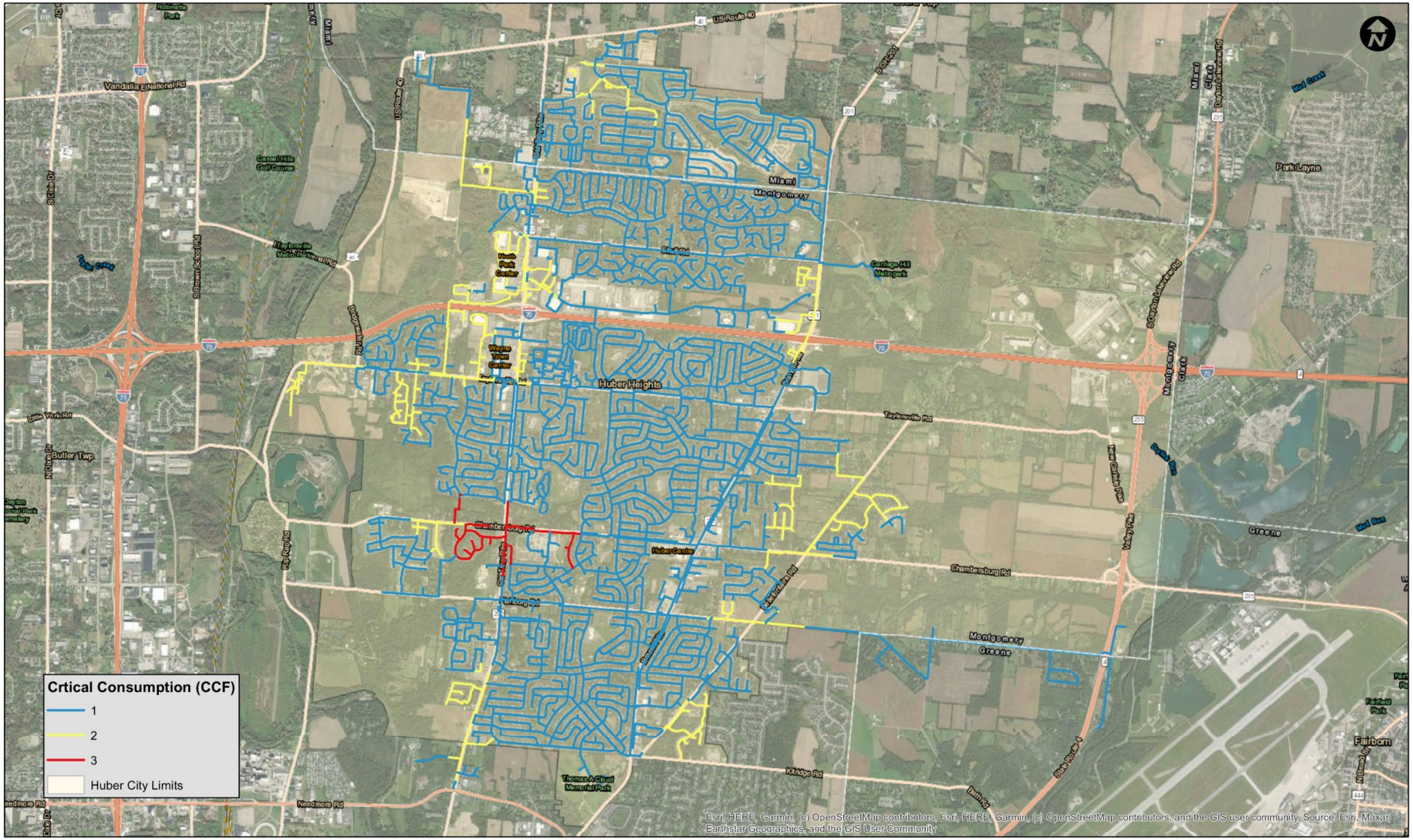


Figure 5-7. Criticality Based on Adjacency to Critical Consumption

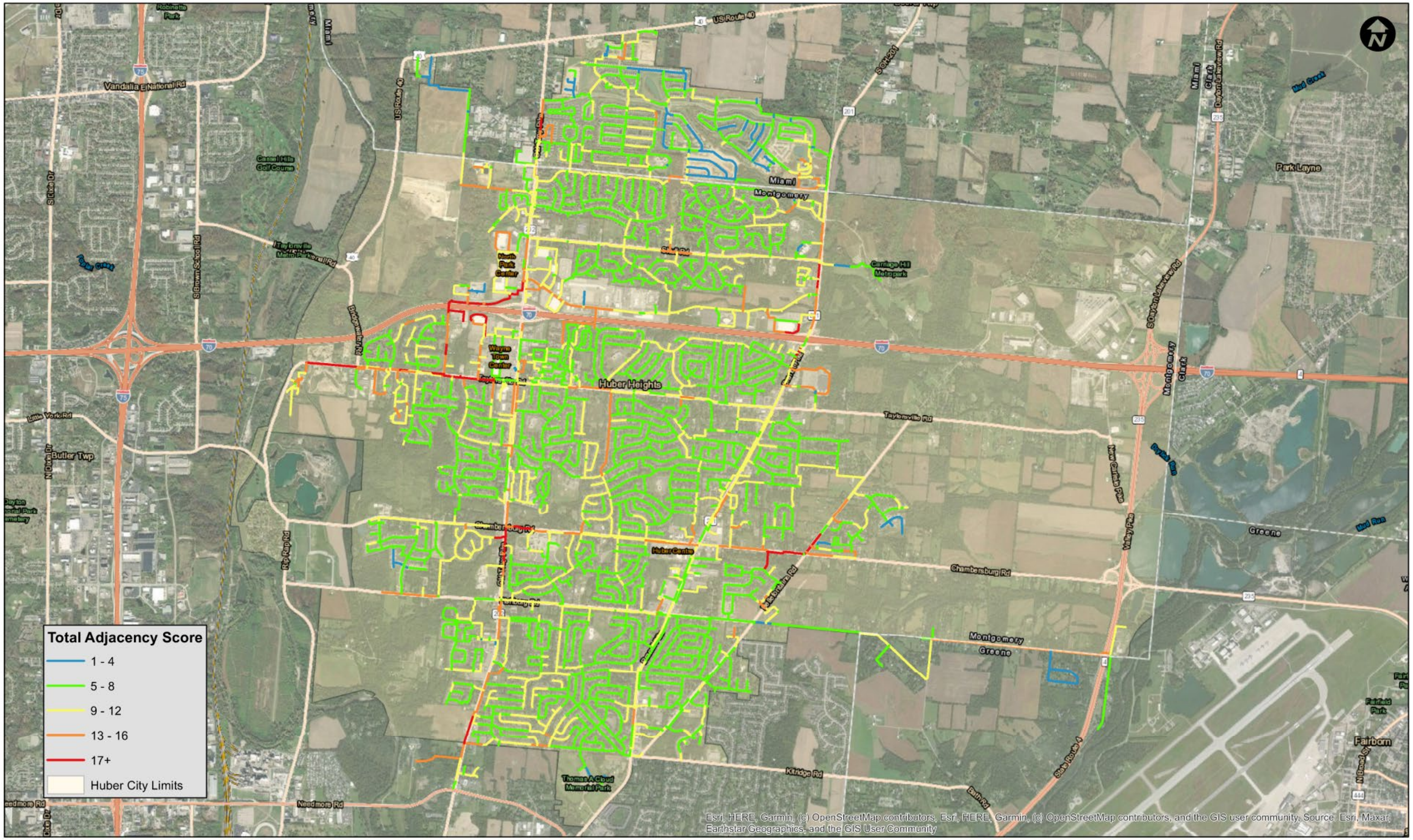


Figure 5-8. Total Criticality Scores

6. WATERMAIN RISK

Risk (defined below) is the primary factor used for prioritizing replacements (in addition to cost) as the reduction in risk is the benefit of a watermain replacement project.

Risk = Likelihood of Failure (LOF) x Consequence of Failure (COF)

While COF remains relatively static, LOF increases over time as pipes age and deteriorate, thereby driving the risk equation.

6.1. Risk Management Strategies

An initial risk management strategy involves establishing a maximum allowable risk for pipes, and when that threshold risk value is reached, pipes are considered to have reached the end of their useful lives. For watermains, this means that as the COF increases, the acceptable LOF is lower to maintain risk below a certain level. A highly critical pipe should be replaced sooner (at a lower break rate) than an otherwise identically-performing pipe with a lower COF. This concept is illustrated in **Figure 6-1**.

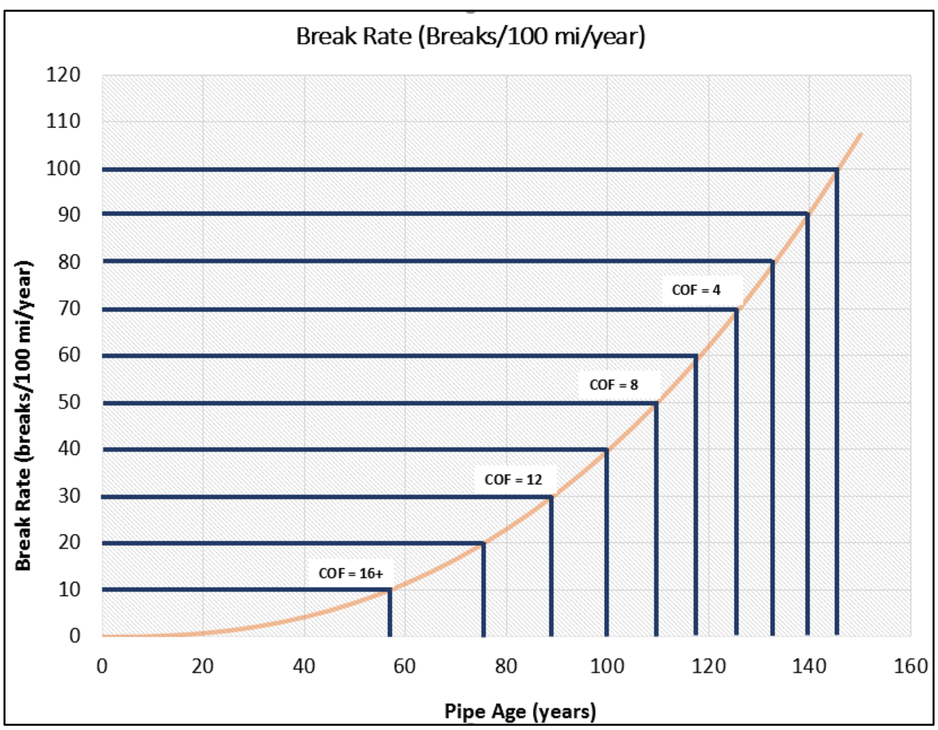


Figure 6-1. Maximum Acceptable Break Rate Based on COF

The maximum acceptable break rates that formed the basis of a "baseline" replacement strategy is shown in **Table 6-1**. The results of this initial strategy are then used to generate and evaluate alternative replacement strategies and investment levels.

By defining the maximum acceptable break rate for pipes for a given COF value (y-axis in Figure 6-1), the age of the maximum acceptable break rate (MABR) for each pipe can be determined (x-axis), which can then be used to determine the year it should be replaced according to the framework. For example, for a pipe that has the aging curve shown in Figure 6-1 and a COF of 8, the MABR is 50 (breaks/100 miles/year); this break rate is reached when the pipe reaches the age of about 110 years old. If that pipe were installed in 1950, replacement would be recommended in 2060. Table 6-1 shows the MABR versus COF relationship that was used for this project to determine a baseline replacement scenario. This methodology is applied to every pipe. Utilization of the results is discussed in **Section 7**.

Table 6-1. MABR versus COF

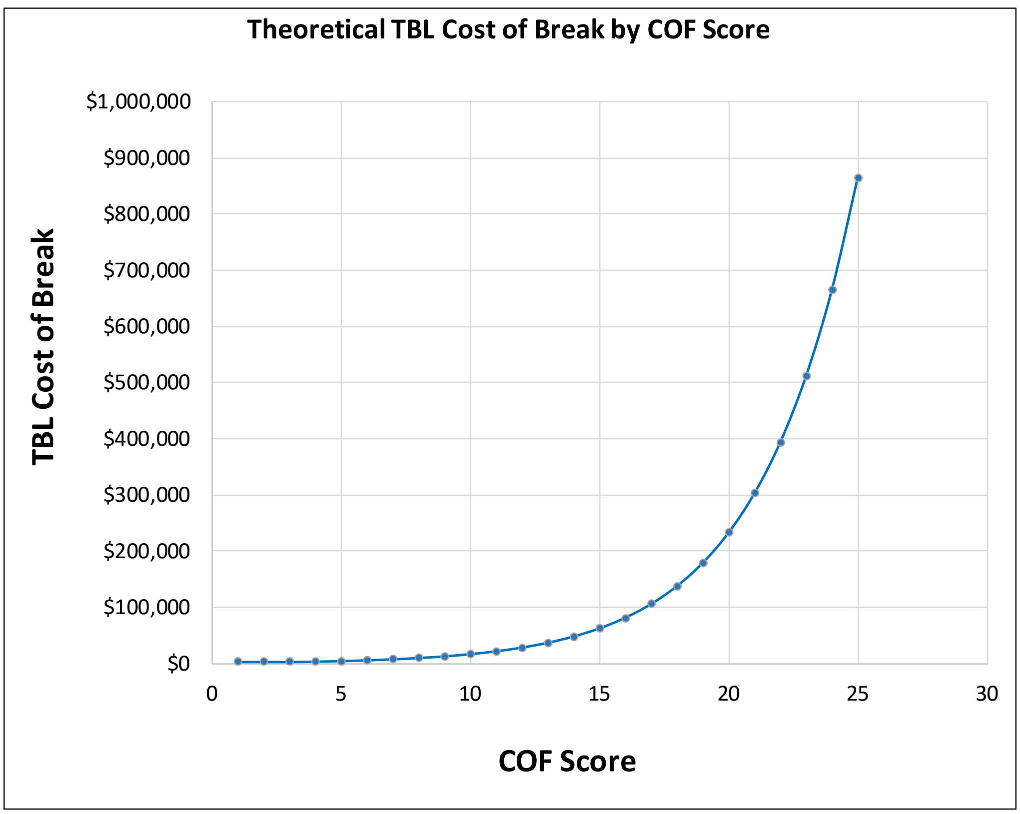
COF	**Maximum Acceptable Break Rate (MABR)** (breaks/ 100 miles/year)
1	100
2	100
3	100
4	100
5	100
6	100
7	100
8	95
9	90
10	85
11	75
12	60
13	45
14	35
15	25
16	20
17	15
18	10
19	7
20+	5

Figure 6-2 shows the relative risk ranking of watermains in the system using color-coding, where red represents the highest risk pipes and green represents the lowest risk. The risk scores in Figure 6-2 represent the cumulative probability of failure over the 50-year planning horizon multiplied by the theoretical monetized consequence of failure. **Figure 6-3** shows the benefit-cost ratio by pipe, calculated by dividing the 50-year risk cost by the cost of pipe replacement.

The monetized cost of failure is based on research conducted by Water Research Foundation Project #4451, which quantifies the financial, social, and environmental impacts of watermain breaks. **Figure 6-4** below shows the monetized cost of breaks based on that research as applied to the City's watermains. Aside from 2 pipes in the system, the maximum COF score for water mains was 20, indicating the overall TBL costs of that COF-20 break would be about $232,000.

Triple bottom line costs include factors such as the direct cost to the utility (main repair, resurfacing, wages, depreciation of vehicles used in the repair, public safety officers, property damage, impact of traffic delays, impacts on businesses and other critical customers, etc.). As an example, the Water Research Foundation Project #4451 included breaks from Ohio, including a watermain break the impacted a central Ohio middle school, causing $75,000 in lost wages by school staff and parents that had to leave work to pick up and care for students who were sent home unexpectedly.

COF	TBL Cost*
1	$3,000
2	$3,000
3	$3,000
4	$3,500
5	$4,550
6	$5,915
7	$7,690
8	$9,996
9	$12,995
10	$16,894
11	$21,962
12	$28,551
13	$37,116
14	$48,250
15	$62,726
16	$81,543
17	$106,006
18	$137,808
19	$179,151
20	$232,896
21	$302,765
22	$393,594
23	$511,672
24	$665,174
25	$864,726



* Based on Triple-bottom Line Costs (Financial, Social, Environmental) of Main Breaks - Water Research Foundation Project 4451

Figure 6-2. Theoretical Monetized Triple-Bottom Line Consequence of Pipe Failure

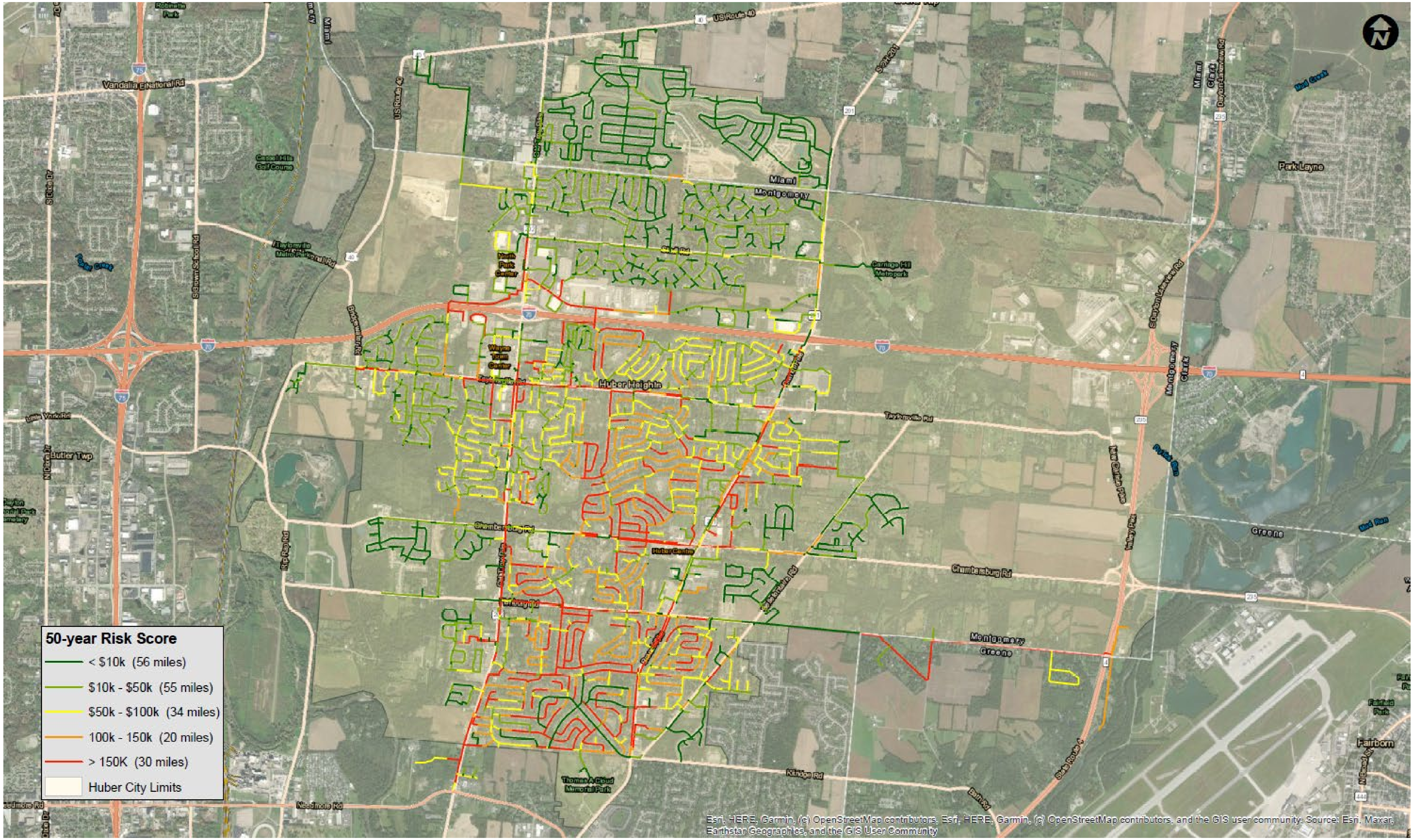


Figure 6-3. 50-Year Risk Scores by Pipe

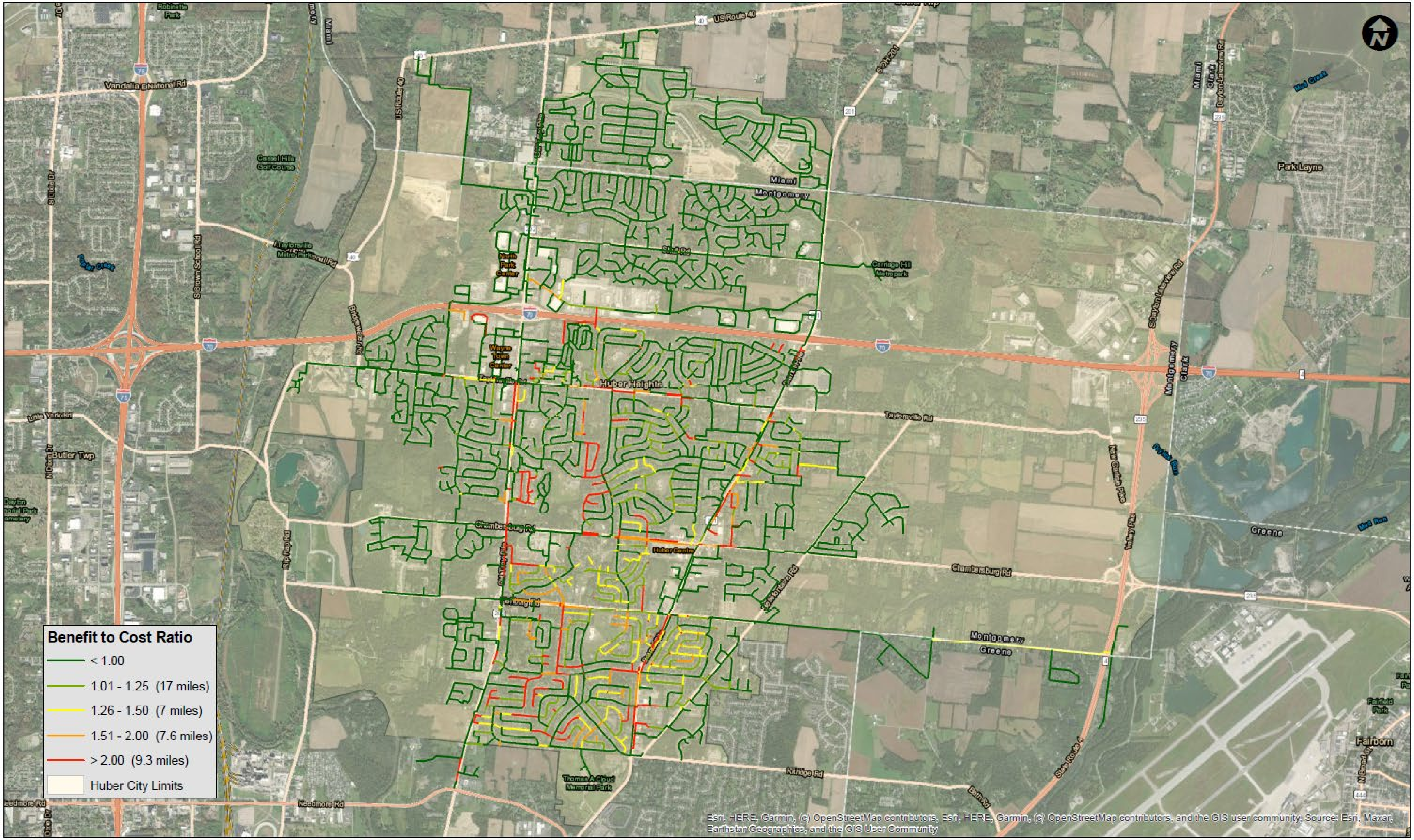


Figure 6-4. Estimated Benefit to Cost Ratio by Pipe

7. REPLACEMENT PLANNING RESULTS

The current systemwide break rate of 21.4 breaks/100 miles/year (excluding the 2019-2022 spike in breaks) is considered high (see **Table 7-1**) and an appropriate time to begin proactive watermain replacement. Additionally, the number of breaks in the system is expected to triple over the next 15 years without any proactive replacements. The analysis in this section evaluates investment scenarios to cost-effectively control the break rate over time.

Table 7-1. AWWA Annual Break Rate (breaks/100 miles) Benchmarking Data			
Percentile	Huber Heights	Water-Only Utilities	Combined Utilities (Water and Wastewater Agencies) – Water Operations
75th	21.4	1.5	2.5
Median		5.8	8.7
25th		11.0	18.4
Source: 2019 AWWA Utility Benchmarking (benchmarking during and post-pandemic is unreliable)			

Determining the costs of the replacement scenarios evaluated herein assumes that ductile iron pipe will be used for all replacements and that all 6-inch pipe will be replaced with 8-inch pipe for improved fire flow and overall capacity. B&N used local bid tabs and industry standard cost estimating software to develop replacement costs based on pipe diameter (see **Table 7-2**). **NOTE: The City may achieve lower total costs if some work is completed in house (e.g., design, construction services). This report assumes the unit prices shown in Table 7-2.**

Table 7-2. Pipe Replacement Unit Costs (per foot) by Diameter		
Diameter	Cost per foot (installed)	Total cost per foot* (2022 USD)
8	$190.00	$273.60
10	$250.00	$360.00
12	$305.00	$439.20
16	$335.00	$482.40
20	$345.00	$496.80
24	$375.00	$540.00

** Total cost per foot includes design, construction, construction mgmt., easements, etc.*
Source: B&N Bid Tabs for Local Work and Industry Standard Cost Estimating Tools

The total replacement cost of the system (all active pipes installed through April 2019), including all design, construction, construction administration, and easements was estimated to be $327 million. Generic industry guidance suggests a 100-year replacement rate on average. The average annual cost associated with different replacement cycles is shown in **Table 7-3**.

Table 7-3. Average Annual Replacement Cost v. Replacement Cycle	
Replacement Cycle	Average Annual Replacement Investment
75-years	$4,357,000
100 years	$3,267,000
150 years	$2,178,000
200 years	$1,634,000

7.1. Baseline Replacement Scenario

Initial results were generated using the replacement strategy described in **Section 6.1**. Replacing the riskiest pipes and pipes with the greatest benefit-to-cost ratio (BCR) first was the strategy employed by subsequent scenarios, though the specific investment levels is varied. The results of the baseline replacement planning scenario are shown in **Figure 7-1**.

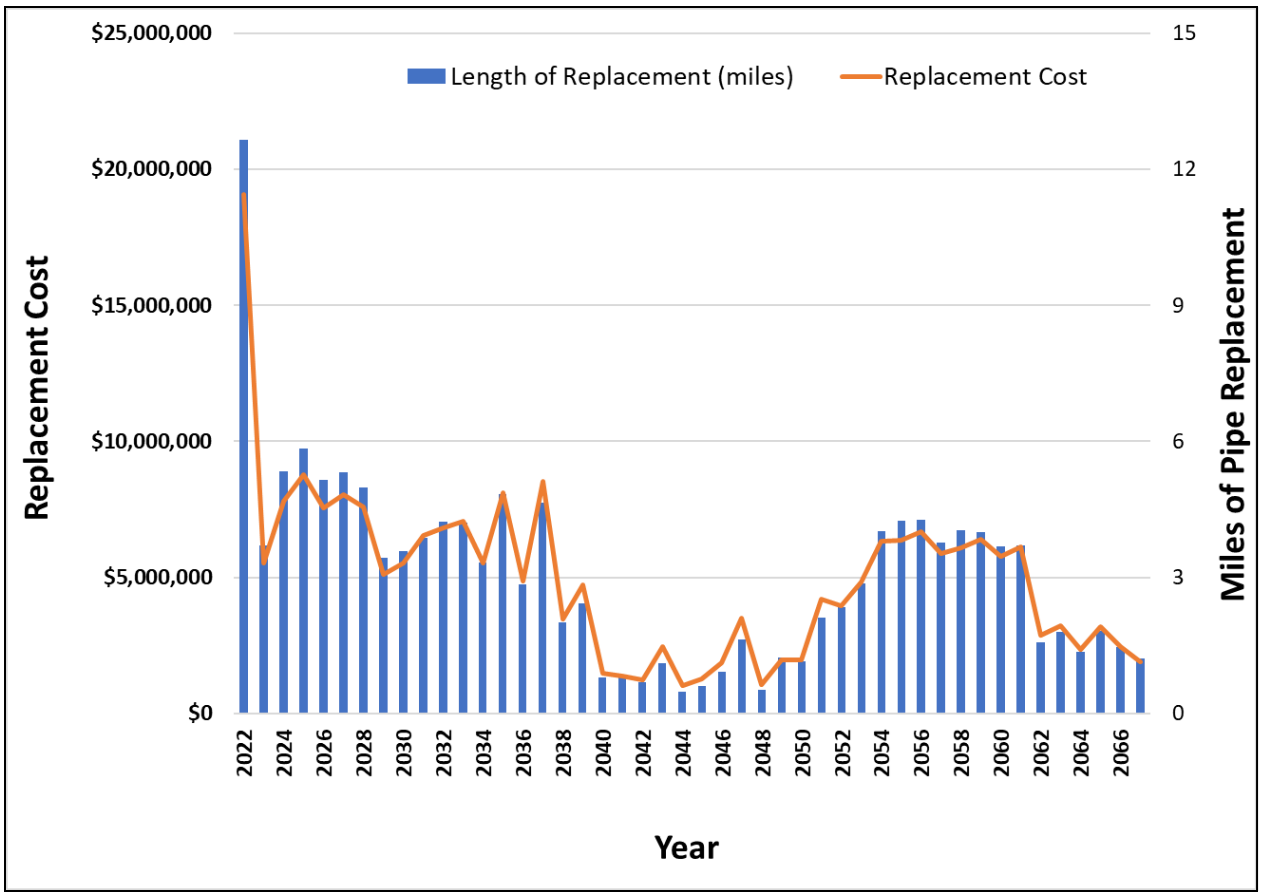


Figure 7-1. Replacement Cost and Length by Year – Baseline Scenario (Not Optimized)

The model for this scenario shows a 13-mile, $21 million backlog of initial replacements for pipes that have already exceeded the maximum acceptable break rate (MABR). A backlog of that magnitude is typical for a water system that has not had a significant proactive replacement plan or a rapidly accelerating break rate. However, this level of investment is generally not affordable, and given the significantly lower level of replacement predicted in 2023 and beyond, other scenarios that spread the initial investment level over time were explored. The average annual investment level for this scenario is $4.25 million, which represents a replacement cycle of about 75-80 years.

Figure 7-2 shows the systemwide number of breaks and risk by year if the baseline replacement scenario were implemented. This investment level would reduce breaks and risk below pre-2019 levels.

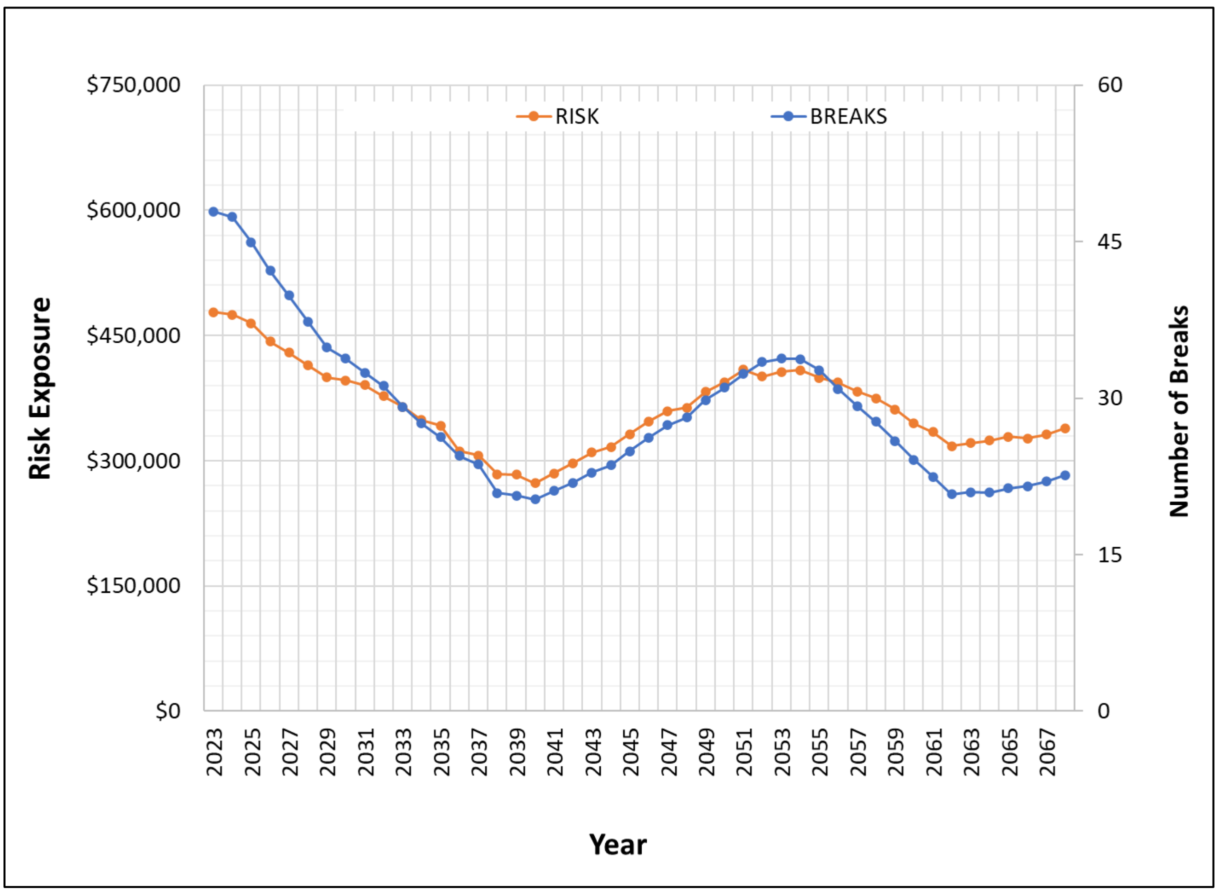


Figure 7-2. Annual Breaks and Risk – Baseline Scenario (Not Optimized)

7.2.Modified Baseline Replacement Scenario – Evenly Distributed Investment

The non-optimized baseline scenario was modified to distribute the investment level to roughly $4.25 million per year (2.62 miles of pipe per year), reducing the initial investment level. Investment levels are shown in **Figure 7-3** and the resultant impacts on breaks and risk are shown in **Figure 7-4**. In Figure 7-4, the number of breaks rises early in the planning horizon while risk decreases. This is because early replacements focus on high-risk pipes driven by high consequence of failure as opposed to low-consequence pipes with a higher break rate.

The deferred initial investment allows for risk exposure to be maintained with minor variations through 2067 at roughly pre-2019 levels (Figure 7-4). The predicted number of breaks also continues to rise, peaking in 2037 before normalizing at about 60 breaks per year. An increase in breaks may be considered acceptable, given those additional breaks are predicted to occur on low-consequence pipes. By about 2050, break rates would be lower than pre-2019 levels.

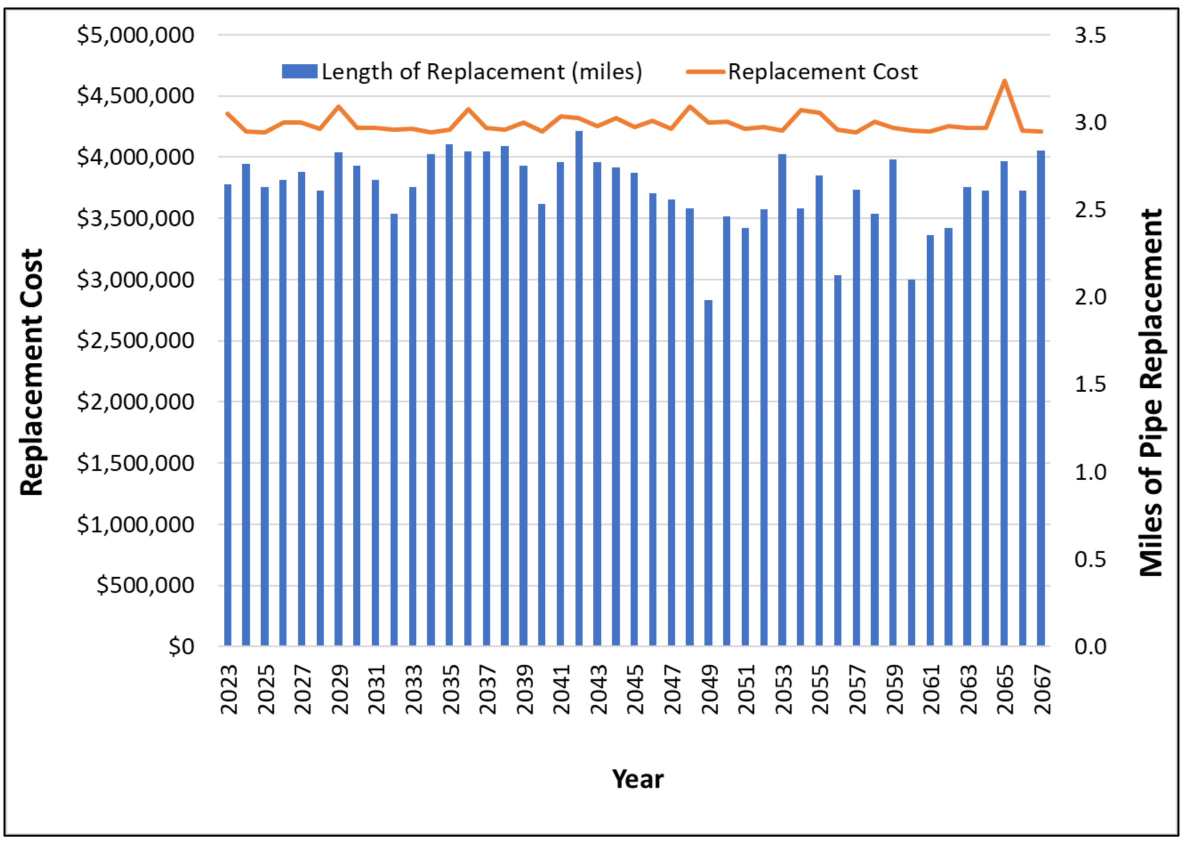


Figure 7-3. Replacement Cost and Length by Year – Modified Baseline Scenario

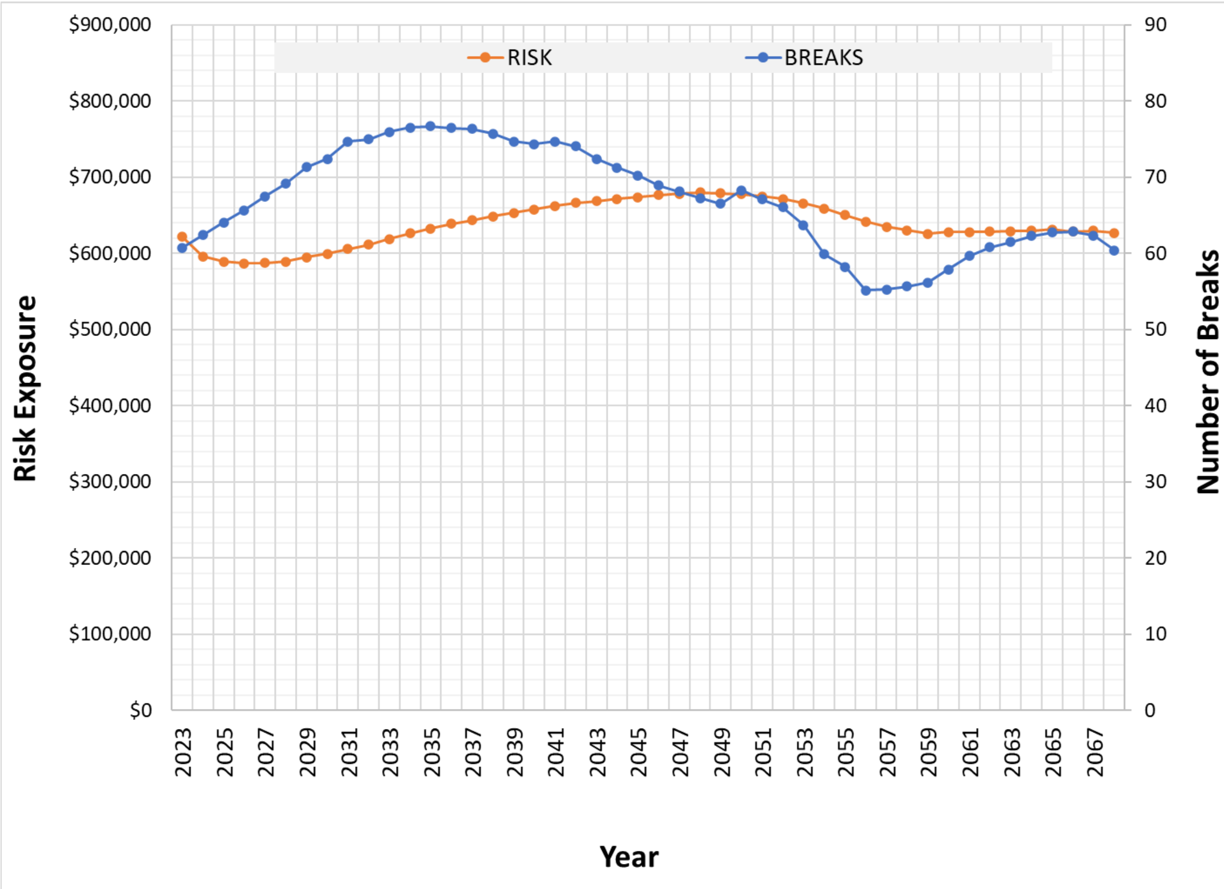


Figure 7-4. Annual Breaks and Risk – Modified Baseline (Even Investment)

7.3. Replacement Scenario – $4.5 Million Investment Level

A consistent annual investment level that would result in risk being maintained at pre-2019 levels through 2045 and thereafter dropping below pre-2019 levels resulted from $4.5 million annual investment. However, for the planning horizon of the next 25-years, the break rate would be higher than pre-2019 levels (See **Figure 7-5**) – though well below 2020-2021 levels.

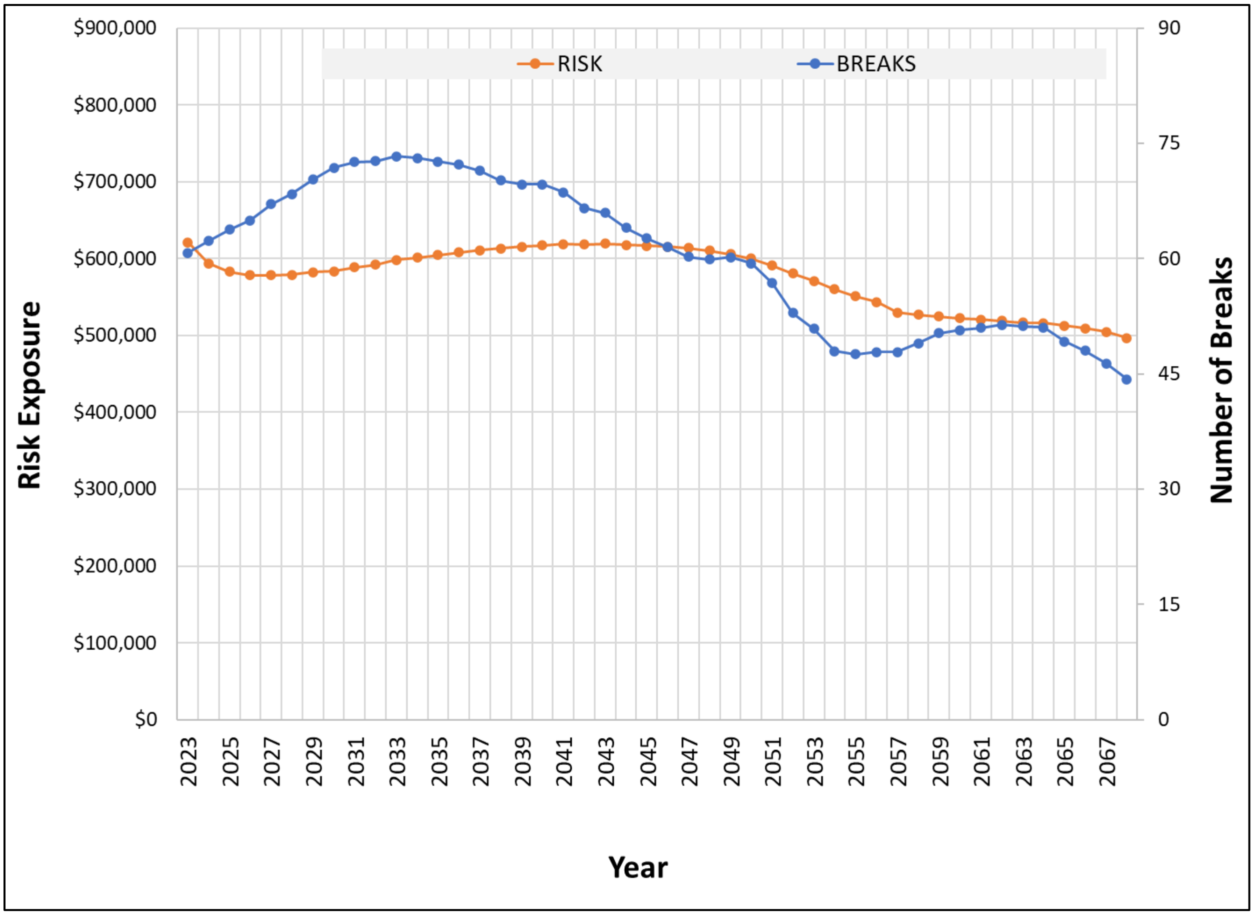


Figure 7-5. Annual Breaks and Risk – $4.5 Million Annual Investment

7.4. Replacement Scenario – 150-Year Cycle ($2.2 Million Investment)

A reduced investment ($2.2 million per year) was analyzed to determine the impacts on risk and breaks. This investment rate represents a replacement cycle for the system of 150 years. Results, shown in **Figure 7-6**, indicate this is not a viable long-term investment rate, with the break rate nearly triple pre-2019 levels by the end of the 25-year planning horizon.

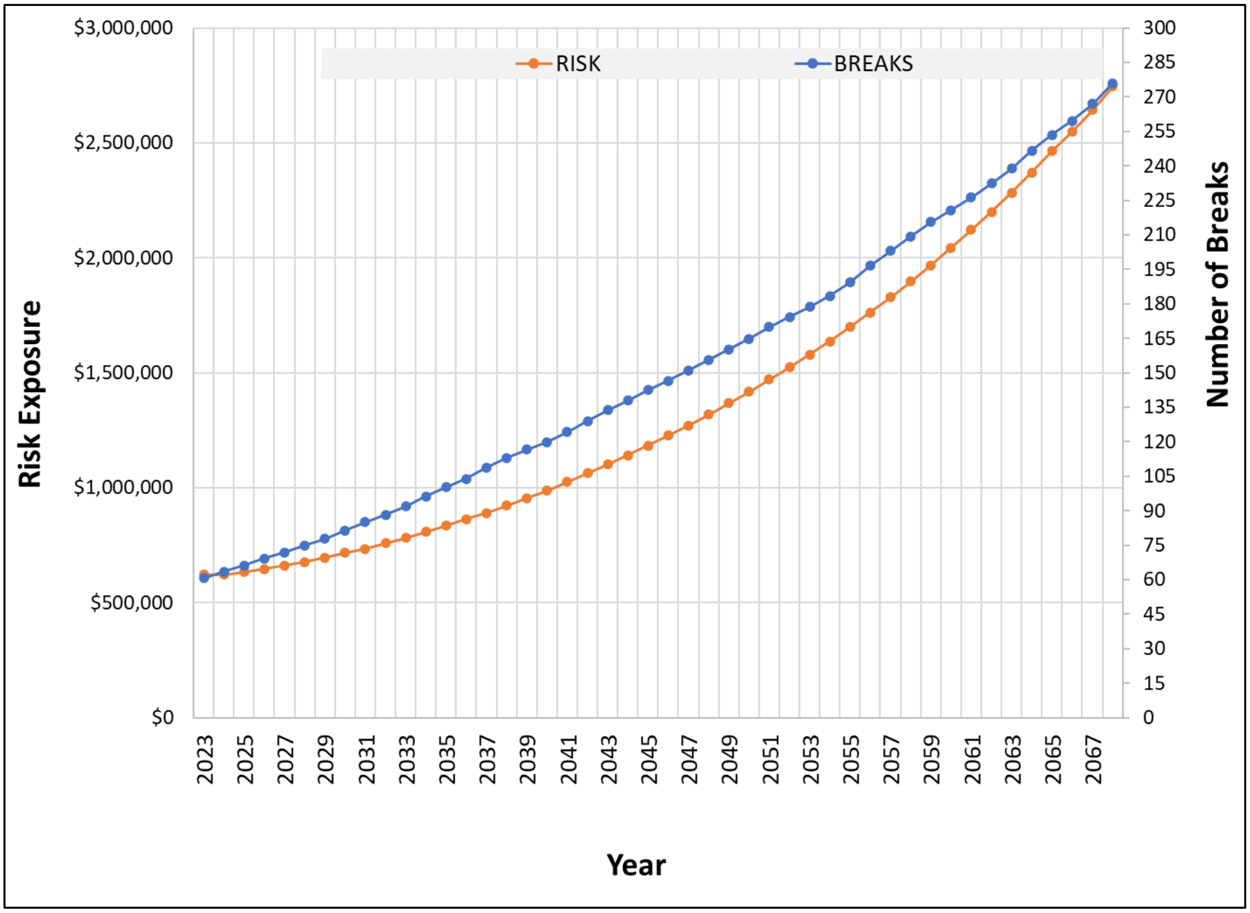


Figure 7-6. Annual Breaks and Risk – $2.2 Million Annual Investment

7.5. Replacement Scenario – Multi-Level Investment

An investment strategy was developed to reduce the initial impact on investment while maintaining risk at pre-2019 levels for the near term (through 2050) and ultimately reducing risk. And breaks below pre-2019 levels. The results are shown in **Figures 7-7 and 7-8**, and the investment framework is shown in **Table 7-4**.

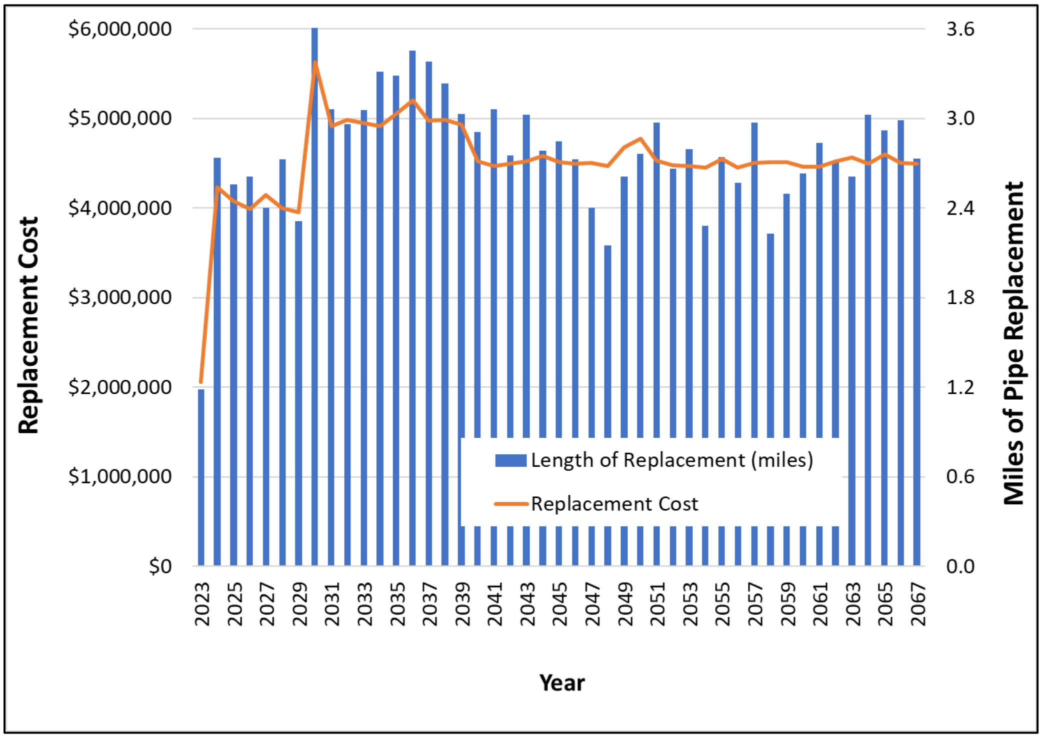


Figure 7-7. Replacement Cost and Length by Year – Multi-Level Investment

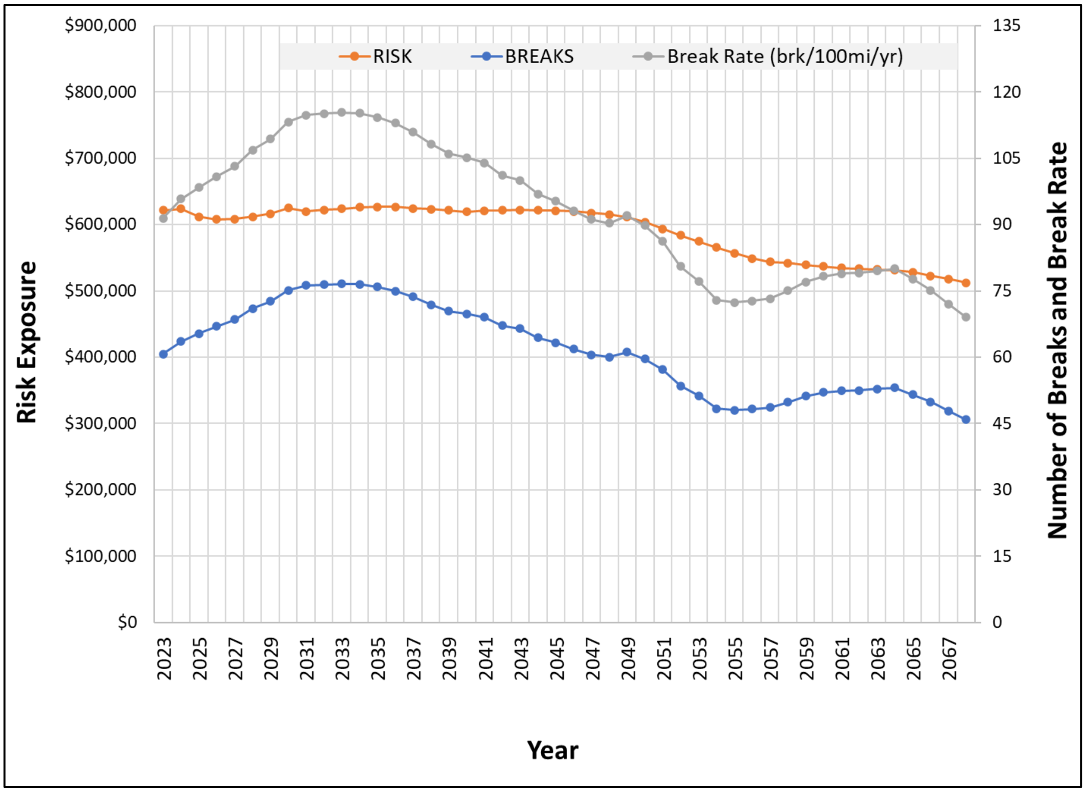


Figure 7-8. Annual Breaks, Break Rate, and Risk – Multi-Level Investment

Table 7-4. Multi-Level Investment Framework	
Year(s)	Investment Level
2023	$2.0 million
2024-2029	$4.0 million
2030-2039	$5.0 million
2040-2067	$4.5 million

This strategy allows for an increase in the annual number of predicted breaks from 45 breaks per year pre-2019 to a maximum of 76 in the early 2030s, but risk levels are stable through the 25-year planning horizon. This number of breaks is still well below the spikes seen in 2020-2021.

8. DISTRIBUTION SYSTEM HYDRAULICS

8.1. Population Projection

The population of the City of Huber Heights in 2020 was 43,439. Population data from 1980 – 2020 was extrapolated to forecast future population growth and subsequently correlated to usage rates to determine potential future water demand ranges. As with any future predictions, there can be many unforeseen factors and variables that can affect such predictions, and the margins of error increase proportionally the further the future prediction extends in time. Therefore, projections were bracketed into potential ranges within lower and upper limits which diverge and create a larger comparative range the further out the prediction extends.

The lower limit used was the extrapolated best fit linear trendline of the population data from the last 40 years (0.4% annual growth). The upper limit used was extrapolated linearly from the percent change of population over the last 40 years (0.6% annual growth). A graphical representation of the population projection is shown in **Figure 8-1**.

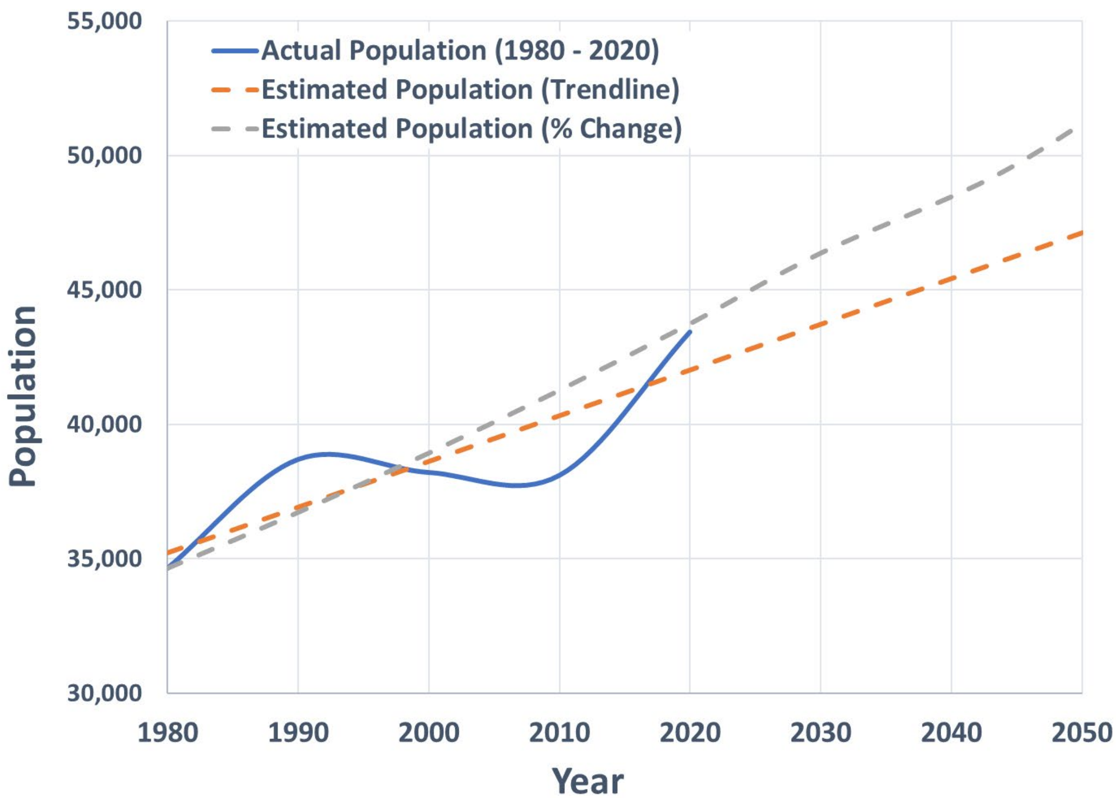


Figure 8-1. Population Forecast

Based on this methodology, the projected 20-year and 30-year population ranges are as follows:

- 2043 Projected Population Range: 45,928 – 49,140
- 2053 Projected Population Range: 47,627 – 52,089

8.2. Demand Rate and Projected Future Demands

The average day demand for 2021 was 3.89 million gallons per day (mgd), and the max day demand (MDD) was 5.18 mgd. The ratio equates to a MDD peaking factor of 1.33. Dividing these demands by population yields a MDD usage of 0.0807 gallons per minute (gpm) per person.

Applying this demand rate and peaking factor to the projected 20-year and 30-year populations yields the projected future demands shown in **Table 8-1.**

Table 8-1. Future Water Demand Ranges		
Year	Projected Average Day Demand Range	Projected Max Day Demand Range
2043	4.02 – 4.30 mgd	5.34 – 5.72 mgd
2053	4.17 – 4.57 mgd	5.54 – 6.06 mgd

8.3.Plant Capacity

The RRRWTP is rated for 7 mgd without softening and nominally 5.6 mgd with membrane softening (assuming a 20% waste stream from the membrane softening process). In general, based on the demand projections outlined herein, the RRRWTP should have adequate capacity for the next 20 years if growth is primarily residential use. However, a new single industrial or commercial customer with high water use could accelerate the need to increase water plant capacity. As max day demands increase and begin to approach 5.6 mgd, increasing WTP capacity will be necessary and additional raw water wells should be considered. An intermediate solution would be to not soften as much of the water a few days a year when the demand exceeds 5.6 mgd, but changes in water quality leaving the water plan into the distribution system can cause unforeseen and undesirable water quality issues unless the changes are subtle.

8.4. Distribution System Capacity

In 2007 the RRRWTP and wellfield was expanded to 7 mgd. Upon completion of the WTP upgrades it was found that the distribution system was unable to handle the pressures needed to convey 7 mgd into the system. In 2010 the distribution system was modeled, and improvements were identified and implemented to allow 7 mgd to be conveyed out of RRRWTP. These improvements included transmission and creating pressure zones near the WTP. The distribution system is currently capable of handling 7 mgd without improvements. Should the WTP be expanded, and the high service pumps become capable beyond 7 mgd capacity, it would be recommended to perform additional modeling and determine if any additional distribution system improvements are needed.

9. RECOMMENDATIONS

9.1. Capital Improvements Plan

Based on the analysis presented in Section 7, the recommended long-range watermain replacement strategy is presented in **Table 9-1**. This investment strategy was presented in more detail in **Section 7.5**. More detailed on potential individual watermain CIP projects are presented in **Appendix C**.

Table 9-1. Multi-Level Replacement Strategy		
Year(s)	Average Annual Replacement Length (miles)	Average Annual Investment*
2023	1.2	$2.0 million
2024-2029	2.6	$4.0 million
2030-2039	3.3	$5.0 million
2040-2067	2.7	$4.5 million

** Average annual investment, based on unit prices shown in Section 7 (Table 7-1), is shown in 2022 US dollars (The City may avoid costs by assuming some design, construction, and inspection services)*

The goals of the recommended replacement plan are to (a) stabilize the break rate and risk in the system to pre-2019 levels through the 25-year planning horizon and (b) to ultimately lower the break rate and risk to below pre-2019 levels in the longer term (beyond 2047). To do so requires a certain length of pipe replacement – the investment level is driven by the length of pipe that needs to be replaced to achieve those goals, not vice versa. Thus, if cost avoidance measures can be achieved in the procurement and installation of pipe, the recommended investment would decrease, while the length of replacement would not.

One ancillary goal of the proactive watermain replacement program is to improve fire flow capacity in the system. The investment levels are based on replacement of all 6-inch pipe with 8-inch pipe, a policy that is already in effect in Huber Heights. Continuation of this practice is recommended.

The recommended 2023 investment of $2 million matches what is currently programmed in the Huber Heights capital plan for 2023. Deferring higher investment levels until 2024 allows an additional year of break observation, as well as time for the City to determine how such an investment level is achievable through existing revenue and spending plans.

There are several factors, discussed below, that may impact the budget levels presented in Table 9-1.

9.1.1. Impact of 2019-2020 Operational Changes

Additional understanding of the impacts of the 2019-2020 operational changes discussed in this report may impact the recommended investment levels. This replacement plan is based on break data through April 2019, prior to major operational changes. If the systemwide watermain break rate does not return to a level near pre-2019 levels, additional investment may be necessary to achieve the level of water system reliability desired by the City and its customers.

9.1.2. Inflation, Supply Chain, and the Labor Market

There also remains a great deal of uncertainty surrounding the market for raw materials (i.e., water pipes). Supply chain interruptions and labor shortages have led to a roughly 50-percent increase in ductile iron costs over the last 2 years, and some utilities have reported up to 18-month delivery time for pipe, particularly in the smaller pipe diameter ranges (less than 12-inches).

9.1.3. Performance of Existing Ductile Iron Watermains

The recommended replacement plan is almost entirely focused on retiring cast iron pipe, which is exhibiting a far greater break rate than ductile iron (DI) and PCCP pipe. The ductile iron watermains in the Huber Heights distribution system have an average age of 25 years, as opposed to 56 years for cast iron pipes. The continued performance of DI pipe may have significant impacts on future replacement needs. Several contributing factors will potentially impact DI performance:

- Moderately- to highly corrosive soils across the entire system
- Improved backfilling practices beginning in the mid-1980s
- Improved corrosion protection (the City began using zinc-coated DI pipe in 2018; zinc acts as a layer of corrosion protection)

9.1.4. Alternative Material Selection

Because of the cost and supply chain issues discussed above, some utilities have begun performing watermain installations using PVC or HDPE pipes. These materials traditionally were lower-cost options and for Huber Heights could be additionally suitable to address soil corrosivity. The drawbacks include (a) rising PVC and HDPE costs resulting from similar supply chain and demand issues (many utilities are forced to use PVC and/or HDPE because DI is not available) and (b) a limited range of PVC and HDPE experience in water distribution systems in the US, with many utilities having approved their use only in the last decade. PVC and HDPE have been used more broadly in the sewer and stormwater industries. Additionally, the lighter weight, increased durability, and better tapping properties of molecularly oriented PVCO C909, has made the use of plastic pipe more acceptable and can often result in lower construction costs especially in small diameter mains as the material is much easier to handle and move. These issues should be considered when implementing the replacement program as a potential opportunity to avoid costs.

In addition, PCCP is still a viable and trusted material for large-diameter water transmission mains. As shown in **Section 3**, PCCP pipe has a relatively low break rate (0.07 breaks per mile per year) despite its average age of 55 years. Longevity predictions of PCCP pipe in the Midwest is 105 years, and because soil surveys indicate soils are not highly corrosive for concrete in the City, it should be considered for large-diameter replacements.

9.2. Corrosion Protection

Because of the corrosivity of native soils in Huber Heights and because DI pipe has historically been the replacement material of choice, the following corrosion protection practices should be considered:

- Corrosion protection liners: The City has been installing DI pipe with an optional zinc coating since 2018. Some pipe manufacturers (e.g., US Pipe) indicated as early as 2018 that they may ultimately cease production of DI without the zinc coating. The City should continue this practice.
- Zinc anode caps and bags: All new water pipe installation should have multiple zinc anode caps installed on bolts of fittings and valves. The caps are extremely inexpensive and easy to install. Additionally, many utilities have begun stocking zinc anode bags for crews to install as part of any routine maintenance call or repair. A thirty-pound bag and associated wire costs approximately $300 and can be installed in minutes, adding over a decade or more, depending on soil conditions, of additional corrosion protection.
- Polyethylene wrapping: Some utilities have opted to install a polyethylene wrapping around DI pipe when installed, generally as a substitute for zinc coating. Wrapping must be conducted by a qualified and experienced construction contractor, as many utilities have reported accelerated corrosion and breaks resulting from improper installation.
- Engineered backfill: The City should also consider the potential to backfill all metal pipes with non-native, engineered soil to reduce corrosion. The potential benefits may be limited due to the predominance of corrosive soils throughout the entire City and the chance for corrosive chemicals to migrate into zones of new construction.
- Alternative pipe materials: As discussed in Section 9.1, PVC pipe (C900 or C909) or HDPE pipe. Some considerations:
    - PVC pipe (C900 and C909) can fit ductile iron fittings without needing special gaskets. HDPE pipe can be welded at joints to another HDPE pipe or to a fitting, resulting in a continuous pipe. Additionally, HPDE can be used with traditional DIP fittings when stainless steel stiffener inserts are incorporated. Service saddles

for HDPE typically require specialized saddles which incorporate "spring" washers to accommodate the greater expansion and contraction of HDPE material.

  - Both PVC and HDPE generally require a higher backfill classification compared to DI pipe. Both PVC and HDPE can be installed as "jointless" pipe, with joints thermally butt fused, eliminating mechanical push-on joints and often other traditional mechanical fitting connections. Fused pipe can be installed via either traditional open-cut or horizontal directional drilling (HDD) methods. HDD is often beneficial for small diameter pipe in residential areas as often 1,000 feet can be installed in one day and it can eliminate a large amount of property restoration and drive or sidewalk replacement.

9.3. Physical Assessment of Pipe Deterioration

Multiple types of physical condition assessment are recommended for consideration on an ongoing basis:

- When watermains are accessed for repairs or as part of other projects, opportunistically extracting pipe coupons and/or large exterior delaminated sample portions of surface material for analysis is recommended to further assess pipe corrosion. The composition of the coupons and samples can be evaluated for properties such as grain size/structure, composition, and determine if graphitization is occurring. Additionally, coupons are a valuable baseline for pipe wall thickness for future wall thickness investigations. Taking coupons would entail having the main depressurized and out of service and would incur a cost for a full body repair clamp and/or welded plate. The City should consider the value of this practice.
- Acoustic Pipe Wall Assessment is recommended for a portion of the DI pipe (e.g., 10-percent of the DI system, or roughly 11 miles) to evaluate the level of deterioration in those pipes. As mentioned in Section 9.1, the continued performance of DI pipe could have significant impacts on future replacement needs. Acoustic pipe wall assessment (e.g., ePulse by Mueller / Echologics) does not require excavating to get physical access to the pipe and is more affordable than other physical condition assessment options. The analysis allows for an estimate of the average wall thickness over an entire pipe (from hydrant-to-hydrant or valve-to-valve. A sound wave is induced in the pipeline and travels along the pipe, and acoustic sensors capture the time it takes the sound wave to travel between two sensor stations. The speed at which the sound wave travels is dictated by the condition of the pipe wall. Measured wall thickness is compared to nominal wall thickness to assess the change from nominal.
- Acoustic-based assessment could also be considered for portions of the CI pipe system if there is a desire to confirm pipe integrity prior to replacement. While the break database if comprehensive and a clear pattern of CI pipe performance is discernable, acoustic

sounding could be conducted to confirm the analytical findings and potentially reprioritize projects on the 5-year CIP or to tweak the scope / breadth of those projects.

- Ultrasonic thickness testing can be performed during excavations on the exterior pipe wall and provides an accurate and location-specific reading of the metallic pipe wall. This can be performed by a specialty consultant, or the utility owner can invest in its own equipment to have on hand. This method is non-destructive and does not affect the operation of the water main.
- Pitting measurement: When a pipe is excavated, a visual inspection for pitting should be performed. Specifically, the approximate number, clustering, and location around the pipe exterior should be noted, with larger significant pits measured, or have a picture taken with a common object such a coin next to it to provide a sense of magnitude. Documenting existing pitting can provide a better sense of the cause and type of corrosion that is ongoing.
- Because the configuration and operation of the system changed significantly beginning in 2021, and because it is unclear if the break rate will settle completely back to pre-2019 levels on its own, micro-pressure monitors should be considered if the break rate continues to be higher than expected. These monitors would be placed in areas where hydrant testing is performed and can help determine if water hammer issues exist from the operations of system, including how booster stations and tanks are cycled.

9.4. Continued Pipe and Break Data Management Processes

The long-term impacts of the 2020 operational changes are unknown. The break rate dropped in 2021 and appears to have decreased further in 2022, but the break rate is higher than pre-2019 levels. The City should continue to record the break rate to inform any adjustments to its proactive pipe replacement program. This includes continuing to archive pipe and break data for abandoned pipe.

9.5. Water Master Plan

The scope of the hydraulic analysis of the distribution system as part of this project was confined to evaluating the long-term hydraulic capacity of the water distribution system within a 25-year planning horizon. Proposed solutions and a plan of action were not included in the scope of services for this project. The conclusions of the hydraulic analysis are that the system is adequate in the near term and that no projects need to be added to the 5-year CIP to address plant or distribution system capacity with one exception: as noted above, replacement of all 6-inch watermains (predominantly older cast iron pipes) with 8-inch pipe is an ongoing practice, and continuation of that practice is recommended. Because 6-inch cast-iron pipe has the highest break rate of any material / diameter combination, the City is expected to realize improvements in fire flows and overall system capacity as a result replacement.

Development of an updated water master plan as part of the 5-year CIP is recommended to further evaluate issues expected to emerge at the end of the 25-year planning horizon. The scope of the master plan would include more detailed analysis of expected population growth and growth of water demands, as well as further evaluation of the condition and capacity of the transmission and distribution system. The long-term water treatment plant capacity may also be of concern based on the adjusted (lower) capacity of the Rip Rap Road facility, coupled with the decommissioning of the Needmore Road Treatment Plant. Water storage tank capacity would also be evaluated.

Since the Needmore Road Water Treatment Plant was decommissioned, the only source of water supply for the City is the wellfield at the Rip Rap Road Water Treatment Plant. Because the capacity of at Rip Rap Road was decreased due to softening upgrades, development of a secondary water supply should also be the subject of the water master plan. With higher-than-expected watermain break rates in recent years and an understanding that the soils in Huber Heights are moderately- to highly corrosive to the 97-percent of the distribution system that is cast iron and ductile iron, the potential for a significant watermain break that impacts the ability to deliver water to customers should be further evaluated.

To the extent that the booster stations and softening portion of the water treatment plant are relatively new, the equipment evaluation and replacement planning scope of the water master plan can be limited to excluded newer facility equipment.

9.6. Emergency Preparedness Plan – Functional or Full-Scale Exercise(s)

The City is required to exercise at least one of the incident-specific action plans in its water system emergency preparedness plan (also known as a Contingency Plan) and must exercise all action plans within 5 years in accordance with Ohio Administrative Code. Emergency action plans, including a major watermain break and a loss of water supply, were last updated in late 2021.

Neither functional nor full-scale exercises are required by regulations (workshops, review, and training alone meet the requirement of exercises as defined by Ohio EPA). Because of the reliance on the Rip Rap Road Water Treatment Plant and its wellfield, a functional or full-scale exercise of an event that impacts the ability to supply water to customers is recommended in the near term (2023). A functional exercise examines and/or validates the coordination, command, and control between various multi-agency coordination centers (e.g., emergency operation center, joint field office, etc.). A functional exercise does not involve any "boots on the ground" (i.e., first responders or emergency officials responding to an incident in real time). A full-scale exercise is a multi-agency, multi-jurisdictional, multi-discipline exercise involving functional (e.g., joint field office, emergency operation centers, etc.) and “boots on the ground” response.

9.7. Asset Management Plan Updates

The City is required to updates it water system asset management plan (AMP) every 3 years by Ohio EPA. The first water system AMP was developed in early 2019, and extensive changes to water systems infrastructure and operations have occurred since then. The AMP should be updated in 2023 to document revisions in the City’s plan to manage existing infrastructure and to maintain regulatory compliance, and to report on required progress in implementing AM.

As part of this update, the City should implement some of the recommendations from the 2019 AMP. Specifically, a structured asset register for facility assets should be developed and should include all mechanical, structural, electrical, HVAC, tank, and valve assets. For each, a physical condition assessment should be conducted with an overall condition score assigned to each asset, as required by Ohio Administrative Code. Additional implementation should also be considered, including the determination of the relative criticality of each asset or asset system.

9.8. Overall CIP Recommendations

A summary of CIP recommendations is shown in **Table 9-2**. Operational changes recommended above are subject to review and consideration by the City and Veolia, and costs for operations changes are not included herein.

Table 9-2. 2023-2027 Water Capital Improvements Recommendations*

CIP Item	2023	2024	2025	2026	2027
Watermain Replacement	$2,000,000	$4,000,000	$4,000,000	$4,000,000	$4,000,000
Acoustic Pipe Wall Assessment: DI Pipe*				$600,000	
Water Master Plan					$150,000
Emergency Response Plan - Functional Exercise(s)	$50,000				
Asset Management Plan Update	$20,000				

** Cost estimates are in 2022 USD.*

*** Acoustic Pipe Wall Assessment assumes 11.3 miles of DI Pipe inspection (≈60,0000 feet) at $10 per foot*

APPENDIX A

Pipes Without Installation Dates in the Initial Data Set

Issues with Initial Data Set

BREAK DATA ISSUES (12 breaks)

The only potential issues with breaks are with 6 pairs of breaks that meet these criteria: Two separate breaks were recorded on the **same** pipe on the **same** day. It is possible that these are separate breaks. All the breaks in these cases were recorded in 2020 and 2021. The breaks occurred on pipes that have installation dates of 1960 (they are all old cast iron pipes). While these could be separate breaks, we are, as a default, treating them as duplicates and removing the duplicate break. If Huber Heights chooses, they can research these breaks to determine if these are (in some cases), not duplicate breaks.

Address of Break	# of parcels away	repair materials?	ID	(initial) Issues	Break Date	Pipe - ID	Pipe Date of Installation	Pipe Material	Pipe Length	Pipe Diameter
7039 Bascombe	6	Diff. matls.	720200013	same Pipe ID, same DOB, diff Break ID	2020-07-26	WM02313	1960-12-31	Cast Iron	1270.0	6
7003 Bascombe			720200014	same Pipe ID, same DOB, diff Break ID	2020-07-26	WM02313	1960-12-31	Cast Iron	1270.0	6
6026 Longford	7	Diff. matls.	820200010	same Pipe ID, same DOB, diff Break ID	2020-08-06	WM04401	1960-12-31	Cast Iron	870.1	10
Longford at Harshmanville			820200009	same Pipe ID, same DOB, diff Break ID	2020-08-06	WM04401	1960-12-31	Cast Iron	870.1	10
6127 Longford	1	Same matls., different repair time	820200024	same Pipe ID, same DOB, diff Break ID	2020-08-25	WM02308	1960-12-31	Cast Iron	538.1	10
6131 Longford			820200025	same Pipe ID, same DOB, diff Break ID	2020-08-25	WM02308	1960-12-31	Cast Iron	538.1	10
7051 Claybeck	0	Yes	820200026	same Pipe ID, same DOB, diff Break ID	2020-08-26	WM02315	1960-12-31	Cast Iron	1057.5	6
7051 Claybeck			820200030	same Pipe ID, same DOB, diff Break ID	2020-08-26	WM02315	1960-12-31	Cast Iron	1057.5	6
5704 Hinckley	4	both 12 hr. repairs	102020004	same Pipe ID, same DOB, diff Break ID	2020-10-03	WM02300	1960-12-31	Cast Iron	801.0	6
5738 Hinkley			102020006	same Pipe ID, same DOB, diff Break ID	2020-10-03	WM02300	1960-12-31	Cast Iron	801.0	6
5464 Storck	2	Yes	920210004	same Pipe ID, same DOB, diff Break ID	2021-09-03	WM00911	1959-12-31	Cast Iron	562.4	6
5480 Storck			920210005	same Pipe ID, same DOB, diff Break ID	2021-09-03	WM00911	1959-12-31	Cast Iron	562.4	6

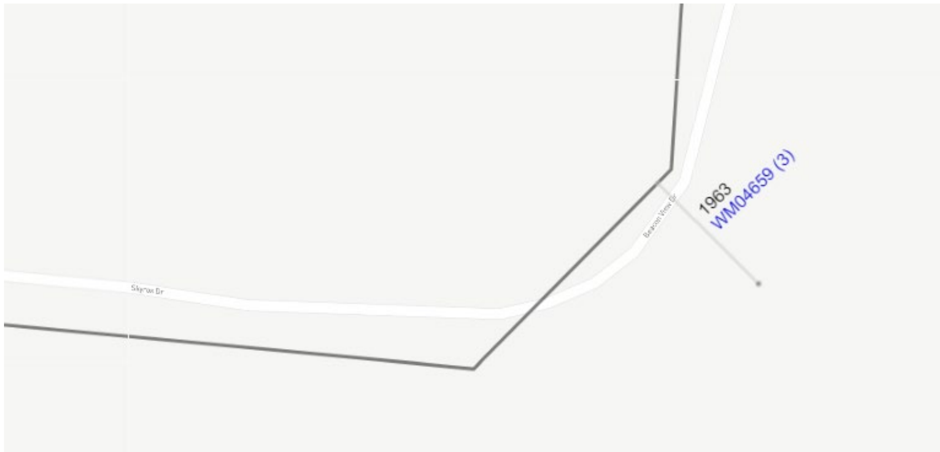
PIPE DATA ISSUES (17 out of 4451 pipes)

The initial dataset had 113 pipes with no date of installation: these were resolved by Huber Heights.

The new data set has 17 issues: 1 of the 17 (Pipe ID WM04659) was a 2-inch pipe with no material, this pipe will be excluded from the analysis as a service connection or hydrant lateral (there is a hydrant at the intersection of Beaconview Drive and Skyros Drive). The other 16 pipes with issues are related to 8 pairs of pipes that have the same ID but are, in fact, adjacent pipes that may have been split for various reasons, in some cases because a portion of a pipe was replaced and now has a new installation date (see below).

ID	New ID	Last Update	Issues	Date of Installa	Material	Length	Diameter	Life Status
WM00944		2022-08-08	DUPL Pipe ID, same Life Status	2000-12-31	DCI	361.2657714	8	ACT
WM00944		2022-08-08	DUPL Pipe ID, same Life Status	2000-12-31	DCI	470.932995	8	ACT
WM02896		2022-08-08	DUPL Pipe ID, same Life Status	1988-12-31	DCI	82.11360719	16	ACT
WM02896		2022-08-08	DUPL Pipe ID, same Life Status	2002-12-31	DCI	117.4945954	16	ACT
WM03607		2022-08-08	DUPL Pipe ID, same Life Status	1967-12-31	Cast Iron	358.3590365	8	ACT
WM03607		2022-08-08	DUPL Pipe ID, same Life Status	1969-12-31	Cast Iron	464.2676727	8	ACT
WM03924		2022-08-08	DUPL Pipe ID, same Life Status	1988-12-31	DCI	257.5968234	8	ACT
WM03924		2022-08-08	DUPL Pipe ID, same Life Status	1975-12-31	DCI	6.7331941	8	ACT
WM04031		2022-08-08	DUPL Pipe ID, same Life Status	1979-12-31	DCI	524.4549411	8	ACT
WM04031		2022-08-08	DUPL Pipe ID, same Life Status	1975-12-31	DCI	663.4043554	8	ACT
WM04085		2022-08-08	DUPL Pipe ID, same Life Status	1963-12-31	PCP	498.5676254	20	ACT
WM04085		2022-08-08	DUPL Pipe ID, same Life Status	1959-12-31	PCP	6.95856558	20	ACT
WM04207		2022-08-08	DUPL Pipe ID, same Life Status	1978-12-31	DCI	443.8818969	8	ACT
WM04207		2022-08-08	DUPL Pipe ID, same Life Status	1989-12-31	DCI	923.8004434	8	ACT
WM04443		2022-08-08	DUPL Pipe ID, same Life Status	1991-12-31	DCI	316.8610459	8	ACT
WM04443		2022-08-08	DUPL Pipe ID, same Life Status	1991-12-31	DCI	124.6363466	8	ACT

Pipe WM04659



Appendix A (continued). Pipes with Missing Installation Dates in Initial GIS Dataset

Pipes with Missing Installation Date in Initial Dataset				
UID	Issues	Material	Length (ft)	Diameter (in)
WM04093	No DOI	DCI	178.46	8
WM04103	No DOI	DCI	197.45	8
WM04171	No DOI	DCI	359.28	6
WM04170	No DOI	DCI	167.76	6
WM04172	No DOI	DCI	509.00	6
WM04399	No DOI	DCI	633.75	8
WM04400	No DOI	DCI	527.06	8
WM04398	No DOI	DCI	214.52	8
WM04113	No DOI	DCI	159.53	6
WM03981	No DOI	DCI	22.31	8
WM04397	No DOI	DCI	538.75	6
WM04055	No DOI	DCI	657.95	6
WM04054	No DOI	DCI	176.84	6
WM04074	No DOI	DCI	34.75	6
WM04053	No DOI	DCI	297.99	6
WM04032	No DOI	DCI	651.28	8
WM04027	No DOI	DCI	1302.28	8
WM03788	No DOI	Cast Iron	433.03	6
WM03920	No DOI	PCP	1026.95	20
WM04142	No DOI	DCI	173.93	6
WM04279	No DOI	DCI	337.08	8
WM03817	No DOI	DCI	29.22	8
WM04081	No DOI	DCI	919.76	12
WM04082	No DOI	DCI	662.64	12
WM04305	No DOI	DCI	172.01	6
WM04105	No DOI	DCI	571.67	8
WM04106	No DOI	DCI	97.20	8
WM04422	No DOI	DCI	318.43	8
WM04111	No DOI	DCI	662.15	8
WM04109	No DOI	DCI	215.98	12
WM04110	No DOI	DCI	640.42	12
WM04112	No DOI	DCI	136.08	6

Pipes with Missing Installation Date in Initial Dataset				
UID	Issues	Material	Length (ft)	Diameter (in)
WM04114	No DOI	DCI	157.54	6
WM04115	No DOI	DCI	399.98	8
WM04117	No DOI	DCI	195.57	6
WM04080	No DOI	DCI	1259.36	6
WM04186	No DOI	DCI	438.95	8
WM04045	No DOI	DCI	695.34	12
WM04047	No DOI	DCI	663.42	12
WM04046	No DOI	DCI	1598.29	8
WM04048	No DOI	DCI	1509.77	12
WM04049	No DOI	DCI	367.61	8
WM04051	No DOI	DCI	60.05	8
WM04050	No DOI	DCI	331.24	8
WM03931	No DOI	DCI	134.07	6
WM03924	No DOI	DCI	253.37	8
WM03917	No DOI	DCI	667.96	6
WM03980	No DOI	DCI	2295.32	12
WM04042	No DOI	DCI	840.11	12
WM04283	No DOI	DCI	976.31	6
WM04285	No DOI	DCI	511.22	6
WM04284	No DOI	DCI	461.06	6
WM04286	No DOI	DCI	130.59	6
WM04450	No DOI	DCI	178.69	6
WM03928	No DOI	DCI	759.44	6
WM03957	No DOI	DCI	130.45	12
WM04225	No DOI	Cast Iron	901.70	8
WM04088	No DOI	DCI	317.24	8
WM04085	No DOI	PCP	498.57	16
WM04087	No DOI	DCI	146.20	8
WM04256	No DOI	DCI	685.28	12
WM04084	No DOI	DCI	689.93	6
WM04238	No DOI	DCI	247.67	8
WM04237	No DOI	DCI	795.72	6
WM03921	No DOI	DCI	295.80	6
WM03922	No DOI	DCI	233.97	6

Pipes with Missing Installation Date in Initial Dataset				
UID	Issues	Material	Length (ft)	Diameter (in)
WM03913	No DOI	DCI	865.90	6
WM04158	No DOI	DCI	193.02	6
WM04388	No DOI	DCI	823.32	6
WM03794	No DOI	Cast Iron	181.40	12
WM04034	No DOI	Cast Iron	287.10	8
WM04187	No DOI	Cast Iron	92.79	8
WM03795	No DOI	Cast Iron	129.11	8
WM03796	No DOI	Cast Iron	586.12	8
WM03202	No DOI	DCI	852.30	6
WM04018	No DOI	DCI	766.63	12
WM04258	No DOI	DCI	351.06	6
WM04015	No DOI	DCI	525.83	12
WM04052	No DOI	DCI	921.25	16
WM04414	No DOI	Cast Iron	196.80	6
WM04413	No DOI	Cast Iron	570.84	6
WM03983	No DOI	Cast Iron	705.34	6
WM03880	No DOI	DCI	323.64	16
WM04208	No DOI	DCI	599.82	8
WM04322	No DOI	DCI	416.36	8
WM03927	No DOI	DCI	1628.79	12
WM03932	No DOI	DCI	837.25	16
WM04196	No DOI	DCI	699.93	12
WM04351	No DOI	DCI	234.43	8
WM04068	No DOI	DCI	162.94	6
WM04069	No DOI	DCI	230.74	6
WM04044	No DOI	DCI	412.53	12
WM03930	No DOI	DCI	111.24	8
WM04039	No DOI	DCI	386.18	6
WM04035	No DOI	DCI	2785.42	12
WM04056	No DOI	DCI	31.65	8
WM04211	No DOI	DCI	194.59	8
WM04169	No DOI	DCI	470.95	6
WM04037	No DOI	DCI	55.17	16
WM04041	No DOI	DCI	596.92	6

Pipes with Missing Installation Date in Initial Dataset				
UID	**Issues**	**Material**	**Length (ft)**	**Diameter (in)**
WM03792	No DOI	DCI	768.05	8
WM04440	No DOI	DCI	20.00	16
WM04038	No DOI	DCI	241.91	12
WM04029	No DOI	DCI	451.25	8
WM04031	No DOI	DCI	1187.86	8
WM04036	No DOI	DCI	859.61	16
WM04040	No DOI	DCI	855.12	6
WM04028	No DOI	DCI	256.87	8
WM04587	No DOI	DCI	900.21	6
WM04209	No DOI	DCI	152.56	6
WM04168	No DOI	DCI	164.83	6
WM04272	No DOI	DCI	2.97	12
WM04030	No DOI	DCI	167.13	8

Source: infraSOFT, based on Huber Heights GIS

APPENDIX B

Abandoned Watermains

APPENDIX B

Summary of Abandoned Watermains						
Asset ID	**Replacement Project**	**Diameter (in.)**	**Material**	**Pipe Length (ft.)**	**Install Year**	**Year of Abandonment**
AWM04674	Nebraska - Neptune	6	Cast Iron	748	1956	2016
AWM04675		6		435	1956	2016
AWM04678		6		792	1956	2016
AWM04677		6		10	1956	2016
AWM04676		6		3	1956	2016
AWM04683		8		228	1956	2016
AWM04684		6		5	1956	2016
AWM04679		6		101	1956	2016
AWM04680		6		258	1956	2016
AWM04681		6		596	1956	2016
AWM04682		6		513	1956	2016
AWM04670	Broad Reach	12	DCI	190	1974	2022
AWM04660	Harshmanville 2020	6	Cast Iron	242	1959	2020
AWM04661		6		462	1959	2020
AWM04662		6		452	1959	2020
AWM04663		6		437	1959	2020
AWM04664		6		851	1959	2020
AWM04665		6		426	1959	2020
AWM04666		6		465	1959	2020
AWM04667		6		310	1959	2020
AWM04685	Harshmanville_ Kitridge_Monitor	6	Cast Iron	448	1956	2011
AWM04686		6		436	1956	2011
AWM04688		6		107	1956	2011
AWM04687		6		364	1956	2011
AWM04689		6		518	1956	2011
AWM04690		6		300	1956	2011
AWM04691		6		124	1956	2011
AWM04692		8		321	1956	2011
AWM04693		6		65	1956	2011
AWM04694		6		128	1956	2011
AWM04702		6		505	1956	2011
AWM04701		12		338	1956	2011
AWM04699		6		310	1956	2011
AWM04700		10		250	1956	2011
AWM04695		6		656	1956	2011
AWM04696		6		474	1956	2011
AWM04697		6		553	1956	2011
AWM04698		10		316	1956	2011
AWM04709		6		213	1956	2011
AWM04708		6		27	1956	2011
AWM04707		6		772	1956	2011
AWM04706		6		111	1956	2011
AWM04705		6		696	1956	2011
AWM04704		6		282	1956	2011
AWM04703		6		159	1956	2011
AWM04672	Mahler_Lambeth 2010	6	Cast Iron	1575	1956	2010
AWM04671		6		1753	1956	2010
AWM04668	NHeights Relocation	8	DCI	336	1989	2007
AWM04669	Trimble Addition	8	DCI	806	2012	2019
AWM04658	YMCA_Sinclair Addition	8	DCI	71	2005	2005
AWM04659		8		245	2005	2005

APPENDIX C

Potential Individual Watermain CIP Projects

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 1

Project BCR Ratio: 2.41

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00155	Cast Iron	8	1974	0
WM00157	Cast Iron	8	1974	0
WM00477	Cast Iron	6	1970	0
WM00481	Cast Iron	6	1970	0
WM00827	Cast Iron	12	1959	0
WM00828	Cast Iron	6	1959	0
WM00829	Cast Iron	6	1959	3
WM00830	Cast Iron	6	1959	0
WM00831	Cast Iron	6	1959	6
WM04524	Cast Iron	6	1959	3
WM04525	Cast Iron	6	1959	5
WM00836	Cast Iron	6	1959	6
WM00837	Cast Iron	6	1959	1
WM00838	Cast Iron	12	1959	0
WM00839	Cast Iron	6	1959	0
WM00840	Cast Iron	6	1959	2
WM01234	Cast Iron	6	1970	0
WM01235	Cast Iron	6	1970	0
WM01236	Cast Iron	6	1970	2
WM01237	Cast Iron	6	1970	0
WM01238	Cast Iron	6	1970	0
WM01239	Cast Iron	6	1970	0
WM01472	Cast Iron	6	1972	0
WM01697	Cast Iron	8	1974	0
WM01700	Cast Iron	8	1974	0
WM01767	Cast Iron	6	1970	0
WM01769	Cast Iron	6	1968	1
WM01770	Cast Iron	6	1968	0
WM01771	Cast Iron	6	1968	0
WM01772	Cast Iron	6	1968	0
WM01838	Cast Iron	6	1969	0
WM01839	Cast Iron	6	1969	1
WM01840	Cast Iron	6	1969	0
WM01841	Cast Iron	6	1969	0
WM01842	Cast Iron	6	1969	0
WM01843	Cast Iron	6	1969	0
WM01844	Cast Iron	6	1969	2
WM01845	Cast Iron	6	1969	0
WM01847	Cast Iron	6	1969	0
WM01848	Cast Iron	6	1970	1
WM01849	Cast Iron	6	1970	0
WM04081	Cast Iron	12	1965	0
WM04082	Cast Iron	12	1965	1

Replacement Cost ($) Total: 3,813,453

50-year Risk ($): 9,199,794

Project 2

Project BCR Ratio: 1.88

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00784	PCP	16	1959	1
WM00785	Cast Iron	6	1959	1
WM00790	Cast Iron	6	1959	0
WM01218	Cast Iron	6	1968	0
WM01219	Cast Iron	6	1968	0
WM01220	Cast Iron	6	1968	0
WM01221	Cast Iron	6	1968	0
WM01222	Cast Iron	6	1968	0
WM01223	Cast Iron	6	1968	0
WM01224	Cast Iron	6	1968	0
WM01225	Cast Iron	6	1968	1
WM01744	Cast Iron	6	1968	0
WM02286	Cast Iron	6	1960	3
WM02287	Cast Iron	6	1960	0
WM02288	Cast Iron	16	1960	0
WM02289	Cast Iron	6	1960	10
WM02306	Cast Iron	6	1960	0
WM02307	Cast Iron	6	1960	8
WM02310	Cast Iron	6	1960	1
WM02312	Cast Iron	6	1960	0
WM02313	Cast Iron	6	1960	15
WM02314	Cast Iron	6	1960	0
WM02315	Cast Iron	6	1960	11
WM02316	Cast Iron	6	1960	4
WM04401	Cast Iron	10	1960	11

Replacement Cost ($) Total: 2,698,415

50-year Risk ($): 5,066,936

Project 3

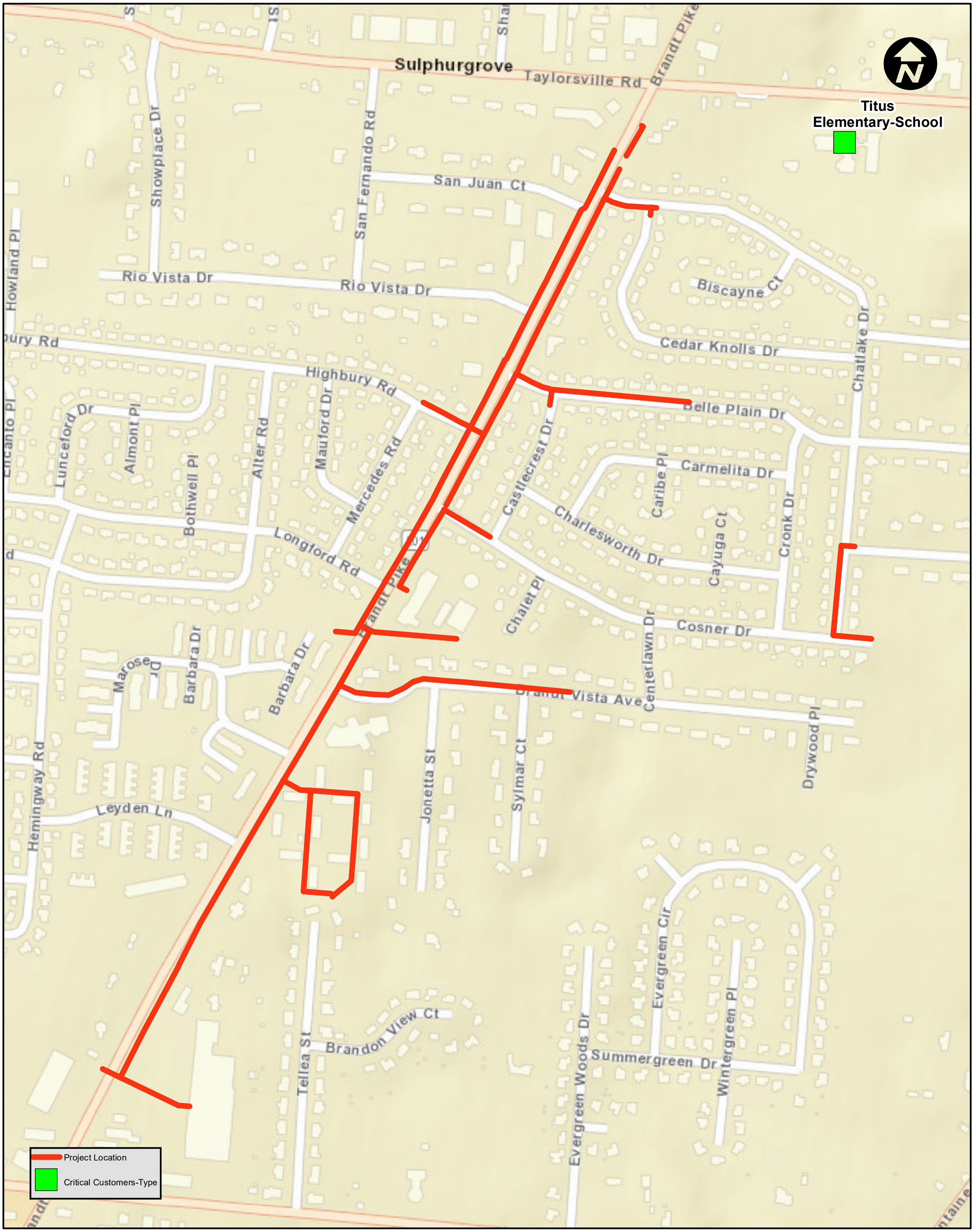
Project BCR Ratio: 1.55

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00726	Cast Iron	6	1959	2
WM00728	Cast Iron	6	1959	1
WM00732	Cast Iron	6	1959	1
WM00843	Cast Iron	6	1959	0
WM00845	Cast Iron	6	1959	0
WM00852	Cast Iron	6	1959	0
WM00857	Cast Iron	12	1959	0
WM00858	Cast Iron	12	1959	0
WM00859	Cast Iron	6	1959	1
WM00860	Cast Iron	6	1959	0
WM00861	Cast Iron	12	1959	0
WM00862	Cast Iron	12	1959	0
WM00863	Cast Iron	12	1959	0
WM00864	Cast Iron	12	1959	0
WM00896	Cast Iron	12	1959	0
WM00897	Cast Iron	6	1959	0
WM01336	Cast Iron	6	1959	2
WM01791	Cast Iron	6	1960	8
WM01792	Cast Iron	6	1960	4
WM01810	Cast Iron	8	1966	0
WM01811	Cast Iron	8	1966	0
WM01812	Cast Iron	8	1966	0
WM01813	Cast Iron	6	1966	0
WM01814	Cast Iron	6	1966	0
WM01815	Cast Iron	6	1966	0
WM01818	Cast Iron	6	1966	0
WM01819	Cast Iron	6	1966	0
WM01820	Cast Iron	6	1966	0
WM01821	Cast Iron	6	1966	0
WM01822	Cast Iron	6	1966	0
WM01823	DCI	6	1994	0
WM01824	Cast Iron	6	1966	0
WM01825	DCI	6	1994	0
WM01937	Cast Iron	12	1960	0
WM01938	Cast Iron	6	1960	1
WM01941	Cast Iron	6	1960	3
WM02293	Cast Iron	12	1960	0
WM02376	Cast Iron	6	1962	0
WM02377	Cast Iron	6	1962	0
WM02378	Cast Iron	6	1962	0
WM03591	Cast Iron	6	1960	0
WM03794	Cast Iron	12	1960	1
WM03795	Cast Iron	8	1960	0
WM03796	Cast Iron	8	1960	1
WM04035	Cast Iron	12	1958	1
WM04036	Cast Iron	16	1962	0
WM04039	Cast Iron	6	1962	0

Replacement Cost ($): 4,356,366
50-year Risk ($): 6,767,785



Project 4

Project BCR Ratio: 1.28

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM02224	Cast Iron	6	1963	0
WM02225	Cast Iron	6	1963	1
WM02227	Cast Iron	6	1963	0
WM02228	Cast Iron	8	1963	0
WM02229	Cast Iron	8	1963	0
WM02249	Cast Iron	8	1963	0
WM02268	Cast Iron	6	1963	0
WM02269	Cast Iron	6	1963	0
WM02274	Cast Iron	6	1963	0
WM02505	Cast Iron	12	1966	0
WM02506	Cast Iron	8	1962	0
WM02513	Cast Iron	6	1970	0
WM02515	Cast Iron	6	1970	1
WM02520	Cast Iron	6	1970	0
WM02521	Cast Iron	6	1970	0
WM02525	Cast Iron	12	1966	0
WM02526	Cast Iron	12	1966	0
WM02527	Cast Iron	12	1962	0
WM02548	Cast Iron	6	1964	0
WM02549	Cast Iron	6	1964	0
WM02550	Cast Iron	6	1964	0
WM02551	Cast Iron	6	1964	0
WM02552	Cast Iron	12	1964	0
WM02553	Cast Iron	12	1964	0
WM02554	Cast Iron	12	1964	0
WM02555	Cast Iron	12	1964	1
WM02556	Cast Iron	12	1964	0
WM02563	Cast Iron	6	1963	1
WM02564	Cast Iron	6	1963	0
WM03606	Cast Iron	6	1967	0
WM03607	Cast Iron	8	1969	0
WM03608	Cast Iron	8	1967	0
WM03788	Cast Iron	6	1973	2
WM03790	Cast Iron	8	1967	0
WM03791	Cast Iron	8	1967	0
WM03821	Cast Iron	8	1963	0
WM03822	Cast Iron	8	1963	0
WM04032	Cast Iron	8	1969	0
WM04033	Cast Iron	8	1967	0
WM04040	Cast Iron	6	1969	0
WM04041	Cast Iron	6	1969	0
WM04104	DCI	8	1995	0
WM04112	Cast Iron	6	1971	0
WM04113	Cast Iron	6	1971	0
WM04114	Cast Iron	6	1971	0
WM04115	Cast Iron	8	1971	0
WM04117	Cast Iron	6	1971	0
WM04118	DCI	8	1995	0
WM04671	Cast Iron	8	1967	0

Replacement Cost ($): 3,893,408
50-year Risk ($): 4,978,909

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 5

Project BCR Ratio: 1.8

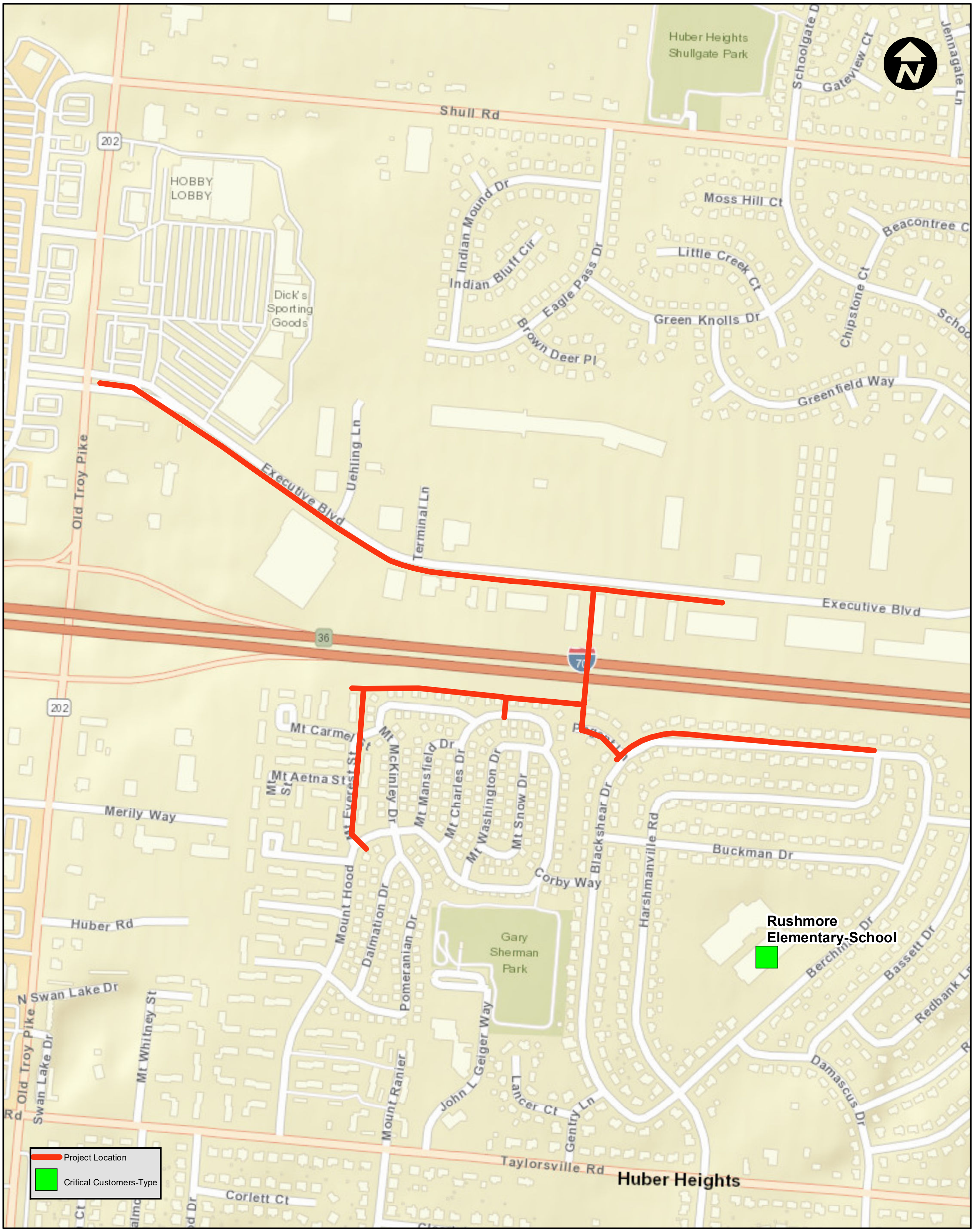
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00379	Cast Iron	12	1967	0
WM01003	Cast Iron	6	1968	0
WM01004	Cast Iron	12	1968	0
WM01005	Cast Iron	12	1968	0
WM01006	Cast Iron	12	1970	0
WM01191	Cast Iron	12	1971	0
WM01192	Cast Iron	6	1971	0
WM01193	Cast Iron	6	1971	0
WM01194	Cast Iron	6	1971	0
WM01195	Cast Iron	6	1971	2
WM01196	Cast Iron	6	1971	0
WM01197	Cast Iron	6	1971	0
WM01410	Cast Iron	12	1971	0
WM01462	Cast Iron	6	1971	1
WM01463	Cast Iron	6	1971	0
WM01781	Cast Iron	6	1970	0
WM01782	Cast Iron	12	1970	0
WM01783	Cast Iron	12	1970	0
WM01788	Cast Iron	6	1970	1
WM04080	Cast Iron	6	1972	3

Replacement Cost ($): 1,687,543

50-year Risk ($): 3,034,461



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 6

Project BCR Ratio: 1.55

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM01979	Cast Iron	8	1961	0
WM02072	Cast Iron	6	1961	0
WM02073	Cast Iron	8	1961	0
WM02074	Cast Iron	8	1961	0
WM02075	Cast Iron	8	1961	0
WM02076	Cast Iron	8	1961	1
WM02077	Cast Iron	8	1961	1
WM02078	Cast Iron	8	1961	0
WM03202	Cast Iron	6	1975	0
WM03270	DCI	8	1979	0
WM03531	Cast Iron	12	1973	0
WM03532	Cast Iron	12	1961	0
WM03533	Cast Iron	12	1967	0
WM03925	Cast Iron	12	1967	0
WM03937	Cast Iron	12	1967	1
WM03938	Cast Iron	12	1967	0
WM03960	Cast Iron	12	1967	0
WM04018	Cast Iron	12	1973	0

Replacement Cost ($): 3,062,477

50-year Risk ($): 4,751,542

Project 7

Project BCR Ratio: 1.47

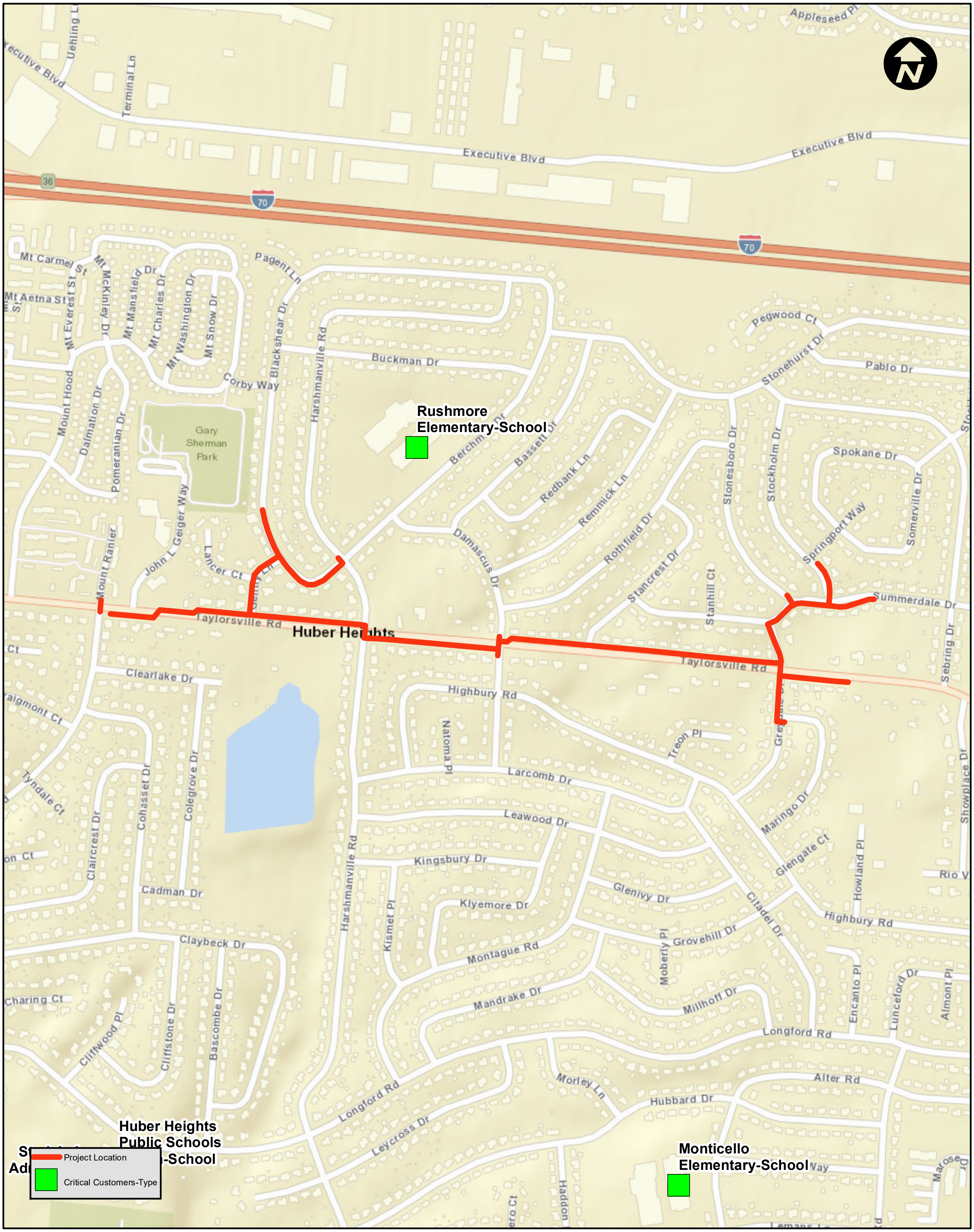
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM04184	DCI	8	1988	0
WM04197	DCI	8	1987	0
WM04198	DCI	8	1987	0

Replacement Cost ($): 666,021

50-year Risk ($): 977,822



Project 8

Project BCR Ratio: 1.56

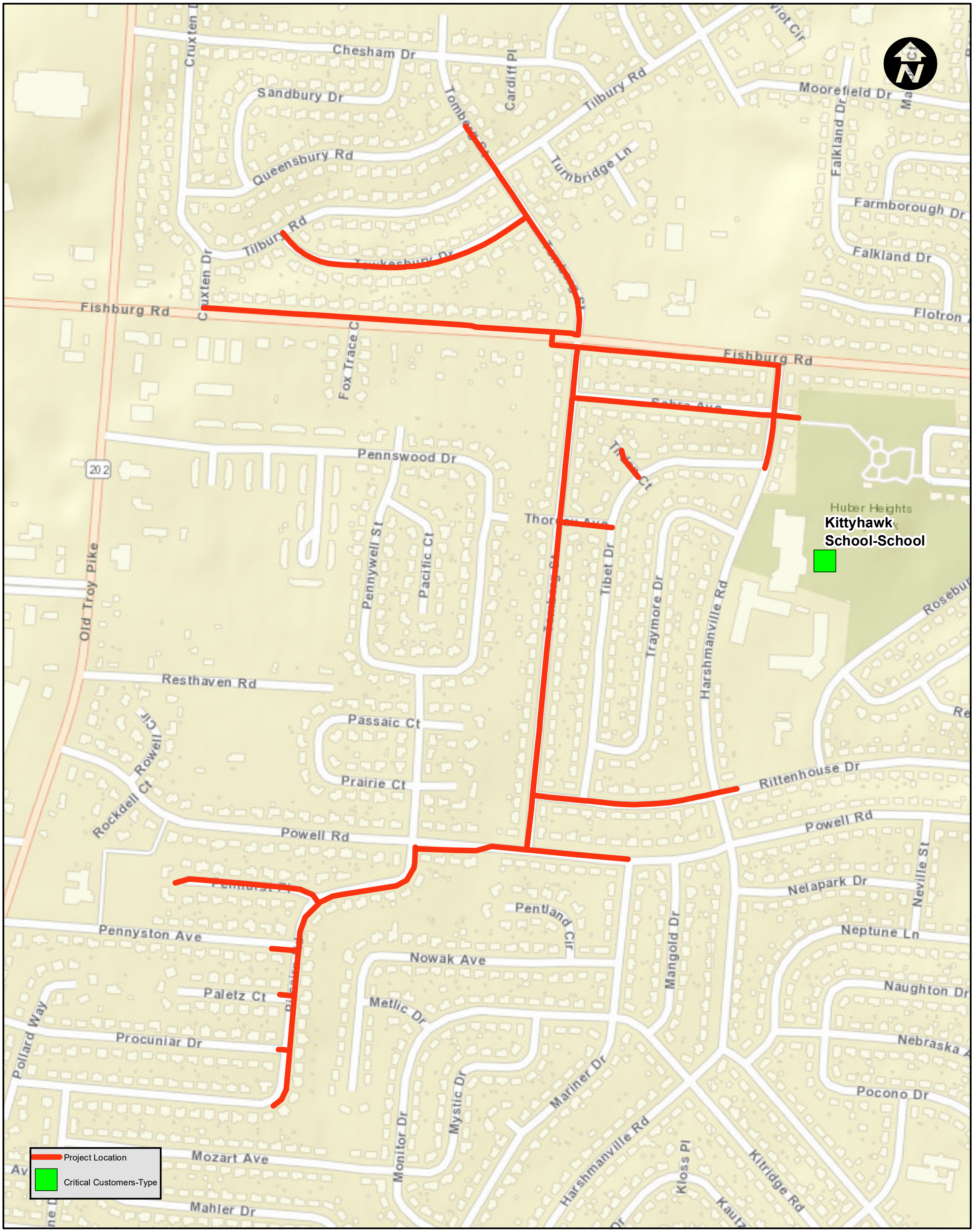
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00399	Cast Iron	8	1960	0
WM01211	Cast Iron	8	1968	0
WM01942	Cast Iron	12	1961	0
WM01943	PCP	16	1961	0
WM01945	Cast Iron	12	1961	1
WM01948	Cast Iron	6	1961	0
WM01960	Cast Iron	6	1961	0
WM01961	Cast Iron	6	1961	0
WM01962	Cast Iron	6	1961	0
WM01963	Cast Iron	6	1961	0
WM01969	Cast Iron	6	1961	0
WM01970	Cast Iron	6	1961	0
WM01972	Cast Iron	6	1961	0
WM01982	Cast Iron	12	1961	0
WM01983	Cast Iron	8	1966	0
WM01984	Cast Iron	8	1964	0
WM01985	Cast Iron	8	1964	0
WM01986	Cast Iron	8	1966	0
WM02006	Cast Iron	8	1966	0
WM02026	Cast Iron	12	1967	0
WM02027	Cast Iron	12	1967	0
WM02028	Cast Iron	8	1967	0
WM02029	Cast Iron	8	1967	0
WM02030	Cast Iron	12	1967	0
WM02031	Cast Iron	12	1967	0
WM02036	Cast Iron	6	1967	0
WM02093	Cast Iron	8	1966	0
WM02099	Cast Iron	12	1967	0
WM02100	Cast Iron	12	1967	0
WM02101	Cast Iron	8	1967	0
WM02102	Cast Iron	12	1967	0
WM02105	Cast Iron	8	1967	0
WM02106	Cast Iron	6	1967	0
WM02107	Cast Iron	8	1967	0
WM02108	Cast Iron	8	1969	0
WM02151	Cast Iron	6	1966	1
WM02152	Cast Iron	8	1966	0
WM02156	Cast Iron	8	1966	0
WM02309	Cast Iron	8	1964	0
WM02374	Cast Iron	6	1964	0
WM02375	Cast Iron	8	1964	0
WM02460	Cast Iron	6	1962	0
WM02464	Cast Iron	12	1962	0
WM02465	Cast Iron	6	1962	0
WM02466	Cast Iron	6	1962	0
WM02467	Cast Iron	6	1962	0
WM04015	Cast Iron	12	1965	0

Replacement Cost ($): 2,562,939

50-year Risk ($): 4,000,547



Project 9

Project BCR Ratio: 1.55

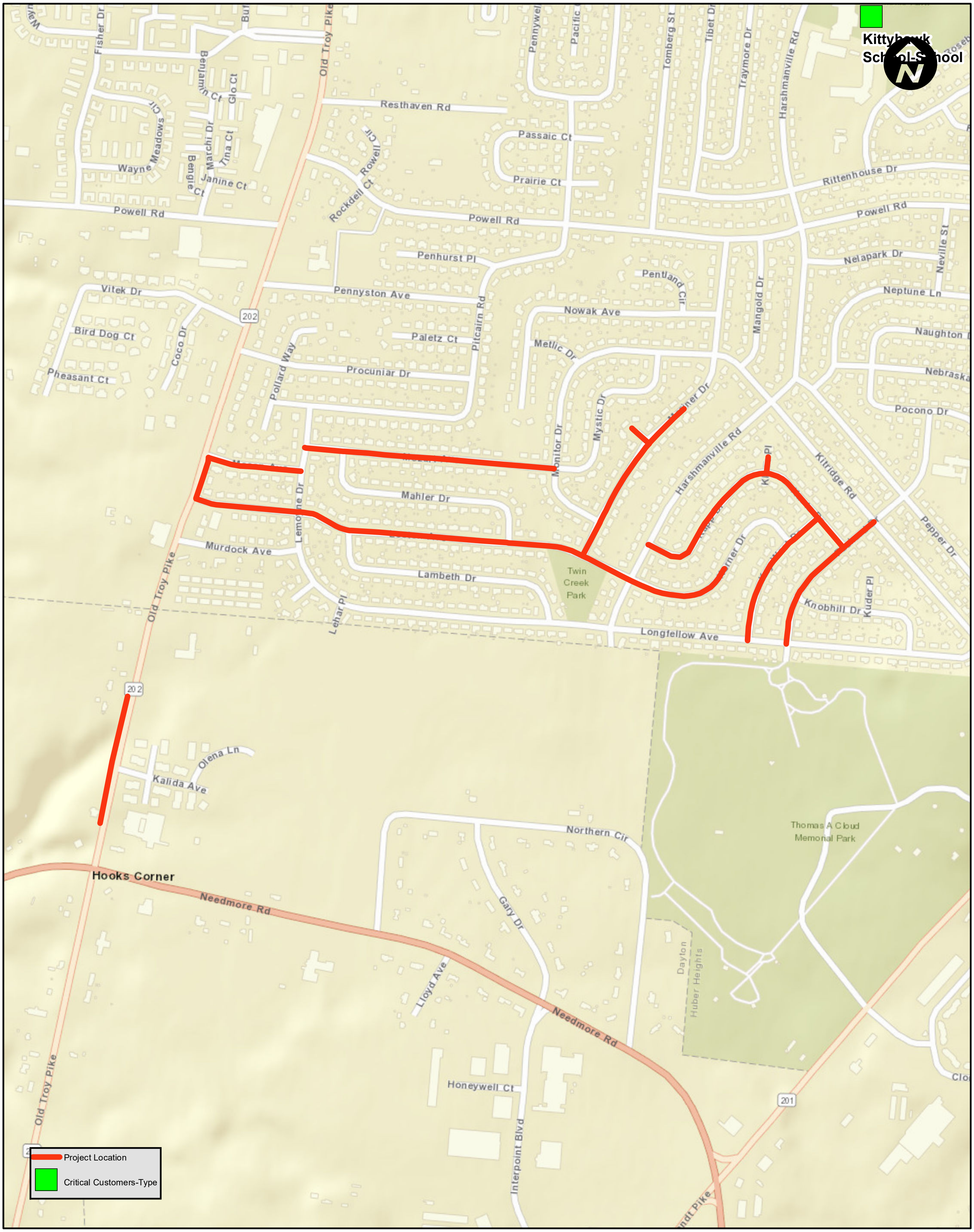
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00027	Cast Iron	6	1962	1
WM00033	Cast Iron	8	1962	0
WM00231	Cast Iron	6	1962	0
WM00232	Cast Iron	6	1962	0
WM00233	Cast Iron	6	1962	0
WM00234	Cast Iron	6	1962	0
WM00235	Cast Iron	6	1962	0
WM00236	Cast Iron	6	1962	0
WM00237	Cast Iron	6	1962	0
WM00346	Cast Iron	6	1956	3
WM00364	Cast Iron	12	1956	0
WM00404	Cast Iron	8	1956	2
WM00406	Cast Iron	6	1956	1
WM00435	Cast Iron	8	1956	0
WM00436	Cast Iron	8	1956	0
WM00584	Cast Iron	6	1962	0
WM00585	Cast Iron	6	1962	0
WM00586	Cast Iron	6	1962	0
WM00588	Cast Iron	6	1962	0
WM00635	Cast Iron	6	1962	1
WM00802	Cast Iron	8	1959	0
WM00803	Cast Iron	6	1959	2
WM00804	Cast Iron	6	1959	0
WM00805	Cast Iron	6	1959	1
WM00811	Cast Iron	8	1959	3
WM00812	Cast Iron	8	1959	0
WM00814	Cast Iron	6	1959	0
WM00815	Cast Iron	6	1959	10
WM01312	Cast Iron	6	1956	13
WM01316	Cast Iron	6	1956	0
WM01317	Cast Iron	6	1956	0

Replacement Cost ($): 4,145,453

50-year Risk ($): 6,413,631



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 10

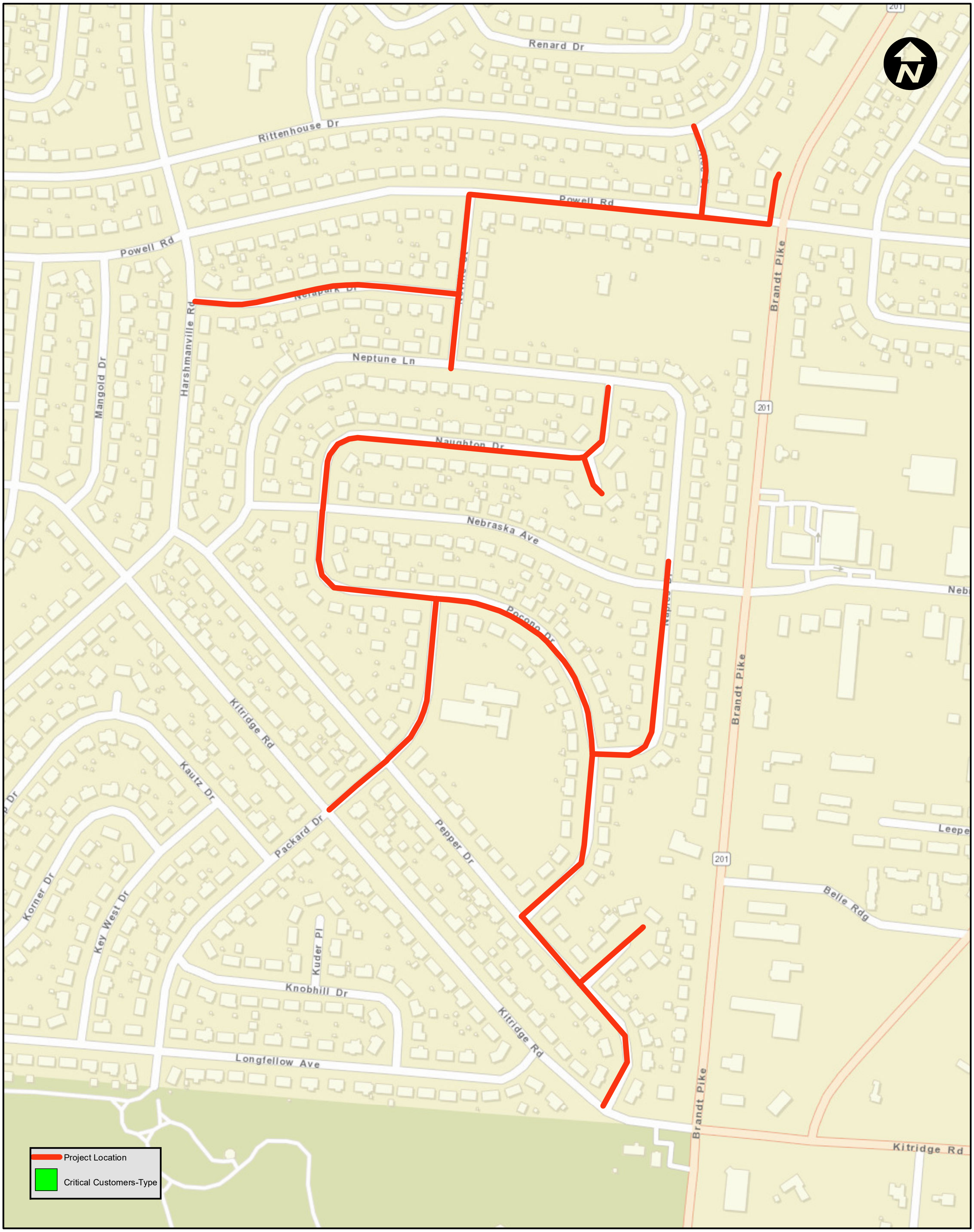
Project BCR Ratio: 1.77

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM04630	Cast Iron	6	1956	2
WM04541	Cast Iron	6	1956	4
WM04515	Cast Iron	6	1956	0
WM04540	Cast Iron	6	1956	2
WM04631	Cast Iron	6	1956	5
WM04516	Cast Iron	6	1956	1
WM00631	Cast Iron	6	1956	0
WM00632	Cast Iron	6	1956	1
WM04519	Cast Iron	6	1956	0
WM00633	Cast Iron	6	1956	2
WM00650	Cast Iron	6	1956	0
WM00651	Cast Iron	6	1956	1
WM00653	Cast Iron	6	1956	3
WM00654	Cast Iron	6	1956	0
WM00655	Cast Iron	6	1956	0
WM00656	Cast Iron	6	1956	0
WM00657	Cast Iron	6	1956	0
WM00658	Cast Iron	6	1956	1
WM04521	Cast Iron	6	1956	1
WM00659	Cast Iron	6	1956	0
WM00662	Cast Iron	6	1956	0
WM00663	Cast Iron	6	1956	0
WM04629	Cast Iron	12	1956	0
WM04602	Cast Iron	6	1956	1
WM04528	Cast Iron	6	1956	1
WM04599	Cast Iron	12	1956	1
WM01318	Cast Iron	6	1956	1
WM01320	Cast Iron	6	1956	1
WM01321	Cast Iron	6	1956	3
WM03913	Cast Iron	6	1965	0
WM04617	Cast Iron	6	1956	3
WM04627	Cast Iron	6	1956	2

Replacement Cost ($): 3,656,446
50-year Risk ($): 6,468,668



Project 11

Project BCR Ratio: 1.26

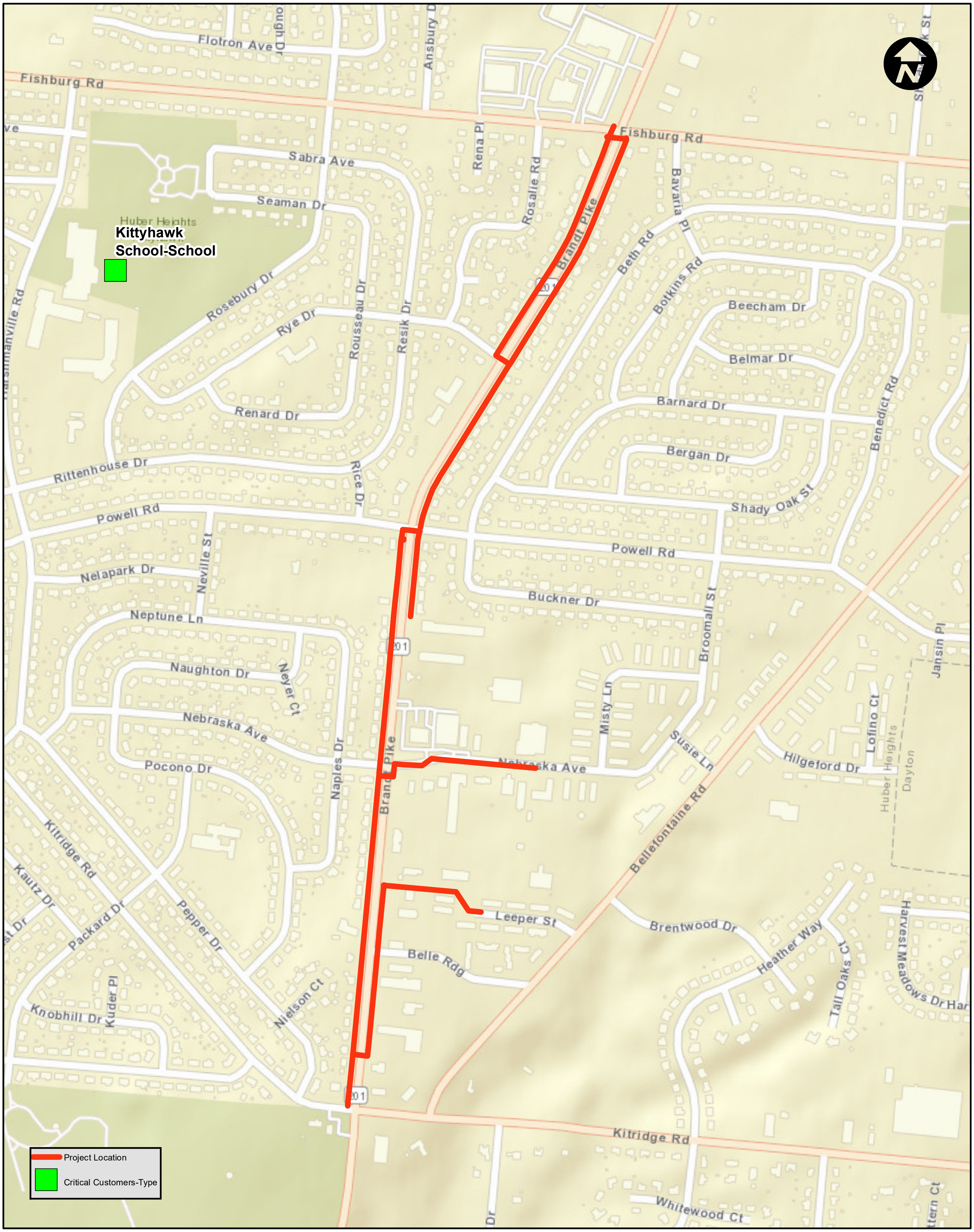
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM04590	Cast Iron	6	1956	0
WM04586	Cast Iron	6	1956	3
WM00001	Cast Iron	6	1956	0
WM00002	Cast Iron	6	1956	0
WM00003	Cast Iron	6	1956	0
WM00004	Cast Iron	6	1956	0
WM04580	Cast Iron	6	1956	0
WM04585	Cast Iron	6	1956	0
WM04546	Cast Iron	6	1956	0
WM04509	Cast Iron	6	1956	0
WM04545	Cast Iron	6	1956	2
WM00024	Cast Iron	6	1956	0
WM04544	Cast Iron	6	1956	1
WM04591	Cast Iron	6	1956	1
WM04547	Cast Iron	6	1956	2
WM00062	Cast Iron	6	1956	0
WM00065	Cast Iron	8	1956	1
WM00066	Cast Iron	4	1956	0
WM04636	Cast Iron	6	1956	0
WM00067	Cast Iron	6	1956	0
WM04543	Cast Iron	6	1956	2
WM00068	Cast Iron	6	1956	0
WM04581	Cast Iron	6	1956	0
WM04512	Cast Iron	6	1956	0
WM04513	Cast Iron	6	1956	0
WM04625	Cast Iron	6	1956	0
WM04619	Cast Iron	6	1956	0
WM01300	Cast Iron	6	1957	0
WM04618	Cast Iron	6	1956	1

Replacement Cost ($): 2,560,959

50-year Risk ($): 3,225,090



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 12

Project BCR Ratio: 1.68

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM04592	Cast Iron	12	1956	1
WM00012	Cast Iron	8	1957	0
WM00013	Cast Iron	4	1957	1
WM00014	Cast Iron	8	1957	1
WM04510	Cast Iron	10	1956	0
WM04593	Cast Iron	10	1956	0
WM00025	Cast Iron	10	1956	0
WM00026	Cast Iron	12	1956	0
WM00072	Cast Iron	12	1957	1
WM00073	Cast Iron	12	1957	0
WM00074	Cast Iron	12	1957	0
WM00075	Cast Iron	12	1957	0
WM00076	Cast Iron	12	1957	0
WM00083	Cast Iron	6	1957	0
WM00085	Cast Iron	6	1957	0
WM00195	Cast Iron	8	1957	0
WM00196	Cast Iron	8	1957	0
WM00197	Cast Iron	8	1957	0
WM00207	Cast Iron	6	1958	1
WM00700	Cast Iron	6	1958	0
WM00701	Cast Iron	12	1958	0
WM00702	Cast Iron	6	1958	0
WM00705	Cast Iron	6	1958	0
WM00720	Cast Iron	6	1958	0
WM01092	Cast Iron	6	1968	0
WM01093	DCI	6	1968	0
WM01094	DCI	6	1968	0
WM01095	Cast Iron	6	1968	0
WM01096	DCI	6	1968	0
WM04587	Cast Iron	6	1960	2
WM04170	Cast Iron	6	1956	0
WM04171	Cast Iron	6	1960	0

Replacement Cost ($): 3,134,839

50-year Risk ($): 5,261,933

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 13

Project BCR Ratio: 1.58

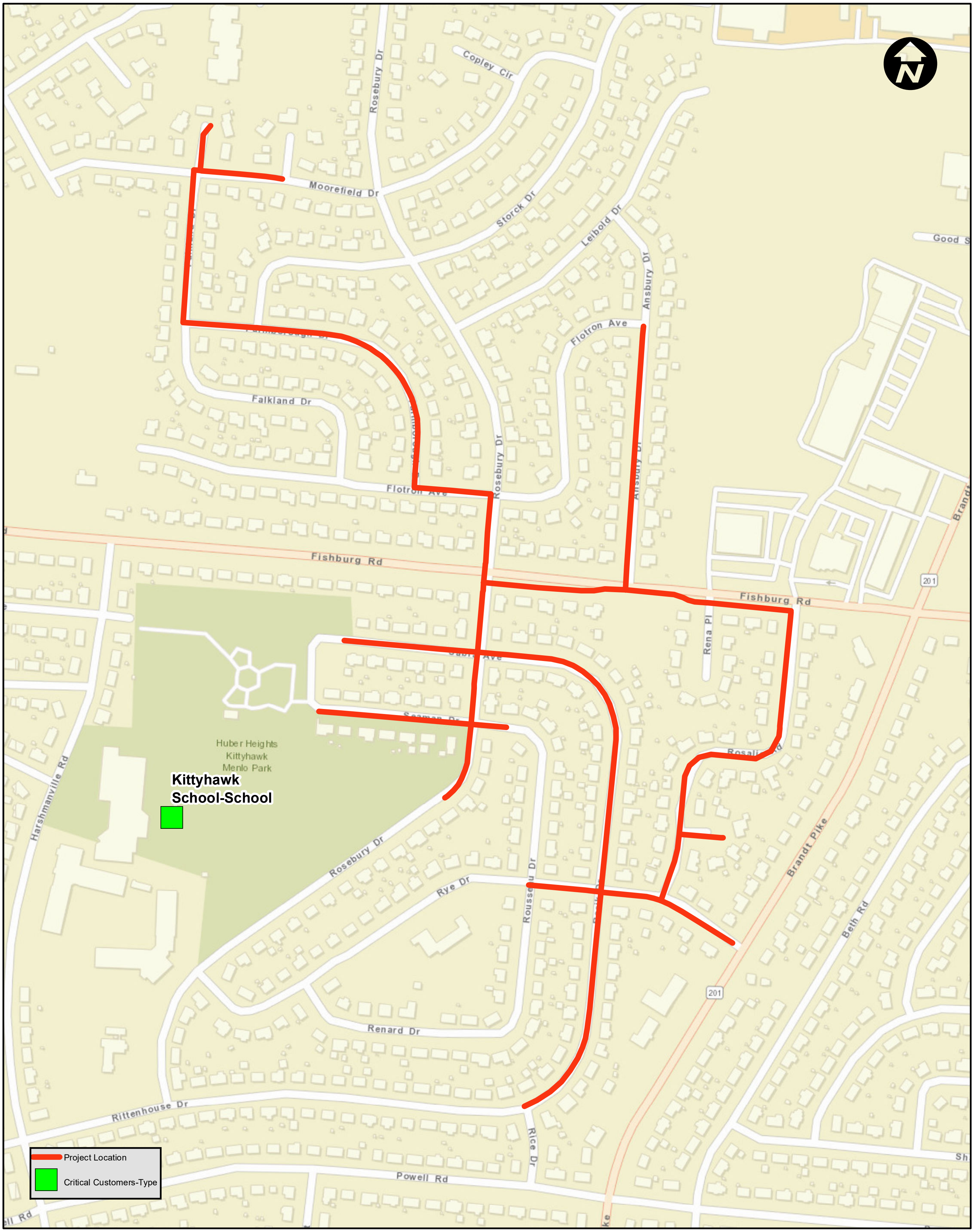
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM04655	Cast Iron	6	1962	0
WM00035	Cast Iron	6	1962	1
WM00044	Cast Iron	6	1960	1
WM00045	Cast Iron	6	1960	0
WM00046	Cast Iron	6	1960	0
WM04605	Cast Iron	6	1960	0
WM00047	Cast Iron	6	1960	0
WM00048	Cast Iron	6	1962	1
WM00052	Cast Iron	6	1962	0
WM00053	Cast Iron	6	1962	0
WM00058	Cast Iron	6	1963	0
WM00212	Cast Iron	6	1963	0
WM00217	Cast Iron	6	1963	1
WM00223	Cast Iron	6	1962	0
WM00224	Cast Iron	6	1962	0
WM00295	PCP	16	1956	0
WM04613	Cast Iron	6	1956	2
WM00400	Cast Iron	6	1956	1
WM04517	Cast Iron	6	1956	1
WM00576	Cast Iron	6	1962	0
WM00577	Cast Iron	6	1962	0
WM00578	Cast Iron	6	1962	0
WM00579	Cast Iron	6	1962	2
WM00581	Cast Iron	6	1962	0
WM00615	DCI	8	1969	0
WM00670	Cast Iron	8	1969	0
WM00672	Cast Iron	8	1969	0
WM04527	Cast Iron	6	1956	1
WM04528	Cast Iron	6	1956	1
WM01348	Cast Iron	6	1957	1
WM01349	Cast Iron	6	1969	0
WM01350	Cast Iron	6	1969	0
WM01351	Cast Iron	6	1969	0
WM04239	DCI	6	1985	0
WM04538	Cast Iron	6	1960	0
WM04661	Cast Iron	6	1957	0

Replacement Cost ($): 2,328,213

50-year Risk ($) 3,685,408



Project 14

Project BCR Ratio: 1.02

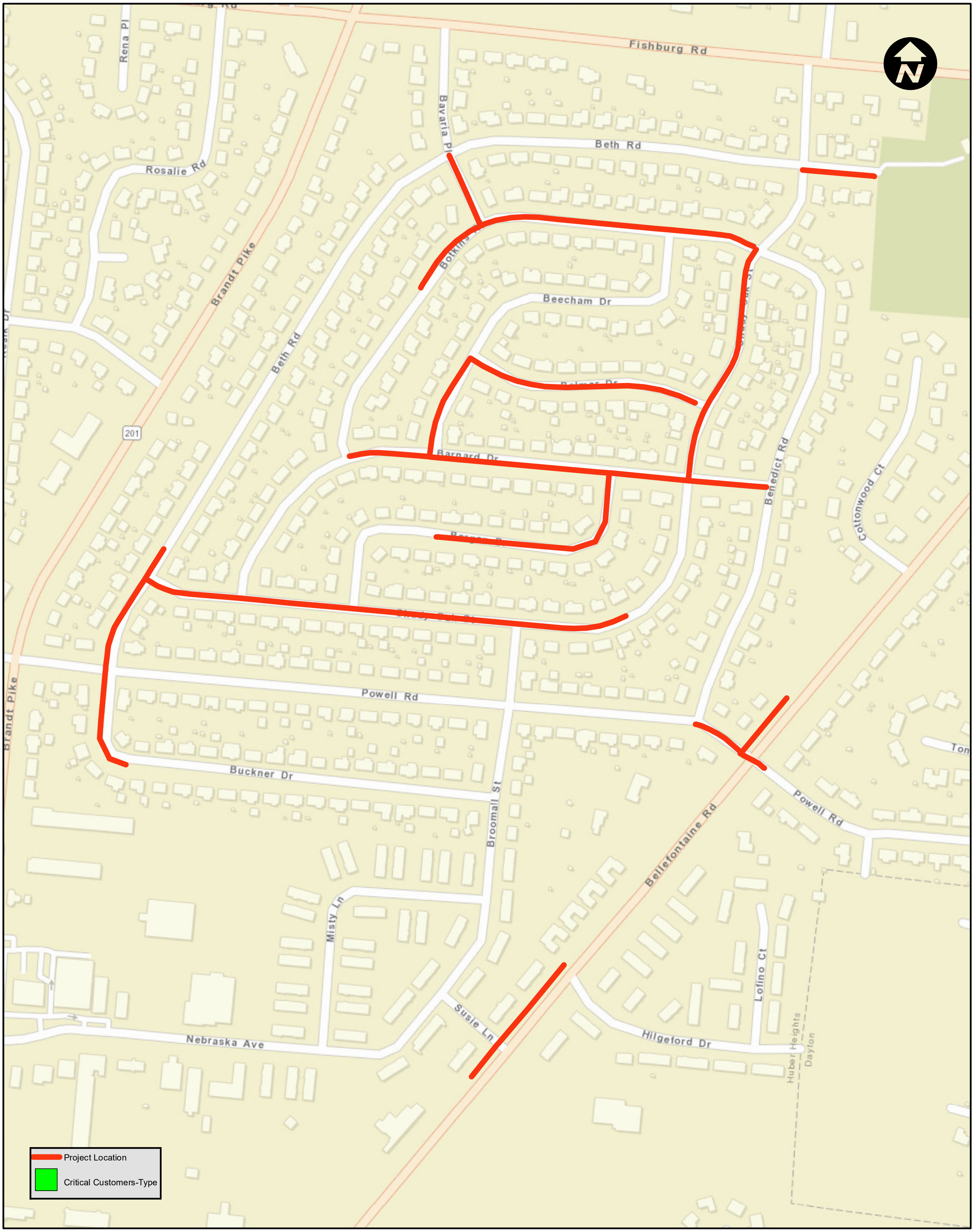
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00008	Cast Iron	6	1957	0
WM00009	Cast Iron	6	1957	0
WM00010	Cast Iron	6	1957	1
WM00011	Cast Iron	6	1957	1
WM00021	Cast Iron	12	1957	0
WM00070	Cast Iron	12	1957	0
WM00077	Cast Iron	6	1957	0
WM00078	Cast Iron	6	1957	0
WM00079	Cast Iron	6	1957	0
WM00081	Cast Iron	6	1957	2
WM00082	Cast Iron	6	1957	0
WM00263	Cast Iron	12	1959	0
WM00280	Cast Iron	12	1957	0
WM00283	Cast Iron	6	1957	0
WM00284	Cast Iron	6	1957	0
WM00286	Cast Iron	6	1957	1
WM00287	Cast Iron	6	1957	0
WM00288	Cast Iron	6	1957	1
WM00290	Cast Iron	6	1957	0
WM00345	Cast Iron	6	1957	0
WM00354	Cast Iron	6	1957	0
WM00441	Cast Iron	6	1957	2
WM00442	Cast Iron	6	1957	1
WM00443	Cast Iron	6	1957	3
WM00590	Cast Iron	6	1959	2
WM00591	Cast Iron	6	1959	1
WM00599	Cast Iron	6	1959	0
WM00718	Cast Iron	6	1957	0
WM00738	Cast Iron	6	1959	0
WM00739	Cast Iron	6	1959	6
WM00841	Cast Iron	6	1959	1
WM00842	Cast Iron	12	1957	0
WM00901	Cast Iron	6	1959	0
WM00902	Cast Iron	6	1959	0
WM00903	Cast Iron	6	1959	1
WM00904	Cast Iron	6	1959	5
WM00907	Cast Iron	6	1959	0
WM00913	Cast Iron	6	1959	0
WM00914	Cast Iron	6	1959	0
WM00915	Cast Iron	6	1959	1
WM01302	Cast Iron	6	1957	0
WM01303	Cast Iron	6	1957	0
WM01304	Cast Iron	6	1957	0
WM01305	Cast Iron	6	1957	1
WM01306	Cast Iron	6	1957	0
WM01307	Cast Iron	6	1957	0
WM01308	Cast Iron	6	1957	0
WM01309	Cast Iron	6	1957	0
WM01310	Cast Iron	6	1957	1
WM01311	Cast Iron	12	1957	0

Replacement Cost ($): 3,307,769

50-year Risk ($): 3,386,632



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Project 15

Project BCR Ratio: 1

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00016	Cast Iron	6	1957	2
WM00017	Cast Iron	6	1957	0
WM00020	Cast Iron	6	1957	2
WM00041	Cast Iron	6	1957	1
WM04569	Cast Iron	8	1960	0
WM00676	Cast Iron	6	1957	1
WM00681	Cast Iron	6	1958	1
WM00682	Cast Iron	6	1958	1
WM00683	Cast Iron	6	1958	0
WM00684	Cast Iron	6	1958	0
WM00687	Cast Iron	6	1958	0
WM00689	Cast Iron	6	1958	0
WM00691	Cast Iron	6	1958	1
WM00692	Cast Iron	6	1958	2
WM00693	Cast Iron	6	1958	1
WM00696	Cast Iron	6	1958	4
WM00697	Cast Iron	6	1958	0
WM00698	Cast Iron	6	1958	0
WM00699	Cast Iron	6	1958	0
WM00706	Cast Iron	6	1958	0
WM00707	Cast Iron	6	1958	2
WM00708	Cast Iron	6	1958	0
WM00712	Cast Iron	6	1957	1
WM00714	Cast Iron	6	1957	0
WM00752	Cast Iron	6	1958	0
WM00753	Cast Iron	6	1958	1
WM00756	Cast Iron	6	1958	2
WM00767	Cast Iron	8	1958	0
WM00768	Cast Iron	8	1958	0
WM04562	Cast Iron	8	1958	0
WM04570	Cast Iron	8	1958	0
WM04571	Cast Iron	8	1958	0
WM00778	Cast Iron	6	1958	1
WM00779	Cast Iron	6	1958	0
WM00780	Cast Iron	6	1958	1
WM00781	Cast Iron	6	1958	0
WM01106	Cast Iron	8	1962	0
WM01157	Cast Iron	8	1962	0
WM04555	Cast Iron	8	1962	1

Replacement Cost ($): 2,490,276

50-year Risk ($): 2,485,560

Project 16

Project BCR Ratio: 0.11

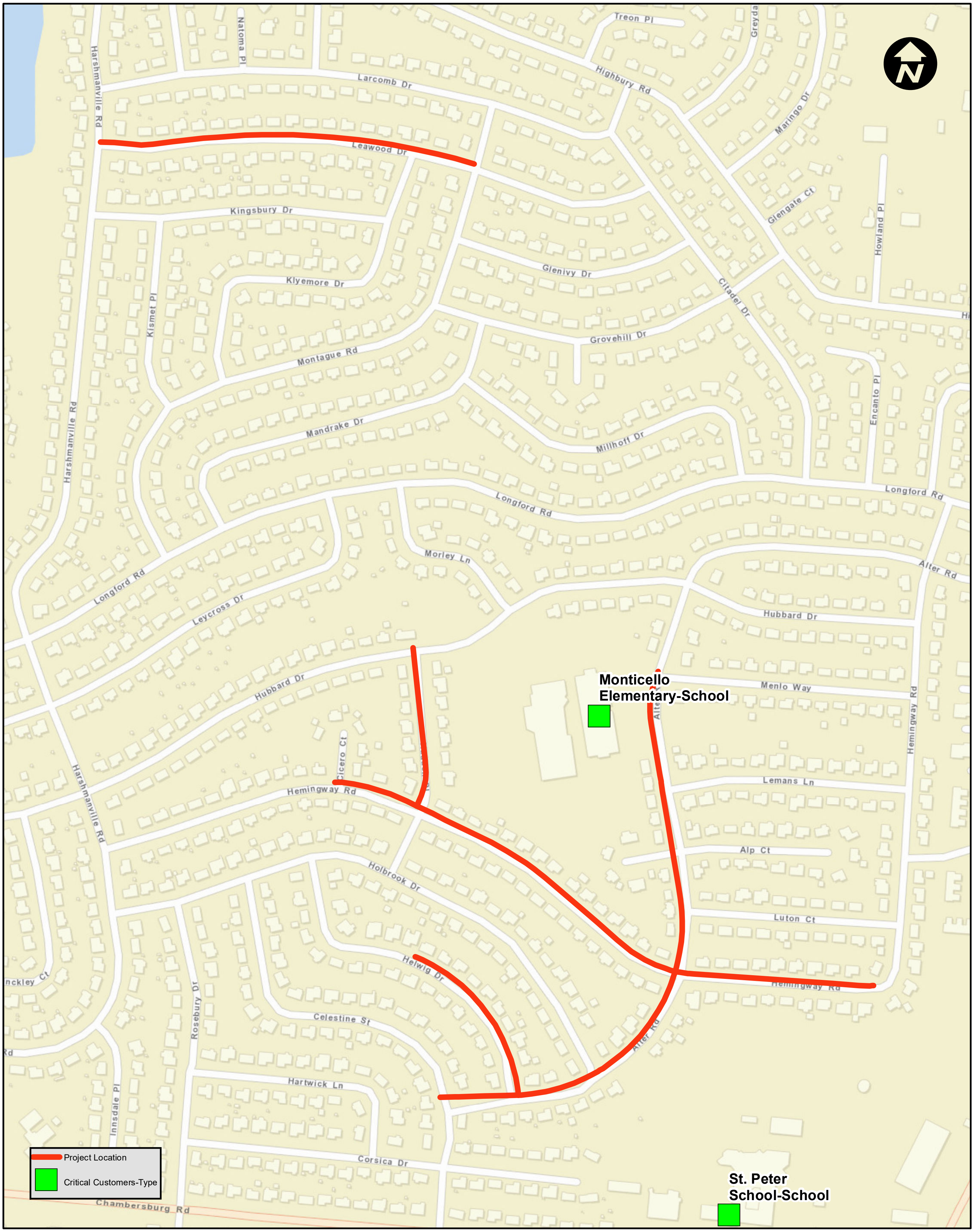
BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM03276	DCI	8	1980	0
WM03297	DCI	8	1980	5
WM03298	DCI	8	1980	7
WM03300	DCI	8	1980	0
WM03301	DCI	8	1980	1
WM03302	DCI	8	1980	1

Replacement Cost ($): 351,300

50-year Risk ($: 40,123



Project 17

Project BCR Ratio: 0.78

BURGESS & NIPLE

BCR & 50-Year Risk Scores

Pipe ID	Material	Diameter (Inches)	Installation Year	Number of Breaks in Past
WM00305	Cast Iron	6	1962	3
WM00392	Cast Iron	6	1963	1
WM01794	Cast Iron	6	1960	3
WM01797	Cast Iron	6	1960	4
WM01798	Cast Iron	6	1962	3
WM01799	Cast Iron	6	1962	0
WM02321	Cast Iron	6	1960	0
WM02322	Cast Iron	6	1960	0
WM02323	Cast Iron	6	1960	2
WM02324	Cast Iron	6	1962	3
WM02330	Cast Iron	6	1963	2
WM02337	Cast Iron	6	1963	1
WM02338	Cast Iron	6	1963	0
WM02380	Cast Iron	6	1962	4
WM02381	Cast Iron	6	1962	0
WM02383	Cast Iron	6	1962	0
WM02385	Cast Iron	6	1962	0
WM02386	Cast Iron	6	1962	0
WM02387	Cast Iron	6	1962	0
WM02392	Cast Iron	6	1962	2
WM02397	Cast Iron	6	1960	2

Replacement Cost ($): 2,068,981

50-year Risk ($): 1,618,200

HUBER HEIGHTS
Come Grow With Us!

BURGESS & NIPLE
Architects ■ Engineers ■ Planners