# Medford, MA
# Asset Management Plan
# Summary

September 2020

# Medford Asset Management Plan Summary

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## Acronyms and Abbreviations

AMP: Asset Management Plan
AWWA: American Water Works Association
CIP: Capital Improvement Plan
CoF: Consequence of Failure
DPW: Department of Public Works
EPA: Environmental Protection Agency
FF: Fire Flow
GIS: Geographic Information System
gpm: gallons per minute
LoS: Levels of Service or Level of Service
LoF: Likelihood of Failure
MS4: Municipal Separated Storm Sewer System
NOI: Notice of Intent for Stormwater Discharges
SR: Structural Rating
WO: Work Order

# 1 Introduction

The City of Medford currently manages capital improvements and operation and maintenance of drinking water, sewer, and stormwater infrastructure using different applications, personnel, and budgets. This decentralization of resources is becoming burdensome for the City, and it is motivating the City to look for a more efficient and cost-effective solution that can also support an integrated approach to infrastructure asset management.

In 2019, the City of Medford's Department of Public Works was awarded an Asset Management Grant issued by the Massachusetts Clean Water Trust (the Trust). The awarded grant funds allowed the City to initiate the beginning of an Asset Management (AM) Program within the Engineering Department which manages the water, wastewater and stormwater assets. The City's ultimate vision for their AM Program is to have a centralized system that can be used by other departments as well to more holistically manage their City assets such as pavement, park assets, trees, street lighting, vehicles (fleet), and signage.

This document provides a brief overview of work completed and of the major findings and outcomes of the work outlined above as well as proposed next steps for the City to take in continuing with their AM Program. An Asset Management Plan (AMP) was developed for each of the three water systems that are included in the Appendices of this Executive Summary as noted: Appendix A – Water System AMP, Appendix B – Sewer System AMP and Appendix C – Stormwater System AMP. Each system AMP contains more detailed descriptions of the approach and methodology used in the risk analysis, detailed findings and recommendations for moving forward. Each of these documents can be read independently; however, they all share a common risk framework, which will be used in the future to compare needs arising from different assets and then to prioritize future investments appropriately.

# 2 Asset Management Planning Overview

## 2.1 Assessing Asset Inventory

The City of Medford owns and maintains their three water systems which consist of the following assets at a macro-level as demonstrated in Table 1.

*Table ES1: Medford Asset Management Summary*

| System | Pipeline (mi.) | Nodes | System Replacement Value |
|---|---|---|---|
| **Sewer** | 120 | 3,400 manholes | $209 million[1.] |
| **Water** | 135 | One pumping station<br>1,400 hydrants<br>Approx.. 10,000 water gate valves | $419 million[2.] |
| **Stormwater** | 120 | 3,300 manholes connected to over 260 outfalls | Undetermined[3.] |

Notes:

1. Value estimated does not include manholes or pumping stations, only sewer mains.
2. Value estimated does not include hydrants or pumping stations, only water main and included valves.
3. There is not enough asset data to determine full stormwater system value at this time.

The City has a well-developed GIS inventory that was improved upon through this effort. Kleinfelder helped the City to identify data that are critical to managing its assets well and began the process of updating each system's asset inventory. The City's sewer and water system inventories are populated enough to allow for an Initial Risk Assessment to be conducted; the stormwater system inventory is missing critical elements of data that made that more difficult. There was minimal value in performing an initial Risk Assessment on the City's stormwater system given the deficits in the data and therefore, was not completed for this study.

This inventory update process will necessarily take time and will be on-going for the next few years as the City begins to track their system real-time with the help of an Asset Management Software.

## 2.2 Prioritizing Based on Risk

In the context of the AMP, risk is a numerical value that is used across all managed assets to prioritize their needs. Having a common risk framework across the entire asset portfolio allows for comparison between different asset types. Risk is defined as the likelihood of failure (LoF) of an asset times the severity and extent of the negative consequences of that failure (CoF), or Risk = CoF x LoF. Figure ES1 illustrates how the resulting risk value of an asset translates into the management and mitigation of that asset's risk. The risk framework used for the City is included in more detail in Appendix D.

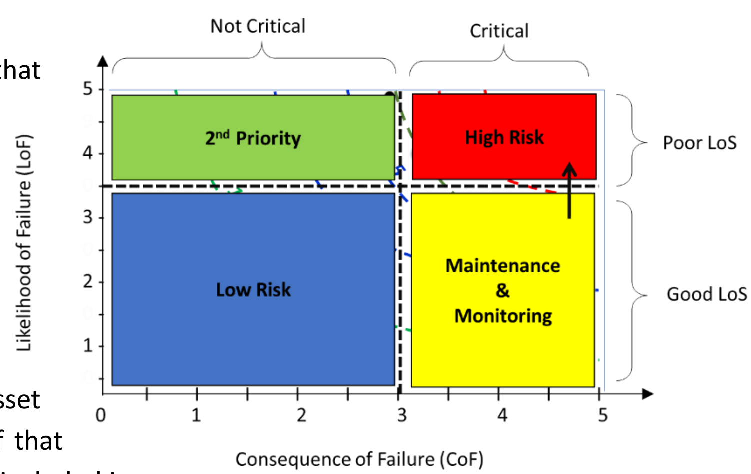


*Figure ES1: Prioritization Matrix for Risk*

For Medford's planning purpose, there is sufficient water and wastewater system inventory data to be able to prioritize their horizontal assets (i.e., pipelines) based upon risk. Based upon available inventory data, roughly 7% (9 miles) of the City's water distribution pipes were designated as being at high risk according to the Risk Framework depicted in Figure ES1. A similar analysis conducted on the sewer collection system yielded approximately 1% (1.5 miles) that falls within the high-risk category. Conversely, approximately 83% (100 miles) of sewer and 50% (69 miles) of water pipe have a CoF value of 2 or less, indicating that the City can really focus its resources in the near term on a smaller portion of the overall systems.

## 2.3 Identifying System Recommendations

Identifying recommendations for system renewal required use of a decision model, or sets of rules that were assigned to each segment of pipe to determine rehabilitation strategies. For the gravity systems (i.e., sewer and stormwater), a pipe segment is defined as manhole to manhole where as for the pressurized system (i.e., water), a pipe segment is defined between two intersections. Depending upon the LoF value of a given segment, the strategies for renewal were assigned according to the following hierarchy:

*Do Nothing (1) → Flag for Assessment (2) → Assess (3) → Spot Rehabilitation (4) → Line or Replace (5)*

While this is a reasonable strategy for determining renewal and replacement, it heavily depends upon the LoF value assigned to each asset. Typically, LoF is determined using a combination of the capacity of the asset and its field condition. For Medford, the field condition and capacity data is lacking or outdated; therefore, estimated service life (ESL) of the pipe assets is used as a surrogate. Again, while this is in line with industry standards for this type of assessment, the risk and renewal analysis for Medford will be dramatically strengthened by a focus on collecting and updating this important field data on their systems in the next few years.

## 2.4 Selecting Asset Management Software

In order to help Medford better track and collect data on their water systems, Kleinfelder assisted the City in selecting and purchasing an Enterprise Asset Management System. The City, through a series of workshops and vendor demonstrations, evaluated three separate software vendors. All of the vendors considered provided the essentials to meet the City's goals and objectives, but each added their own nuances and flavor to the way their system's managed and summarized the data. City Engineering staff as well as staff from other Departments that might use this system in the future weighed in on the process. In the end, the City has selected Cartegraph Systems Asset Management Software to move forward and purchase. A summary memo detailing the software selection process is included in Appendix E .

# 3 Recommended 10-Year Renewal Plan

Combining the risk analysis with the system renewal decision model, Kleinfelder was able to derive a recommended renewal and assessment plan for each of the three systems. As noted, the quality of the input data to the decision model is very important to obtain significant results; therefore, these are preliminary recommendations that the City can use to begin discussions around planning and funding.

Simultaneously, we recommend the City continue to further their data collection and inventory updates to improve future asset management and funding decision-making. Table ES1 summarizes level of investment recommended for the 10-Year Renewal Plan for the City derived based upon the rationale provided below.

## 3.1 Water system

- **Sustainable Renewable Investment:** The replacement cost of the entire network (135 miles of water mains) is estimated at $419 million (M). Considering the average ESL of the system at 123 years, the sustainable renewable investment for asset replacement would be roughly **$3.4 M per year**. Sustainable renewable investment value is equal to replacement cost divided by average estimated service life (years).
- **10-Year Renewal Plan:** The total preliminary investment identified by the decision model based upon the assessed system risk is estimated at $185.5 M, over the entire water portfolio. Recognizing that this level of investment is much too high for the City to take on even in a 10-year renewal plan, estimates were made based upon the 'best and highest' use of resources for the next 10-years. The recommended Renewal Plan is as follows:
  - Year 1 & 2: The cost of addressing the assets in the high-risk quadrant is **$1.54 M**, which should be addressed in years 1 and 2.
  - Years 3 – 10: Six (6)-inch water mains make up 42% of the City's water system; 21% of those 6-inch mains are assessed to be at a LoF of 5. Further, 50% of those high risk 6-inch mains are connected to a hydrant. Replacement and upsizing of that portion of 6-inch mains to 8-inch is a recommended priority for Years 3 – 10. This replacement is estimated at $17 M, which can be distributed over an 8-year period resulting in **$2.1 M per year**.

## 3.2 Sewer system

- **Sustainable Renewable Investment:** The complete replacement of 119 miles of sewer pipe is estimated at $209 M. Considering that the average ESL of the sewer system is 140 years, the sustainable renewable investment for asset replacement would be roughly $**1.5 M per year**. We consider this an "upper bound" of the average investment.
- **10-Year Renewal Plan:** The total preliminary costs identified by the model based upon assessed system risk is estimated at $9.1 M. However, this estimate relies heavily on age and ESL versus actual pipe condition.
  - Assessment Cost: The cost for assessing the entire system is approximately $942,000. It is common practice to have an inspection program on a 10-year schedule. However, given that there is current condition information for only 8% of the system, we recommend implementing a more aggressive inspection program that would complete a current condition assessment within a 5-year period (i.e., inspecting at 24 miles/year). We estimate this level of assessment at $190,000 per year. After that 5-year period, the City could proceed with a 10-year recurring assessment program.
  - Years 1 – 5: From the subset of pipes already inspected, we determined that about 40% of those require some sort of renewal strategy having a LoF greater than or equal to 4.

Therefore, assuming in Years 1 – 5 that the City is inspecting their sewer pipe at a rate of 24 miles per year, we would recommend $920,000 per year is needed for renewal of approximately 50% (adding contingency for planning) of the inspected pipes. Adding in the $190,000 per year for inspection, we arrive at a recommended level of investment of **$1.1 M per year.**

- Years 6 – 10: Using a similar methodology, for years 6 – 10, we recommend that the City could reduce its inspection rate to 12 miles/year and plan to invest $95K per year for the inspection plus $460K per year to address issues found during those inspections for a total of **$555,000 per year**.

## 3.3 Stormwater system

Though we were not able to develop a full risk-based renewal plan for the Stormwater System, we have been able to identify many "next steps" for the City to further advance their stormwater inventory and data to a point that a full analysis can be conducted. In talking with the City, however, we learned that many of their corrugated metal stormwater pipe is failing and is in need of replacement. The current City inventory shows approximately 8,400 linear feet of corrugated metal pipe. An investment of approximately $2.4 M is estimated to replace all the corrugated metal pipe, which would equate to $236,000 per year if spread out over the 10-year period. We recommend allotting this amount as a 'placeholder' for this initial 10-Year Renewal Plan and that the City invest future resources towards improving upon the Stormwater Risk Model in the near-term to confirm this level of investment.

# 4 Next Steps for the Asset Management Program

For immediate next steps of the City's Asset Management Program, completing implementation of the Asset Management Software system is imperative. Priority activities that will be involved with that include:

*Table ES2: Investment Recommended for 10-Year Renewal Plan (Costs shown in $M/Year)*

| Description | Sustainable Renewal Investment | 10- Year Renewal Plan | | | Avg. Annual over 10 years |
|---|---|---|---|---|---|
| | | Year 1 - 2 | Year 3 – 5 | Year 6 – 10 | |
| Sewer System(1) | $1.5 | $1.1 | $1.1 | $0.55 | $0.83 |
| Water System | $3.4 | $0.75 | $2.1 | $2.1 | $1.8 |
| Stormwater | N/A | $0.24 | $0.24 | $0.24 | $0.24 |
| (1) Included renewal and assessment costs. | | | | | |

1. Finalizing the list of activities from the Water and Sewer Division to be implemented in the asset management software, with corresponding fields, default values, drop-down menus, recurrence settings etc. This can be done by reviewing the preliminary work order dictionary provided by Kleinfelder to the City as a starting point for this task (included in Appendix F).
2. Configure the software for these activities.

3. Identify key personnel involved in the resolution of these activities, both from the dispatcher end (task assigner), and the resolution end (task assignee).
4. Start using the software for conducting the work.
5. Develop Level of Service metrics and benchmarks.

This process might require a couple of rounds of configuration until the workflows are fully adopted by the City staff and 100% supported by the software. From there, to take the implementation further we recommend:

6. Configuring operation management dashboards for each division head.
7. Configuring reports.
8. Configuring dashboards for level of service tracking.
9. Integrating software with other systems such as See Click Fix.
10. Expanding the software with other modules, if necessary, such as fleet, or storeroom inventory.

We highly recommend that the stormwater plan be revisited after workflows are setup using the software. Applying for a second round of Clean Water Trust Asset Management Plan Grant funding is a great vehicle to continue planning using the framework and assess next steps after the implementation begins. Other avenues such as Coastal Zone Management Resiliency Funding and MVP Assistance may also provide avenues to fund investigation and feature class updates to the stormwater data. Table ES3 summarizes key next step tasks that will help the City to further asset management of each of these systems.

*Table ES3: Recommended Next Steps for Continuing Asset Management for Medford*

| Water System | Sewer System | Stormwater System |
|---|---|---|
| Complete GIS inventory | Complete GIS inventory | Complete inventory in GIS focusing on connectivity, age and condition information |
| Identify 6" mains connected to hydrants | Continue Inspection program at the proposed rate of 24 miles / year | Develop a plan for asset inspections based upon risk |
| Start work order (WO) process to track Structural Rating (SR) and to help with monitoring breakages and other issues | Start work order process to track overflows and other issues | Monitor O&M/MS4 Metrics |
| Incorporate hydraulic capacity into LoF & condition info as available | | |
| Continue Leak Detection program | | |
| Improve Risk model by adding failure modes: Capacity (FF); Corrosion (Assessment Program), and actual water usage | | |
| **All Systems:**<br>Pursue a 2nd Year of AMP Grant Funding to pursue additional program opportunities<br>Consider investing in financial planning to determine how best to fund the Recommended 10-Year Renewal Plan and develop Levels of Service to determine benchmarking and metrics for tracking progress. | | |

# APPENDIX A:

# Water System AMP

# Medford, MA
# Water System Asset Management Plan

September 2020

# Medford Water System Asset Management Plan (W-AMP)

## Table of Contents

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# Acronyms and Abbreviations

AMP: Asset Management Plan
AWWA: American Water Works Association
CIP: Capital Improvement Plan
CoF: Consequence of Failure
DPW: Department of Public Works
EPA: Environmental Protection Agency
gpm: gallons per minute
IWA: International Water Association
LoF: Likelihood of Failure
LoS: Levels of Service or Level of Service
MWRA: Massachusetts Water Resources Authority
WMA: Water Management Act

# 1 Introduction

In 2019 the City of Medford's Department of Public Works was awarded an Asset Management Grant issued by the Massachusetts Clean Water Trust (the Trust). The awarded grant funds are to help the City kick off an Asset Management Program that will be first adopted by the Water and Sewer Division – which manages the water and wastewater assets - and the Engineering Division for the stormwater assets. Eventually, the City's vision for asset management is to have a centralized system that can be used by other departments to also manage their pavement, park assets, trees, street lighting, vehicles (fleet), and signage.

Under this grant, the City, with the assistance of Kleinfelder, is to:

1. Assess the current asset inventory and condition for their water, stormwater and wastewater assets;
2. Develop a risk-based prioritization process that will allow the City to compare assets from the different systems and their needs;
3. Identify system recommendations and formalize a 5-year capital plan;
4. Assist the City with the selection of an Enterprise Asset Management Software; and,
5. Document the process and findings in the form of an asset management plan.

This document constitutes the first Asset Management Plan (AMP) for the water system. It is accompanied by the Stormwater System AMP and the Sewer System AMP. Each of these documents can be read independently, however, they all share a common risk framework, which is explained in Section 5.1. The common framework will be used in the future to compare needs arising from the different assets and consequently prioritize investments appropriately.

# 2 Business Overview

The City of Medford obtains their water from the MWRA system. The water is distributed to the residents through the following asset breakdown:

| System | Pipeline (mi.) | Nodes | System Replacement Value |
|---|---|---|---|
| **Water** | 135 | One pumping station (Doonan St.)<br>1,400 hydrants<br>approx.. 10,000 water gate valves | $419 million[1.] |

Note:
1. Value estimated does not include hydrants or pumping stations, only water main and included valves.

To maintain and ensure the reliability of these assets, the Water and Sewer Division typically conducts the following activities:

- Water quality control
- Maintenance of the pumping station
- Repair of water main breaks and leaks
- Relining of water mains
- Replacement of water mains
- Valve exercising
- Valve repairs and replacements
- Hydrant inspections and maintenance (flushing)
- Hydrant repairs and replacements
- Installation of new meters
- Meter replacements
- Leak Detection

Under this phase of work, the City identified an Asset Management Software product that helps the Water and Sewer Division conduct the tasks listed above efficiently. The City evaluated the products based on type of activities typically conducted by the Division staff and the IT infrastructure and resources available to the City. They cited the following characteristics as critical for the preferred software:

- Can integrate with ESRI's GIS technology
- Is a subscription-based online application
- Requires no additional licensing for products other than the asset management software and, at the most, ArcGIS Online
- Has a desktop and a mobile interface to support planning and dispatching tasks, and field tasks
- Accepts any types of assets at no additional cost
- Offers reliable technical support
- Is easy and user-friendly

Other preferred (but not essential) characteristics are:

- Integrates with See-Click-Fix
- Integrates with Micro-Paver or specific pavement-management capabilities
- Has resource or storage inventory capabilities

The City invited software demonstrations from three different vendors and interviewed current users for feedback regarding their experience with the software in terms of:

1. Implementation;
2. Satisfaction with the product; and,
3. Satisfaction with technical support.

The three vendors evaluated were Cityworks, Dude Solutions and Cartegraph. A table outlining the specifics on the asset management selection process is presented in Appendix D. The City decided to acquire and implement Cartegraph as their asset management software. Implementation will start in mid-late 2020.

## 2.1 Next Steps for the City

To continue the implementation of the asset management program we recommend:

1. Finalize the list of activities from the water division to be implemented in the asset management software, with their corresponding fields, default values, drop-down menus, recurrence settings, etc. This can be done by reviewing the preliminary work order dictionary provided by Kleinfelder to the City as a starting point for this task.
2. Configure the asset management system for these activities.
3. Identify key personnel involved in the resolution of these activities, both from the dispatcher end (task assigner), and the resolution end (task assignee).
4. Start using the software for conducting the work.

This process might require a couple of rounds of configuration until the workflows are fully adopted by the City staff and 100% supported by the software. From there, to take the implementation further we recommend:

5. Configure operation management dashboards for each division head.
6. Configure reports.
7. Configure dashboards for level of service tracking.
8. Integrate software with other systems such as See Click Fix.
9. Expand the software with other modules, if necessary, such as fleet, or storeroom inventory.

# 3 Levels of Service

The term Level or Levels of Service (LoS) refers to the standard to which a service is delivered to the customer. LoS are a key component of an asset management program:

1. They allow for departmental performance assessment from actual data.
2. They help to convey information to stakeholders, justify expenses, measure return-on-investment and when requesting funds.
3. They help to identify areas of improvement, areas of over-performance and allocating resources optimally.
4. They help to align operations with departmental goals.

LoS have a definition, a performance measure, and a target. For water systems, levels of service typically address customer satisfaction (e.g. “0 complaints about colored water per year”) , compliance with regulatory demands (e.g. “0 violations/year of the Safe Drinking Water Act primary and secondary standards”) , and organizational (e.g. “Maximum response time to an emergency break of 2 hrs.”).

The DPW has not defined their LoS for their water system in this first AMP. This section is a placeholder for the upcoming years, for the DPW to 1) State their levels of service, with metrics and targets and 2) Evaluate the DPW performance over time against those targets.

## 3.1 Levels of Service Recommendations

We recommend developing LoS next year and their corresponding tracking tools in the upcoming years.

# 4 Asset Inventory

Asset management starts with an inventory of the assets. It is important to know what you own and its condition to identify asset needs. Furthermore, once an asset management program is implemented, other information about the assets might reveal inefficiencies or other asset priorities. For example, an asset that still works but needs constant repairs may be more costly to the organization than a new one, or a critical asset that is obsolete, although still operational, could be too much of a risk for the City if it were to fail and no replacement part were available.

The inventory of the main water infrastructure assets, water mains, valves, and hydrants, is maintained in GIS format. The inventory consists of:

- 2,450 water main segments (defined as intersection to intersection), representing 135 miles in length
- 1,410 hydrants
- 3,676 system valves
- 81 control valves
- 2,049 fittings
- 1 pump station

A starting asset management program requires capturing some information about these assets, just to ensure that 1) their value is captured correctly 2) their estimated replacement date is calculated correctly, and that 3) operations against those assets are supported by the system (for example, knowing the diameter of the pipe before replacing the pipe, or how many turns a valve has to be fully open or closed). Different asset types require storing different information. The information collected about the assets is usually compiled over time, as work gets done on those assets. The information about assets is stored as part of the attribute table in the GIS. The fields names and data types in each feature class in the database constitutes the database schema.

Water mains are the principal asset type of the water system (besides facilities). At a minimum, the water main feature class (or database) should contain the following information:

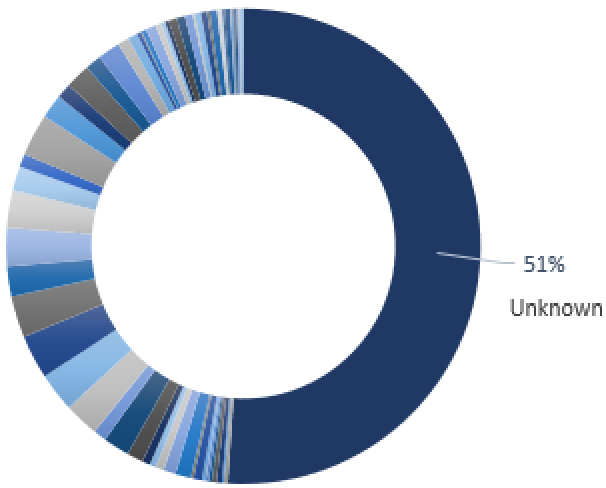
- Location and length (given by the geometry and the accuracy of such), in GIS
- Material
- Diameter
- Year of installation

A secondary set of attributes to further enhance the water main inventory should capture:

- Whether the pipe is lined or not and when it was lined
- Pressure
- Typical flow
- Roughness coefficient and year when it was estimated
- Maximum available fire flow

## 4.1 Data Gap Analysis

The water mains feature class was inspected to assess data gaps regarding material, diameter and year of installation, which are the basic fields needed for estimating future replacement costs. More than 53% of the system (by length) had missing material, and 51% of the system had missing year of installation. The percentage missing material and year of installation was 26.56%. These distributions are found in Figure 1 ,Figure 2, and Figure 3.



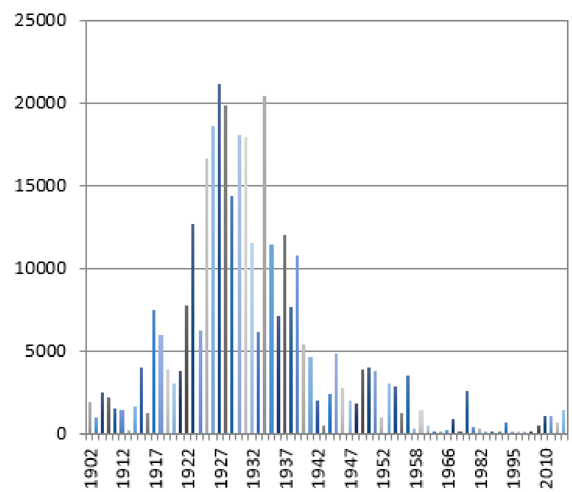




*Figure 1: Distribution of materials (percent by length) from original (raw) data.*

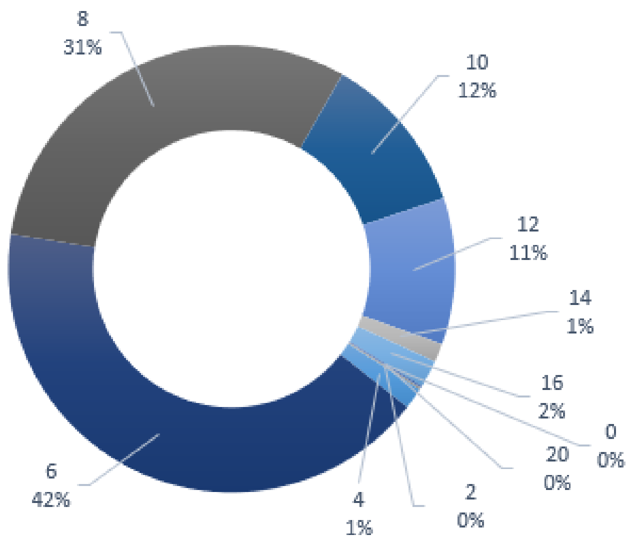
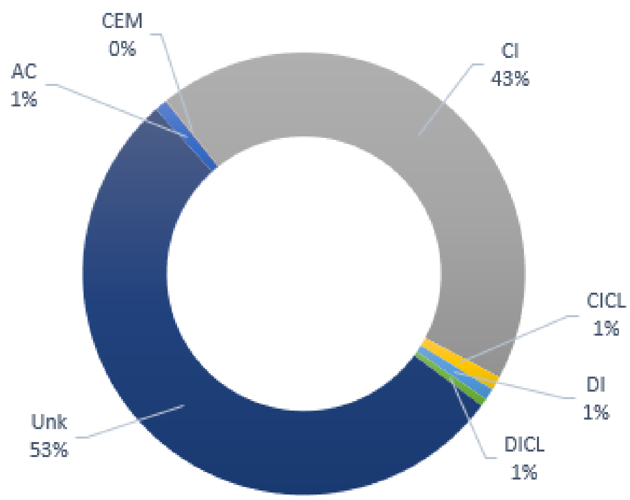



*Figure 2: Distribution of Pipe Diameters (by Percent of Total Lengths)*




<u>Values:</u>
AC - asbestos cement
CEM – cement
CI -cast iron (CI)
CICL - cement-lined cast iron
DI - ductile iron
DICL - cement-lined ductile iron
UNK - unknown material

*Figure 3: Distribution of year of installation from raw data.*

For the purpose of estimating future replacement cost, data gaps were addressed based on knowledge of historical pipe data from the Boston area. The assumptions made were[1]:

- Pipes installed before or during 1922 were made of pit cast iron (PCI)
- Pipes installed between 1923 through 1950 were made of spun cast iron (CI)
- Pipes installed between 1950 through 1969 were made of cement-lined cast iron (CLCI)
- Pipes installed between 1970 through 1974 were made of ductile iron pipe (first type, DI type I)

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[1] Sources: *Buried No Longer: Confronting America's Water Infrastructure Challenge, AWWA* and Kleinfelder

- Pipes installed after 1975 were made of ductile iron pipe (second type, DI type II with polyethylene encasement)
- Pipe segments with year of installation but no material was assigned material based on the above assumptions.

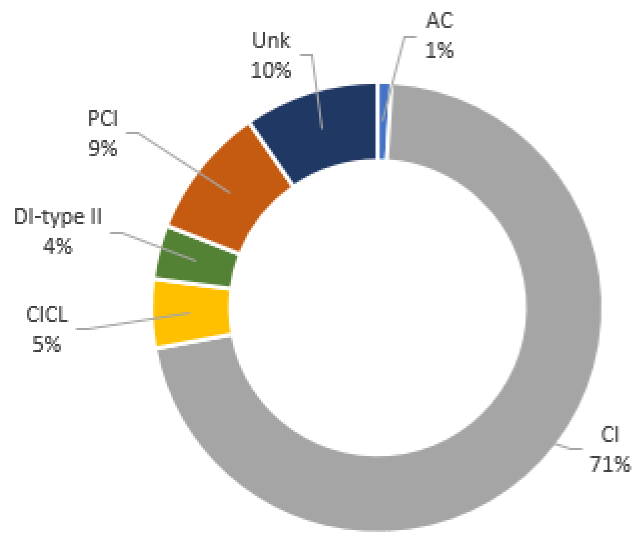


*Figure 4: Distribution of Materials after Minimizing Data Gaps*

Pipe segments without installation year values were assumed to be the same as similarly sized segments in the street (e.g. an unknown installed 4” clay pipe segment in the same street as a 4” clay pipe segment installed in 1975 would be assumed to have an installation year of 1975). Pipes noted as cement (very low percentage) were assigned asbestos cement as material, although the actual pipe material may vary within the cement category. Distribution is illustrated in Figure 5.

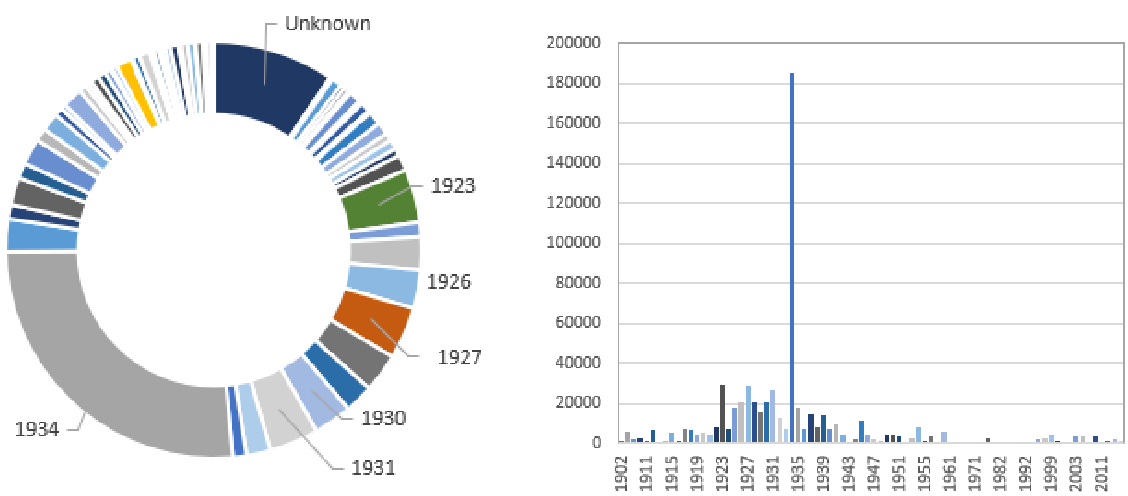


*Figure 5: Distribution of year of installation data after gap mitigation**

*1933 is the default year for missing values, as this was when a large part of the system was installed.

For the purposes of the simulation modelling, the user may assign manually a year of installation and a material to the remaining unknown values. The default values for those are, for material, cast iron (the most common material in the system), and for installation year, 1933, the most common year for that type of material.

### 4.1.1 Data Recommendations

The gaps in the data provided introduce uncertainty in the predictive model to forecast future replacement costs. We recommend:

- Addressing the data gaps to the extent possible by reviewing record drawings
- Facilitating field data collection so that information about material can be entered from the field or into a work order during maintenance activities
- Maintaining a dynamic GIS system that is updated regularly
- Adding feature classes such as meters to the inventory
- Make sure the hydrants and valves inventories are complete
- Creating an inventory of assets for the pump station

## 4.2 Condition

Condition is an important aspect of asset management since it serves the purpose of assessing the remaining useful life of the assets. Regulations may also require periodic inspections of certain asset types (for example, tanks). In addition, condition assessment and tracking can help streamline operations by providing data on the performance of assets and therefore the appropriate frequency for maintenance.

Since there is no condition information available for any of the water system's assets, at least in digital format, we compiled recommendations regarding gaining more understanding of the condition of the water system's assets.

### 4.2.1 Condition Recommendations

#### *4.2.1.1 Water Mains*

Some strategies to better understand the conditions of the water mains are:

1. Having an up-to-date hydraulic model of the system
2. Analyzing the history of water main breaks
3. Gathering information about the pipe while conducting repairs
4. Conducting non-destructive testing
5. Obtaining water main coupons

A **hydraulic model** can help identify problematic areas in a system. If areas are not getting enough flow or pressure, it could be due to too much head loss from fiction, which may indicate heavy tuberculation on a pipe. We recommend updating a water model every 5 years.

The **history of water main breaks** can reveal important information about the reasons for the breakages, or root cause, which might inform which failure modes are at play – is corrosion a factor? Is it traffic loads? Poor installation? Graphitization? This analysis may also reveal patterns by location. The information from this history can also be used to estimate the service life of the different asset types of the system more accurately.

Since historical water main break data might not be available or might not be useful (without information about the location of the break, or the characteristics of the break), we recommend designing the work order form for water main breaks accordingly so that this analysis can be done efficiently in the future, using the information collected through the asset management system.

**Non-destructive methods** assess the condition of the pipe using technologies such as acoustic signals. In this example, sensors are attached to fire hydrants or valves, then a sound wave is induced in the pipeline and travels along the pipe. The 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. Once the acoustic data is captured, algorithms convert the data into a measure of the average minimum remaining wall thickness of the inspected pipe segment. This technology is more powerful when combined with knowledge of the original nominal diameter because then corrosion rates can be derived.

**Destructive methods**, or water main coupons, require collecting samples from the water mains in the system and sending them to a lab for analyzing their properties.

We recommend considering some of these strategies to better understand the current condition of the system. AWWA M58: Internal Corrosion Control in Water Distribution Systems might be a helpful guide in this process.

#### *4.2.1.2 Other System Assets*

Besides water mains, there are other assets in the system that require proactive maintenance activities to ensure they are reliable and can be operated as expected. Valves need to be exercised regularly, and hydrants need to be flushed regularly. However, these assets might not need to be tracked over time to deduct deterioration patterns. Some recommendations regarding these asset types follow.

**Pump Station's Assets**

The pumps and motors should be inspected regularly, and any O&M tasks against those asset types should be logged into the asset management system. *Obsolescence,* which makes it difficult to obtain replacement parts, is a common failure mode.

**Valves and Hydrants**

Valves and hydrants need to undergo recurrent maintenance activities which should be logged in the asset management system. However, there is no need to forecast their condition to estimate future repair costs.

# 5 Risk and Financial Forecast

Risk is a numerical value that is used across all managed assets to prioritize their needs. Having a common risk framework across the entire asset portfolio allows for comparison between different asset types.

Risk is defined as the likelihood of failure (LoF) of an asset[2] times the severity and extent of the negative consequences of that failure (CoF).

*Failure* occurs when an asset does not meet its desired or intended purpose. The ***likelihood of failure*** of an asset is the chance of the asset of not meeting its intended use. To calculate risk, first we need to identify the ways an asset type might fail, also referred to as *failure modes*. These are specific to each asset type. Typical failure modes for water mains are:

- Corrosion: it thins the pipe thickness, making it more susceptible to breakages and pitting.
- Poor installation: lead to leaks and/or breakage.
- Abrupt temperature changes: can lead to main breaks.
- Tuberculation: build-up of iron oxide in the pipe reduces its effective capacity and increases the need for more disinfectant.
- Poor water quality: due to direct contact with leaching lead joints.

***Consequences of failure*** are the negative outcomes resulting from the failure of an asset. Consequences represent what is important to prevent. There are three main consequence factors which constitute the triple-bottom-line (TBL): social, environmental and economic although others can be considered (such as impacts to operations, and regulatory non-compliance).

## 5.1 Medford's Risk Framework

Medford's risk framework uses a scale from 1 to 5 both for likelihood of failure and consequence factors, as shown in Table 1.

*Table 1: Risk Scoring System*

| Rating | Condition / Likelihood of Failure (LoF) | Consequence Factor |
|---|---|---|
| **1** | Excellent Condition / Minimal LoF | Insignificant |
| **2** | Good Condition – Low LoF | Minor |
| **3** | Acceptable Condition – Probable, or likely LoF | Moderate |
| **4** | Poor Condition – High LoF | High |
| **5** | Out of Service, not operational - Failed | Very High |

[2] Also referred to as probability of failure, however *likelihood* is more precise since it is not derived from a statistical analysis.

With this rating system risk scores range between 1 and 25, in a risk *space* as depicted in Figure 6.

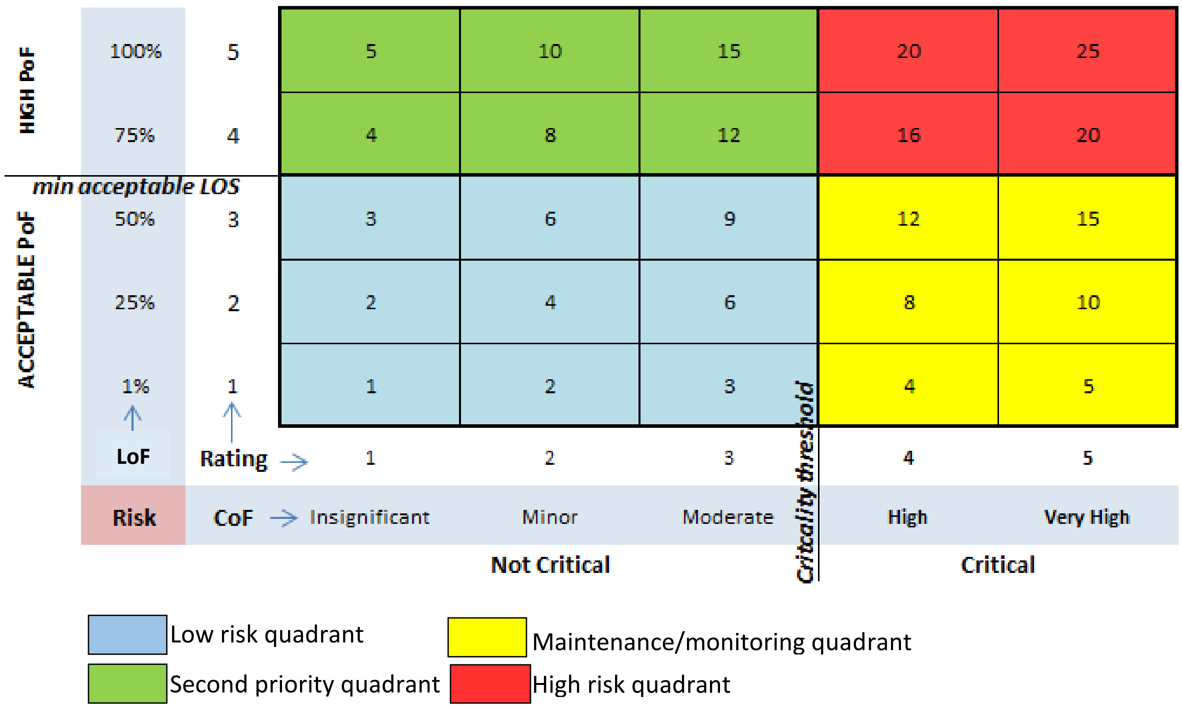


*Figure 6: Risk Space and Quadrants*

An LoF threshold, and a CoF threshold divide the risk space in four quadrants. The LoF threshold represents the minimum acceptable LoS or maximum acceptable likelihood of failure. The CoF threshold represents the limit beyond which criticality is a concern. The top right quadrant, shown in red (Figure 6), is the *high-risk quadrant*. Assets that fall in this quadrant have LoF greater than the threshold and critical CoF. Assets in this category are prioritized over the rest.

Below this quadrant, in yellow, is the *maintenance and monitoring quadrant*. Assets that fall into this category have an acceptable LoF but have high consequence. As time progresses and assets deteriorate, the LoF of the assets will increase, and the asset risk score might eventually fall in the high-risk quadrant. For this reason, assets that fall into this category need to be maintained and monitored regularly.

The top left quadrant, in green, corresponds to the assets that have LoF above acceptable levels, but are not critical. These are the *second-priority* items (also referred to as the "Important" quadrant).

Finally, the bottom left quadrant, in blue, corresponds to the assets with acceptable LoF and low criticality: The *low-risk quadrant.*

Note how assets in the maintenance and monitoring quadrants and assets in the second-priority quadrants may have the same risk scores but will need different risk management strategies since the causes of the high-risk values are different.

The next sections outline the methodology to evaluate the LoF scores and the CoF scores.

## 5.2 Likelihood of Failure

This framework considers two **failure modes**: failure modes that affect the physical integrity of the asset, and failure modes that affect their capacity.

Physical Integrity, a measure of the "general condition of the pipe," is measured using two proxies:

- **Remaining useful life (RUL):** Calculated from estimated service life (ESL) – the expected maximum life of an asset, and its age, which is a function of the installation year.

$$RUL = \frac{ESL - Age}{ESL}$$

Estimated Service Life for the different materials are model parameters for which default values were determined from the literature and studies of similar systems.

*Table 2: Estimated Service Life Values*

| Material | ESL (Years) |
|---|---|
| **PCI – Pit Cast Iron** | 180 |
| **CI – Cast Iron (Spun)** | 130 |
| **CICL – Cement-lined Cast Iron** | 130 |
| **DI-Type II – Ductile Iron** | 150 |
| **AC – Asbestos Cement** | 50 |

- **Condition**: This mode will be used when data is available.

Capacity, a measure of "how well the pipe is conducting flow," is measured with the following proxies:

- **Pressure**: from hydraulic model results
- **Reduction of pipe diameter**: from hydraulic model (C value)
- **Fire Flow adequacy**: the difference between available fire flow (output from hydraulic model) and needed fire flow. Needed fire flow is calculated following the National Fire Protection Association Method of the M31 Standard[3].

Only remaining useful life was used to estimate likelihood of failure on this first AMP. The rest of the failure modes will be integrated in the analysis as data to assess them comes available.

[3] Distribution System Requirements for Fire Protection – Manual of Water Supply Practices M31. AWWA

## 5.3 Consequence Factors

**Consequence** factors, or the negative impacts of a failure, are grouped in two categories: social impacts, and financial impacts. Environmental impacts have not been considered relevant in the case of water main failure.

Social impacts represent impacts to the public including health and safety, and loss of service. They are estimated based on:

- **System criticality**: importance of the pipe segment as part of the system. We used the diameter of the pipe as a proxy to determine the system criticality score.
- **Customers affected**: based on land use or the use of the parcel closest to the pipe. The user might give more weight to pipes that service schools or wellness centers than to other land uses.

We modeled financial impacts based on how dense is the nationhood that the pipe services (**population density**). This is based on census track information. The metric for this factor is the relative density to Medford's average at the city level, for each census block group. We assigned this value, calculated for each block group, to each pipe segment based on location.

1. In ArcMap we calculated the City's average population density by dividing the total population by the City's area, based on Census data of 2010
2. In ArcMap, we calculated each census block group population density by dividing their corresponding populations by their areas, using GIS)
3. In ArcMap, we calculated the relative population of each census block group to the city's average by dividing the density of each block by the average density of the City.
4. We assigned this last result to each pipe segment by performing a spatial join in ArcMap based on the location of the center of the pipe segment.

Neighborhoods that have Medford's average population density (3,273 people per square mile, as reported in 2010) have a score of 3 (average). Assets in neighborhoods with less than half of the population density (i.e. less than 1,636 people per square mile) have the lowest consequence score, and assets on neighborhoods that have twice or more of the average density (i.e. more than 6,546 people per square mile) get the highest score.

The risk framework gives us the rules and exact math needed to calculate risk scores, which are then used to prioritize assets. These rules and scoring system for this risk framework are presented in Appendix D - Risk Framework. The next step is to determine what happens to each pipe segment. Does it need to be replaced? Rehabilitated? Inspected? This requires another set of rules that are explained in section 5.4.3, Decision Model. To effectively calculate risk, preliminary actions, and costs for each pipe segment, Kleinfelder developed a numerical model in Excel that uses the data available at the segment level (length, material, diameter, age, condition, etc.) and user-input parameters such as unit costs, ESLs, budget, etc. to create a list of action items and costs which will constitute the CIP. The mechanics of this model are explained in this section, and the results obtained are provided in Section 5.4.

## 5.4 Water Model

Kleinfelder developed a risk model for the water system that calculated risk scores based on the GIS data available. The model, in Excel, allows for the user to modify some parameters so that the results of the model are representative of the system. This model was built using the risk framework described in the previous section.

The model performs the following calculations for each water main segment:

1. Assigns estimated service life (ESL) based on material
2. Calculates age based on current date and year of installation
3. Calculates Remaining Useful Life (RUL) based on age and ESL
4. Calculates percent life left from RUL and ESL
5. Calculates LoF based on percent life left
6. Calculates consequence factors scores for system criticality, customers affected (land use), and population density
7. Calculates a final CoF score based on the three consequence factors used
8. Calculates risk
9. Calculates the corresponding risk box to which the asset belongs
10. Calculates the corresponding priority into which the asset falls
11. Assigns a renewal strategy (clean and line) or replacement (replace with same diameter or with larger diameter) based on LoF and CoF data
12. Calculates renewal or replacement costs based on replacement strategies
13. Allows for Action Override: the user might want to change the action selected by the software
14. Calculates Final costs
15. Allows the user to manually assign CIP years to allocate their budgets

### 5.4.1 Model inputs

The model requires the following input data:

- Water Mains attributes from GIS (for each pipe segment)
  - AssetID or unique identifier
  - Material
  - Diameter
  - Street
  - Year of installation
  - Length
  - Land use associated with the pipe segment - from the assessor's database, based on proximity (closest to the segment centroid)
  - Population density associated with the pipe segment - from census data at the census block group level, based on census of 2010. Population density was normalized to average population density in Medford.

- Deterioration equations[4]
- Unit costs table
- Year of analysis (starting in 2018)
- Default values for missing data
- Prioritization matrix
- Consequence factors parameters

### 5.4.2 Model Parameters

The user may change the model parameters and assess the sensitivity of the model to those. Cells in light yellow are model parameters. These are:

- **Start Year**: Start year is the starting year for the simulation. It is used to calculate the age of the pipe at the beginning of the simulation.
- **Year if Null**: Is the year assigned to those segments that are missing year of installation (after the data cleaning). The default value is 1933, as this was the most common installation year.
- **Diameter if Null**: is the diameter assigned to those segments with missing diameter data (after cleaning). The default is 6 inches, as this is the most common size in the system.
- **Material if Null**: is the material assigned to those segments with missing material (after data cleaning). The default is cast iron (CI).
- **Unit costs:** unit costs for pipe replacement and cement lining by pipe diameter. The unit costs entered here should include all the costs associated with the activity including design, disposal, traffic details etc.
- **Yearly Budgets:** amount allocated for renewal and replacement of the pipes for the 5-year plan.
- **System Criticality**: allows the user to assign consequence of failure ratings based on diameter, as displayed in Table 6-3. By changing the “to diameter” parameter, the user can define what diameters get a rating of 1 (insignificant), 2 (Minor), 3 (Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. The percentages next to each category, which have a green bar conditional formatting indicate the percentage of the system that falls into each category. These are dynamic and change as the user changes the parameters. The default values for system criticality are displayed in Table 3, which indicates that 43.6% of the system has diameter 6 or less (and corresponds to the consequence rate *insignificant*).

[4] Deterioration equations were built using two linear equations for each material, representing the slow deterioration that occurs first, and a steeper deterioration rate that occurs later in the life of the asset. These equations were built based on best- known estimated service life data.

*Table 3: System Criticality - Input Parameters Table*

| System Criticality | Weight | 25% | |
|---|---|---|---|
| Consequence | From Diam | [To Diam] | |
| Insignificant | 1 | 6 | 43.60% |
| Minor | 7 | 10 | 42.40% |
| Moderate | 11 | 12 | 10.59% |
| High | 13 | 16 | 3.32% |
| Very High | 17 | 20 | 0.09% |
| | | | 100.00% |

- **Financial Impacts**: As explained in Section 5, financial impacts are represented by the density of population the pipe is servicing. Therefore, a failure in a high-density neighborhood can cause more disruption due to traffic and other factors than a break in a sparse area. The user can assign consequence of failure ratings based on population density, as displayed in Table 4. By changing the "to population density" parameter, the user can define what pipes get a rating of 1 (insignificant), 2 (Minor), 3 (Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. Population density is relative to the average population in Medford, so that a value of 0.5 means "half the average density" while a value of 2 means "twice the average". The default values are represented in Table 4.

*Table 4: Financial Impacts - Input Parameters Table*

| Financial Impacts | Weight | 50% | |
|---|---|---|---|
| Consequence | From Pop Dens | [To Pop Dens] | |
| Insignificant | 0.00000 | 0.50000 | 7.98% |
| Minor | 0.49000 | 0.75000 | 6.35% |
| Moderate | 0.74000 | 1.25000 | 17.00% |
| High | 1.24000 | 2.00000 | 52.11% |
| Very High | 1.99000 | 3.85783 | 16.56% |
| | | | 100.00% |

- **Loss of Service**: As explained in Section 5, loss of service impacts are represented by the land use the pipe is servicing. Therefore, a failure in a school, or a residential parcel can cause more disruption than a break in a garage or industrial parcel. The user can assign consequence of failure ratings based on land use, as displayed in Table 5. Ratings are: 1 (insignificant), 2 (Minor), 3 (Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. The percentages next to each land use indicate the total of the system by length assigned to that land use. 78.4% of the system is residential, 6.6% is on vacant property and 2.3% is in warehouses.

*Table 5: Loss of Service Ratings based on Land Use*

| Loss of Service | Weight | 25% |
|---|---|---|
| Land Use | Consequence | |
| Automotive Sales and Service | 1 | 1.5% |
| Charitable Services | 1 | 0.0% |
| Clubs/Lodges | 1 | 0.4% |
| DCR Park | 1 | 0.7% |
| Education | 4 | 1.3% |
| Fire Station | 3 | 0.3% |
| Garages | 1 | 0.1% |
| Government | 1 | 1.1% |
| Hospitals | 5 | 0.3% |
| Hotels | 3 | 0.0% |
| Industrial | 1 | 0.1% |
| Nursing Homes | 5 | 0.1% |
| Office Buildings | 2 | 2.1% |
| Open Space | 1 | 0.0% |
| Other | 1 | 0.3% |
| Religious | 1 | 0.7% |
| Residential | 3 | 78.4% |
| Retail | 2 | 3.6% |
| Utility | 1 | 0.0% |
| Vacant | 1 | 6.6% |
| Warehouses | 1 | 2.3% |
| | | 100.00% |

- **Likelihood of Failure**: the user might distribute condition ratings (from 0 being "failed" to 100, being "in excellent condition") to likelihood of failure ratings, as displayed in Table 6.

*Table 6: Likelihood of Failure – Input Parameters Table*

| Likelihood of Failure | | | |
|---|---|---|---|
| Consequence | From Cond | [To Cond] | |
| Insignificant | 100.0 | 80 | 15.90% |
| Minor | 79.9 | 60 | 34.46% |
| Moderate | 59.9 | 40 | 13.48% |
| High | 39.9 | 20 | 25.54% |
| Very High | 19.9 | 0 | 10.62% |
| | | | 100.00% |

- **Prioritization Matrix** This is a 5x5 matrix that represents, as the risk matrix, the combinations of CoF (on the horizontal axis, from 1 to 5), and the LoF (on the vertical axis, from 1 to 5). The values of each cell correspond to the priority assigned to it. Since it is a 5x5 matrix, the values on these cells should be unique and range from 1 to 25. This matrix helps differentiate between cells that have the same risk scores. For example, Asset 1 and Asset 2 could both have a risk score of 8. Asset 1's score results from a CoF of 2 and a LoF of 4. Asset 2's score is due to a CoF of 4 and a LoF of 2. Which one takes priority? The priority matrix allows the user to define it. In this case, the Asset 1 would take priority over Asset 2 (see Figure 7).

**Risk Scores**

| LoF | | | | | |
|---|---|---|---|---|---|
| 5 | 5 | 10 | 15 | 20 | 25 |
| 4 | 4 | 8 | 12 | 16 | 20 |
| 3 | 3 | 6 | 9 | 12 | 15 |
| 2 | 2 | 4 | 6 | 8 | 10 |
| 1 | 1 | 2 | 3 | 4 | 5 |
| CoF | 1 | 2 | 3 | 4 | 5 |

**Priority Matrix**

| LoF | | | | | |
|---|---|---|---|---|---|
| 5 | 17 | 10 | 5 | 2 | 1 |
| 4 | 19 | 12 | 7 | 4 | 3 |
| 3 | 21 | 14 | 9 | 8 | 6 |
| 2 | 23 | 16 | 15 | 13 | 11 |
| 1 | 25 | 24 | 22 | 20 | 18 |
| CoF | 1 | 2 | 3 | 4 | 5 |

*Figure 7: Comparison between Risk and Priority*

The default setting for the prioritization matrix is depicted in Figure 8.

| LoF | | | | | |
|---|---|---|---|---|---|
| 5 | 17 | 10 | 5 | 2 | 1 |
| 4 | 19 | 12 | 8 | 4 | 3 |
| 3 | 21 | 14 | 9 | 7 | 6 |
| 2 | 23 | 16 | 15 | 13 | 11 |
| 1 | 25 | 24 | 22 | 20 | 18 |
| CoF | 1 | 2 | 3 | 4 | 5 |

*Figure 8: Prioritization Set-up Used in AMP*

- **Deterioration Functions** – The purpose of these equations is to convert age to condition score and vice-versa. These equations are used to calculate the condition of an asset over time. The functions used here are simplified versions of more complex functions that were inferred from thorough statistical analysis. Since these equations are only used here to get a LoF score from a pipe's age, these simplifications are acceptable.

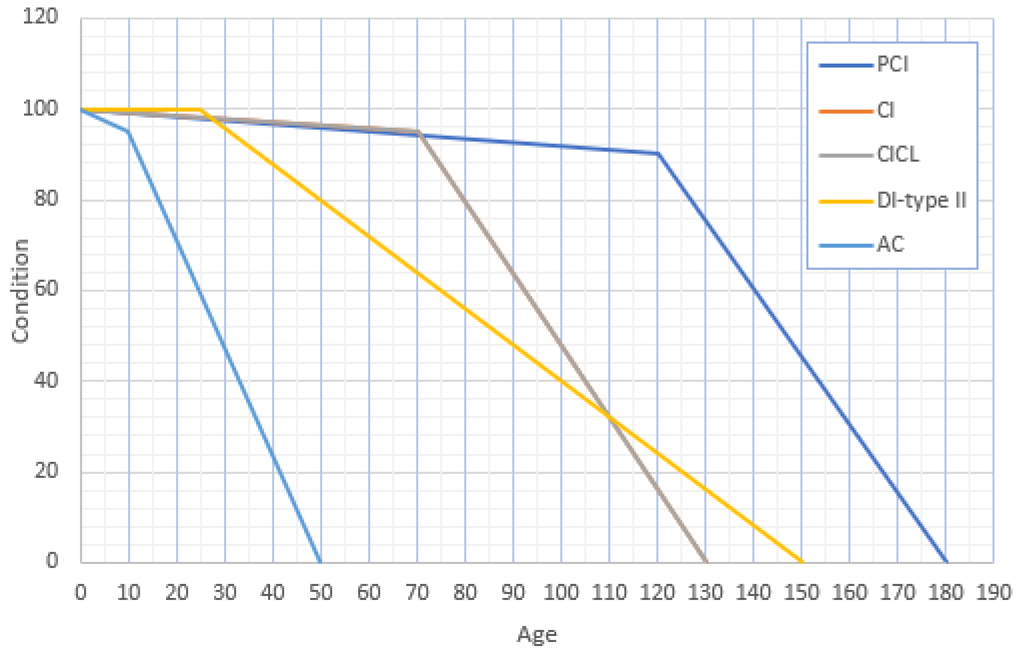


*Figure 9: Pipe Deterioration Functions by Material*

1. Max score is 100.
2. Cast Iron (CI) is same deterioration curve as Cast Iron – Cement Lined (CICL) deterioration curve.

### 5.4.3 Decision Model

The decision model is the algorithm or set of rules that the model uses to assign rehabilitation strategies to each segment. Each strategy has an associated unit cost (by linear foot), which is used to calculate the cost of applying a given strategy to an asset. This is a ballpark cost since it is only based on length and diameter and does not take into consideration other factors such as permitting costs, depth of the pipe, traffic management and such.

The decision model considers the following strategies:

- Replacement – consists of replacing the entire segment for a new pipe of same diameter. This strategy has unit costs per linear foot associated.
- Cement lining – consists of lining the pipe using trenchless technology. This strategy has unit costs per linear foot associated.
- Monitor Leaks - this strategy has zero costs.

The unit costs used in the model are presented in Table 7. These costs include construction, and engineering services towards design calculated as 18% of the construction cost, plus 30% of contingency to capture all other activities associated with the construction of that main (such as traffic details). These unit costs are model parameters and can be changed by the user at any time.

*Table 7: Unit Costs per Linear Foot ($/lf) for Pipe Replacement by Diameter (in.)*

| Diameter | Replace | Cement Line | Monitor Leaks |
|---|---|---|---|
| 2 | $ 551.06 | $ 425.11 | $ - |
| 4 | $ 551.06 | $ 425.11 | $ - |
| 6 | $ 551.06 | $ 425.11 | $ - |
| 8 | $ 551.06 | $ 425.11 | $ - |
| 10 | $ 708.52 | $ 456.59 | $ - |
| 12 | $ 708.52 | $ 456.59 | $ - |
| 14 | $ 818.72 | $ 524.83 | $ - |
| 16 | $ 818.72 | $ 795.98 | $ - |
| 20 | $ 897.44 | $ 822.23 | $ - |

The model uses the following logic to assign preliminary strategies for each segment:

1. Any segment that has reached the end of their service life should be replaced. Therefore, segments with LoF of 5 get "Replace" as their preliminary action.
2. If the segment has an LoF smaller than 5 then, if it was installed after 1950 (material should be CICL, DI-Type I or DI-type 2), it gets the preliminary action "monitor leaks."
3. If the segment has an LoF smaller than 5, but it was installed before or in 1950 (PCI or CI pipe), then,
    a. Segment gets assigned "Replace" if it is an 8-inch pipe or a 10-inch pipe with high consequence (CoF of 4 or 5).
    b. Segment gets assigned "Cement Line" if its diameter is greater than 12 inches, and it has not been cement lined before, OR if it is an 8-inch or 10-inch pipe with low consequence.
    c. Segment gets assigned "Monitor Leaks" if its diameter is greater than 12 inches and has been lined before.

This decision model is a simplified version of a more complex model that would require additional information that is not available at this time. The step that assigns Cement Line and Replace to 8 and 10-inch pipes based on their consequence factor really should state to Cement Line the pipes that do not have issues and Replace the ones with issues. The goal of this model is to highlight segments and areas which need investigation for solution application, and can provide better assumptions with structural ratings provided by Work Order input. The model can be updated in the future as this information comes available. The model does not include a rule to represent the upcoming industry standard by which pipes connected to a hydrant should be at least 8 inches to ensure enough fire flow.

## 5.5 Risk Analysis Results

### 5.5.1 Likelihood of Failure

Overall, the system has a good distribution of LoF values with the majority of the system having a score of 1 and 2. There are 10% of the pipes with an LoF of 5, which means they are reaching if not already have reached, the end of their service life. Although this percentage is low, a little bit more concerning is the 26% of the system that, with and LoF score of 4, might be reaching the end of their service life in the upcoming years.

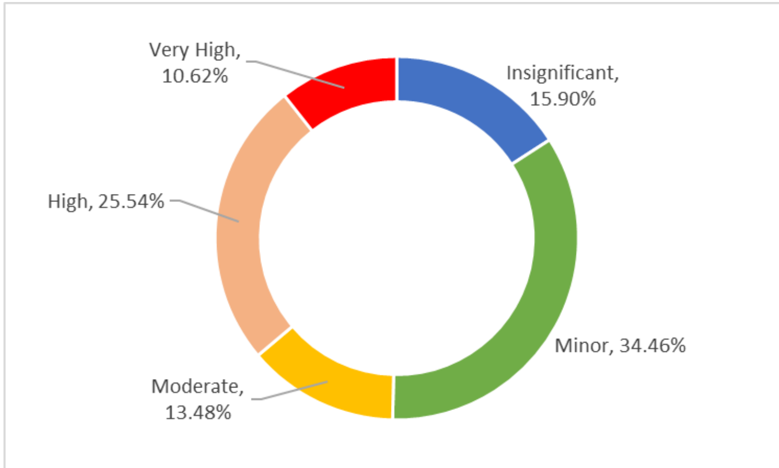


*Figure 10: Distribution of LoF*

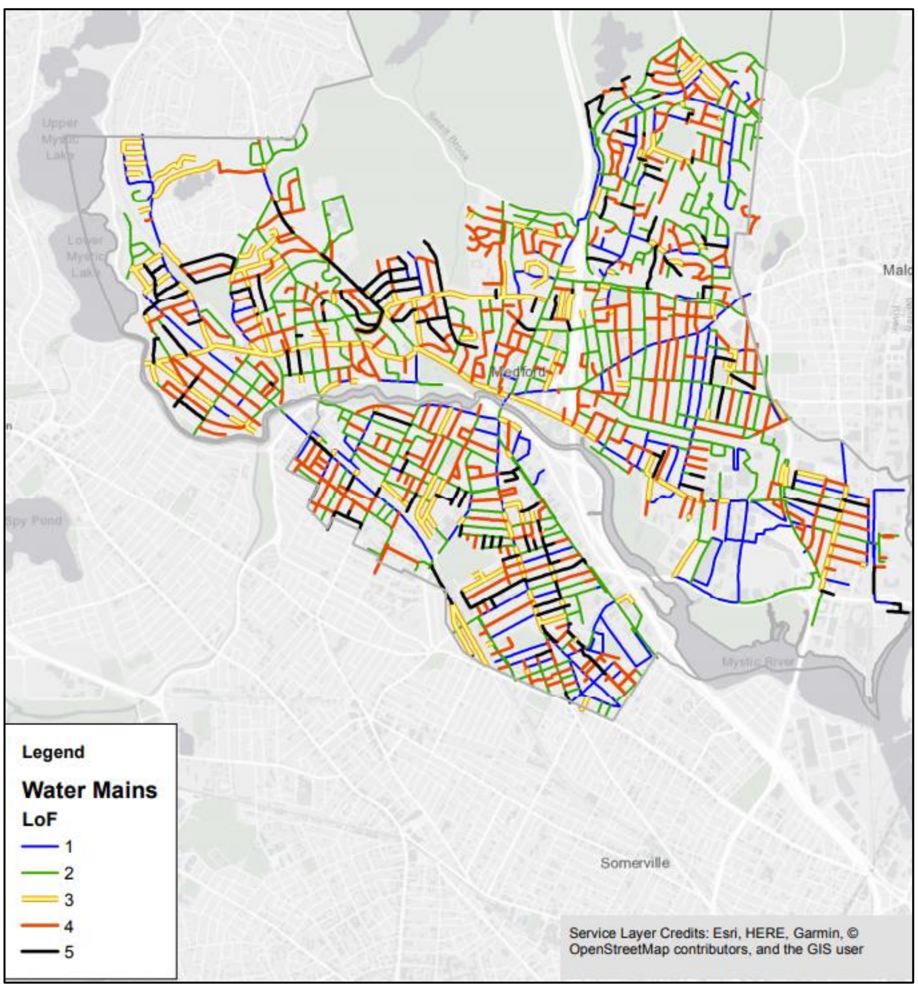


*Figure 11: Map of the system by LoF scores*

The replacement cost of the 12.9 miles of system that have a LoF of 5 represent a $2.81 M investment.

42% of Medford's water system is 6-inch mains. 21% of these have a LoF of 5. We estimate that approximately 50% of those would be connected to a hydrant. Those assets should be replaced for 8-inch pipe in the next few years.

### 5.5.2 Consequence of Failure

The model calculates consequence of failure (CoF) scores for each consequent factor as described in Section 6.2, and uses the weights indicated by the user through the interface to calculate the weighted average of the consequence factors, which is the final consequence score.

The model allows the user to set weight for the three consequence factors described in Section 6.2. The default weights used were: 25% for System criticality (or order of the segment within the network), 50% for financial impacts (or population density), and 25% for loss of service (or land use). This combination of weights provides a distribution of consequence where most of the system falls in categories 3 and 4. Only 0.22 miles of pipe have CoF of 5.

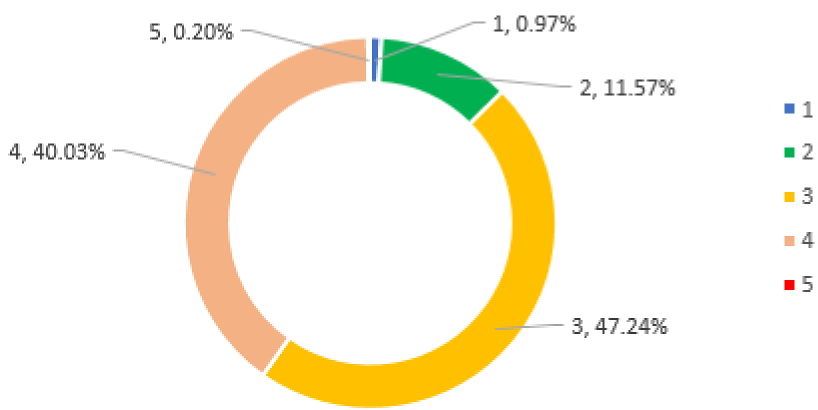


*Figure 12: Distribution of CoF*

### 5.5.3 Risk

With likelihood of failure (LoF) and consequence of failure (CoF) scores calculated, the model then proceeds to calculate risk and express the results in terms of "Risk Box", "Risk Score", and "Priority".

The **Risk Box** is the combination of CoF-LoF expressed as such. It indicates where the asset falls in the risk matrix (as presented). For example, an asset with risk box 4-2 has a CoF of 4 and a LoF of 2. This metric is important because it paints a very clear picture of where the system is, especially after adding the lengths of segments by their risk box and presenting the results in a risk-matrix format as displayed on Figure 13.

| | LoF | 1 | 2 | 3 | 4 | 5 | | |
|---|---|---|---|---|---|---|---|---|
| LoF | 5 | 1,544 | 9,938 | 52,423 | 10,843 | - | 14.16 mi | 11% |
| | 4 | 543 | 13,675 | 128,760 | 36,696 | - | 34.03 mi | 26% |
| | 3 | 3,909 | 7,498 | 38,782 | 44,200 | 433 | 17.96 mi | 13% |
| | 2 | 766 | 32,099 | 79,046 | 129,851 | 739 | 45.93 mi | 34% |
| | 1 | 55 | 18,199 | 33,363 | 60,075 | 202 | 21.19 mi | 16% |
| | | 1.29 mi | 15.42 mi | 62.95 mi | 53.35 mi | 0.26 mi | 133.26 mi | |
| | | 0.97% | 11.57% | 47.24% | 40.03% | 0.20% | | |
| | | | | CoF | | | | |

*Figure 13: Risk Distribution Indicating Total Length of Pipe in Feet for Each Risk Box*

The results indicate that:

- There are no pipes in category 5-5 (greatest risk value)
- The total length of pipes in the high-risk quadrant is 48,404 feet (CoF >3, LoF >3)
- There are 14.16 miles with LoF of 5, which should start being replaced
- There are 128,760 feet of pipe on the risk box 3-4 that will likely deteriorate at a similar rate and reach LoF of 5 in the upcoming years

We must emphasize that the LoF results are based only on the age of each pipe – which depends on the year of installation, and on the ESL, which in this model, depends on the material. Given the data gaps discussed on Section 5, and lack of data regarding the actual condition of the water mains, we must acknowledge the uncertainty associated with the results.

#### 5.5.4 Financial Results

The model provided the following results:

- The replacement of the entire network (133.3 miles of water main), results in $419 million.
- Considering that the average ESL of the system is 123 years, the average yearly investment on asset replacement should be $3.4 million.
    - However, understanding that more critical repairs and replacements will increase service lift, this cost is expected to be lower per year if Risk Rating is considered in renewal project selection and prioritization.
- The total preliminary investment identified by the model is $185.5 million (this is over the entire portfolio).
    - This represents April 2020 costs (ENR 11412), and depending on when the repairs/replacement are initiated, the preliminary investment will vary from year to year in practice.
- The investment needed to address the 12.9 miles of main with LoF of 5 is $2.81 million.
- The cost of addressing the assets in the high-risk quadrant is $1.54 million, which should be addressed in years 1 and 2.
- 42% of the system is 6-inch main, and 21% of those have LoF of 5 (11.67 miles of 6-inch pipe with LoF of 5). Replacing these assets with 8-inch pipe would cost $34 million. We estimate that

50% of those would require upsizing to 8-inch for being connected to a hydrant, while the other 50% could be replaced by 6-inch main. If we prioritize the mains connected to hydrants, that results in $17 million, which distributed over an 8-year period results in $2.1 million year.

*Table 8: Estimated Annual Investment Options*

| Description | Estimate |
|---|---|
| Investment needed for sustainable renewal | $3.4 M/year |
| Preliminary system investment (results from model, April 2020) | $185.5 M total |
| Recommended Investment | $1.5M to be addressed in Years 1 – 2; ~2.1 M/year for 6-inch replacement program on years 8 –10 |

### 5.5.5 Recommendations Regarding Risk and Financial Forecast

With the risk framework developed, and after this first year of risk analysis, we recommend reviewing the framework and the analysis over time to incorporate failure modes that might prove to be relevant in the City. That type of information will become more evident as you capture information from daily operations and maintenance tasks in the asset management system.

As stated in previous sections, the quality of the data is very important to obtain significant results, and therefore we recommend minimizing the data gaps addressed in Section 5.

We highly recommend implementing a program to assess the condition of the system, particularly the older pipes of medium and large diameters. The inspection information will be useful not only to determine the status of a pipe segment, but also for assessing the service lives of the different materials, specifically for Medford, since they may differ from the typical ESLs found in the literature. The inspection information may also reveal failure modes that could be important and that were not considered in this first year. If internal corrosion is an issue, the best methodology is to collect water main coupons through destructive methods, which can be expensive. We emphasize the prioritization of implementing a thought-through *water main repair work order form* in the asset management system that can complement the inspection program.

In addition to inspection, it would be valuable to implement a leak detection program. There are new technologies in the market that can assess the entire city in a matter of days.

In terms of consequence factors, these can be improved in the future by incorporating data such as actual consumption from users (by adding water meters to the GIS with their associated consumption data).The *financial impacts* consequence factor could also be updated in the future once the census of 2020 data is published, since that is the proxy used.

# 6 Renewal Items

The model was set up with an annual budget cap of $1.5 Million and based on the risk values obtained, assigned the recommended action to a given year. Note that this prioritization doesn't take into consideration the replacement of the 6-inch mains connected to hydrants (these are flagged for replacement or renewal based on their risk scores as the rest of the assets). Nonetheless, about 42 miles of 6-inch pipe had been identified by the model to be replaced in the next 10 years.

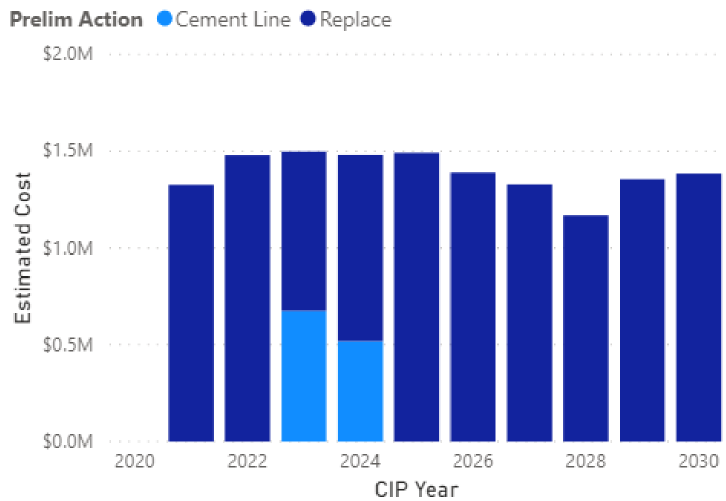


*Figure 14: Budget Allocation*

Tables 9 and 10 displayed the prioritized list of items with their corresponding years. For more details on the actual segment's lengths, diameters etc. refer to the excel spreadsheet model associated with this AMP.

*Table 9: List of Identified Action Items for Years 1-5 with Corresponding Estimated Costs (April 2020, ENR 11412)*

| Year | Street | Action | Estimated Cost |
|---|---|---|---|
| 2021 | BOSTON AVENUE | Replace | $904,943 |
| 2021 | MEDFORD STREET | Replace | $213,037 |
| 2021 | NEWBERN AVENUE | Replace | $209,749 |
| 2022 | BOSTON AVENUE | Replace | $209,869 |
| 2022 | CORPORATION WAY | Replace | $461,360 |
| 2022 | REVERE BEACH PARKWAY | Replace | $807,767 |
| 2023 | CENTURY STREET | Replace | $272,715 |
| 2023 | HIGH STREET | Cement Line | $11,323 |
| 2023 | HIGH STREET | Replace | $240,013 |
| 2023 | LAWRENCE ROAD | Cement Line | $192,928 |
| 2023 | LINWOOD STREET | Replace | $105,419 |
| 2023 | MAIN STREET | Cement Line | $216,884 |
| 2023 | MIDDLESEX AVENUE | Cement Line | $14,475 |
| 2023 | MIDDLESEX AVENUE | Replace | $144,251 |
| 2023 | RIVERSIDE AVENUE | Cement Line | $119,183 |
| 2023 | SHERWOOD ROAD | Replace | $37,266 |
| 2023 | WILLARD AVENUE | Replace | $21,874 |
| 2023 | WINTHROP STREET | Cement Line | $121,563 |
| 2024 | BROOKSIDE PARKWAY | Replace | $17,469 |
| 2024 | CENTURY STREET | Replace | $134,077 |
| 2024 | CHARNWOOD ROAD | Replace | $118,549 |
| 2024 | FELLSWAY | Replace | $108,484 |
| 2024 | HIGH STREET | Cement Line | $195,119 |
| 2024 | HIGH STREET | Replace | $275,502 |
| 2024 | MAIN STREET | Cement Line | $188,743 |
| 2024 | MIDDLESEX AVENUE | Cement Line | $16,652 |
| 2024 | SUFFOLK STREET | Cement Line | $9,303 |
| 2024 | WARREN STREET | Replace | $267,338 |
| 2024 | WINSLOW AVENUE | Replace | $39,337 |
| 2024 | WINTHROP STREET | Cement Line | $109,571 |
| 2025 | ASHCROFT ROAD | Replace | $74,298 |
| 2025 | AUBURN STREET | Replace | $3,160 |
| 2025 | BURGET AVENUE | Replace | $307,479 |
| 2025 | COLLEGE AVENUE | Replace | $97,354 |
| 2025 | HIGH STREET | Replace | $173,872 |
| 2025 | HUME AVENUE | Replace | $500,431 |
| 2025 | MIDDLESEX AVENUE | Replace | $140,306 |
| 2025 | WILLIS AVENUE | Replace | $127,145 |
| 2025 | WINSLOW AVENUE | Replace | $67,252 |
| **Total** | | | **$7,276,061** |

*Table 10: List of Identified Action Items for Years 6-10 with Corresponding Estimated Costs (April 2020, ENR 11412)*

| Year | Street | Action | Estimated Cost |
|---|---|---|---|
| 2026 | BOSTON AVENUE | Replace | $812,602 |
| 2026 | BURGET AVENUE | Replace | $204,541 |
| 2026 | JEROME STREET | Replace | $6,358 |
| 2026 | SHERWOOD ROAD | Replace | $245,323 |
| 2026 | WILLIS AVENUE | Replace | $121,160 |
| 2027 | FULTON STREET | Replace | $196,729 |
| 2027 | JEROME STREET | Replace | $333,656 |
| 2027 | MIDDLESEX AVENUE | Replace | $165,872 |
| 2027 | MYSTIC VALLEY PARKWAY | Replace | $287,778 |
| 2027 | SUFFOLK STREET | Replace | $3,608 |
| 2027 | WILLARD AVENUE | Replace | $342,269 |
| 2028 | CENTURY STREET | Replace | $137,959 |
| 2028 | FELLSWAY WEST | Replace | $132,472 |
| 2028 | GOVERNORS AVENUE | Replace | $162,913 |
| 2028 | JEROME STREET | Replace | $515,278 |
| 2028 | SUNSET AVENUE | Replace | $220,809 |
| 2029 | AMES STREET | Replace | $202,261 |
| 2029 | CHARNWOOD ROAD | Replace | $374,598 |
| 2029 | FULTON STREET | Replace | $70,903 |
| 2029 | GOVERNORS AVENUE | Replace | $328,401 |
| 2029 | HASTINGS LANE | Replace | $23,352 |
| 2029 | JEROME STREET | Replace | $40,584 |
| 2029 | MIDDLESEX AVENUE | Replace | $310,209 |
| 2029 | SUFFOLK STREET | Replace | $4,268 |
| 2030 | BURGET AVENUE | Replace | $431,791 |
| 2030 | CENTURY STREET | Replace | $121,225 |
| 2030 | FOUNTAIN STREET | Replace | $112,161 |
| 2030 | HIGH STREET | Replace | $417,142 |
| 2030 | JEROME STREET | Replace | $207,055 |
| 2030 | NORTH STREET | Replace | $94,982 |
| **Total** | | | **$6,628,260** |

# APPENDIX B:

# Sewer System AMP

# Medford, MA
# Sewer System Asset Management Plan

September 2020

KLEINFELDER
Bright People. Right Solutions.

# Medford Sewer System Asset Management Plan (S-AMP)

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## Acronyms and Abbreviations

AMP: Asset Management Plan
EAM: Enterprise Asset Management
AWWA: American Water Works Association
CCTV: Closed Circuit Television
CIP: Capital Improvement Plan
CoF: Consequence of Failure
DPW: Department of Public Works
EPA: Environmental Protection Agency
ESL: Estimated Service Life
GIS: Geographic Information System
gpm: gallons per minute
I/I: Infiltration/Inflow
LoS: Levels of Service or Level of Service
LoF: Likelihood of Failure
NASSCO: National Association of Sewer Service Companies
PACP: Pipeline Assessment Certification Program
QSR: Quick Structural Rating
QMR: Quick Maintenance Rating
RUL: Remaining Useful Life

# 1 Introduction

In 2019 the City of Medford's Department of Public Works was awarded an Asset Management Grant issued by the Massachusetts Clean Water Trust. The awarded grant funds are to help the City kicking off an Asset Management Program that will be first adopted by the Water and Sewer Division – which manages the water and wastewater assets, and the Highway Division – for the stormwater assets. Eventually, the City's vision for asset management is to have a centralized system that can be used by other departments to manage also their pavement, park assets, trees, street lighting, vehicles, and signage.

Under this grant, the City, with the assistance of the consulting company Kleinfelder, is to:

1. Assess the current asset inventory and condition for their water, stormwater and wastewater assets
2. Develop a risk-based prioritization process that will allow the City to compare assets from the different systems and their needs
3. Identify system recommendations and formalize a 5-year capital plan
4. Assist the City with the selection of an Enterprise Asset Management Software
5. Document the process and findings in the form of an asset management plan.

This document constitutes the first Asset Management Plan (AMP) for the sewer system. It is accompanied by the Water System AMP and the Stormwater System AMP. Each of these documents can be read independently of each other. However, they all share a common risk framework, which is explained in section 6. The common framework will be used in the future to compare needs arising from the different assets.

# 2 Business Overview

The City of Medford owns and maintains a sewer collection network that conveys wastewater to the MWRA collection system. The sewer infrastructure consists of the following assets:

| System | Pipeline (mi.) | Nodes | System Replacement Value |
|---|---|---|---|
| **Sewer** | 120 | 3,400 manholes | $209 million[1.] |

Note:
1. Value estimated does not include manholes or pumping stations, only sewer mains.

To maintain and ensure the reliability of these assets, the Water and Sewer Division typically conducts the following activities related to the sewer system:

- Sewer manhole inspection
- Sewer manhole repair
- Maintenance of sewer laterals
- Repair of sewer pipe breaks

- Relining of sewer pipe
- Replacement of sewer pipe
- Installation of new sewer connection
- Coordination and supervision of sewer pipe inspection projects

Under this phase of work, the City identified an Asset Management Software product that helps the Water and Sewer Division conduct the tasks listed above efficiently. The City evaluated the products based on type of activities typically conducted by the Division staff and the IT infrastructure and resources available to the City. They cited the following characteristics as critical for the preferred software:

- Can integrate with ESRI's GIS technology
- Is a subscription-based online application
- Requires no additional licensing for products other than the asset management software and, at the most, ArcGIS Online
- Has a desktop and a mobile interface to support planning and dispatching tasks, and field tasks
- Accepts any types of assets at no additional cost
- Offers reliable technical support
- Is easy and user-friendly

Other preferred (but not essential) characteristics are:

- Integrates with See-Click-Fix
- Integrates with Micro-Paver or specific pavement-management capabilities
- Has resource or storage inventory capabilities

The City invited software demonstrations from three different vendors and interviewed current users for feedback regarding their experience with the software in terms of:

1. Implementation;
2. Satisfaction with the product; and,
3. Satisfaction with technical support.

The three vendors evaluated were Cityworks, Dude Solutions and Cartegraph. A table outlining the specifics on the asset management selection process is presented in Appendix D. The City decided to acquire and implement Cartegraph as their asset management software. Implementation will start in mid-late 2020.

## 2.1 Next Steps for the City

To continue the implementation of the asset management program we recommend:

1. Finalize the list of activities from the Water and Sewer Division to be implemented in the asset management software, with their corresponding fields, default values, drop-down menus, recurrence settings, etc. This can be done by reviewing the preliminary work order dictionary

provided by Kleinfelder to the City, and by reviewing the library of work orders and forms available from Cartegraph.
2. Configure the software for these activities.
3. Identify key personnel involved in the resolution of these activities, both from the dispatcher end (task assigner), and the resolution end (task assignee).
4. Start using the software for conducting the work.

This process might require a couple of rounds of configuration until the workflows are fully adopted by the City staff and 100% supported by the software. From there, to take the implementation further we recommend:

5. Configure operation management dashboards for each division head.
6. Configure reports.
7. Configure dashboards for level of service tracking.
8. Integrate software with other systems such as See Click Fix.
9. Expand the software with other modules, if necessary, such as fleet, or storeroom inventory.

# 3 Levels of Service

The term Levels of service (LoS) refers to the standards to which a service is delivered to the customer. LoS are a key component of an asset management program:

1. They allow for departmental performance assessment from actual data.
2. They help to convey information to stakeholders, justify expenses, measure return-on-investment and when requesting funds.
3. They help to identify areas of improvement, areas of over-performance and allocating resources optimally.
4. They help to align operations with departmental goals.

LoS have a definition, a performance measure, and a target. For sewer systems, LoS typically address customer satisfaction (e.g. “no sewer backups”), compliance with regulatory demands (e.g. “no sanitary sewer overflows”), and organizational (e.g. “Response time of 2 hours or less to an emergency break”).

The DPW hasn’t defined their LoS for their sewer system in this first AMP. This section is a placeholder for the upcoming years, for the DPW to 1) state their levels of service, with metrics and targets and 2) evaluate the DPW performance over time against those targets.

## 3.1 Levels of Service Recommendations

We recommend developing LoS next year and their corresponding tracking tools in the upcoming years, focusing on meeting regulatory compliance first. It is our understanding that sanitary sewer overflows (SSOs) are a concern for the City. Therefore, a suggested level of service is to set the goal of SSOs occurrences to zero per year.

# 4 Asset Inventory

Asset management starts with an inventory of the assets. It is important to know what you own and its condition to identify asset needs. Furthermore, once an asset management program is implemented, other information about the assets might reveal inefficiencies or other asset priorities. For example, an asset that still works but needs constant repairs may be more costly to the organization than a new one, or a critical asset that is obsolete, although still operational, could be too much of a risk for the City if it were to fail and no replacement part were available.

The sewer system inventory of assets is maintained in GIS format. The inventory consists of approximately:

- 3,600 sewer pipe segments (defined from manhole to manhole), representing 120 miles in length
- 3,650 manholes

A starting asset management program requires capturing some information about these assets, just to ensure that 1) the represent the actual inventory or asset portfolio accurately, 2) their value is captured correctly, 3) their estimated replacement date is calculated correctly, and that 4) operations against those assets are supported by the system (for example, knowing the diameter of the pipe before replacing the pipe). Different asset types require storing different information. The information collected about the assets is usually compiled over time, as work is accomplished in the system. The information about assets is stored as part of the attribute table in the GIS. The fields names and data types in each feature class in the database constitutes the database schema.

Sewer pipes are the principal asset type of the sewer system (since there is no treatment facility). At a minimum, the sewer pipe feature class (or database) should contain the following information:

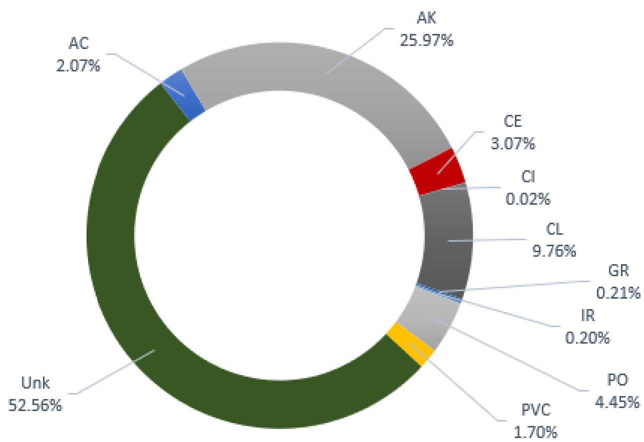
- Location and length (given by the geometry and the accuracy of such, in GIS)
- Material
- Diameter
- Year of installation

A secondary set of attributes to further enhance the sewer pipe inventory should capture:

- Whether the pipe is lined or not and when it was lined
- Capacity
- Typical flow
- Depth
- Upstream structure or manhole
- Downstream structure of manhole
- Condition (as PACP quick rating code)
- Condition date

## 4.1 Data Gap Analysis

The sewer pipes feature class was inspected to assess data gaps regarding material, diameter and year of installation, which are the basic fields needed for estimating future replacement costs. About 53% of the system (by length) had missing material, and 17% of the system had missing year of installation. The diameter data is essentially complete, with only 0.55% missing data. Most of the system is composed of 8-inch pipe.




Values:
AC - Asbestos cement
AK - Akron Clay Pipe
CE - Cement
CI - Cast iron
CL - Clay
GR - Granite
IR - Iron
PO – Portland Cement
PVC – Polyvinyl-Chloride
UNK - Unknown

*Figure 1: Distribution of materials (percent by length)*

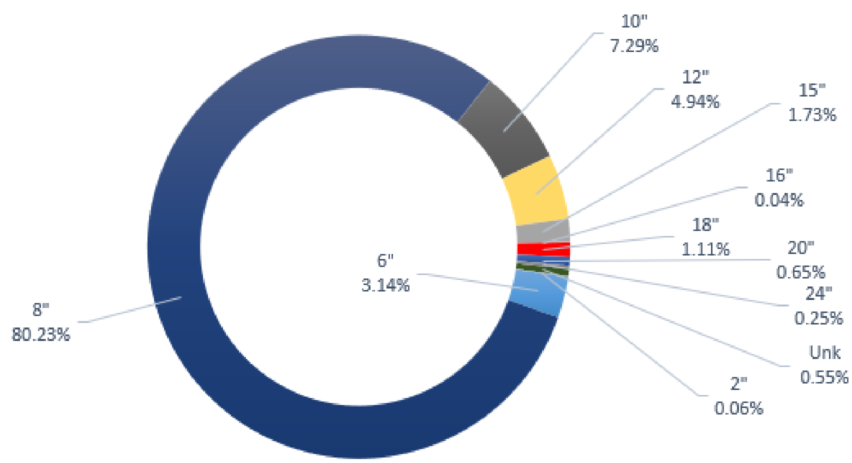



*Figure 2: Distribution of diameters (percent by length)*

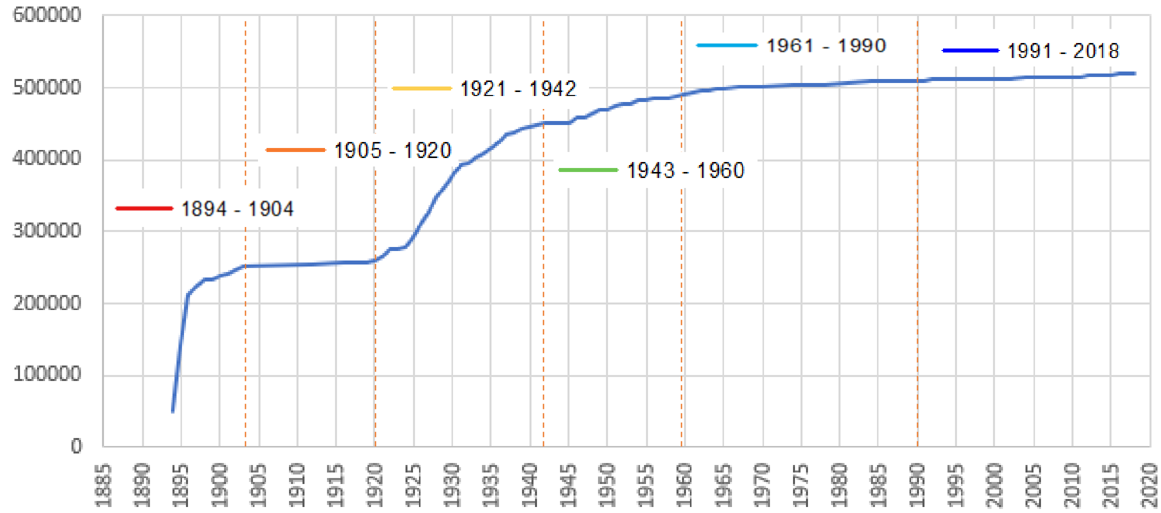



*Figure 3: Distribution of year of installation from raw data (oldest pipe from 1894)*

The data indicates a good portion of the system being built in the late 1800s, and a second period of growth starting around 1925 through 1940s and 1960. From 1965, there has been a steady slow growth of 500 feet per year on average.

Some of the data gaps, especially material, were addressed using data from past CCTV inspections records, where material was indicated. To our knowledge, Akron was a manufacturer of vitrified clay pipe (VCP), and all pipes with that material were considered in the simulation model as VCP. The majority of those were installed between 1894 and 1900, with 52% of all Akron pipe dating back to 1895.

Asbestos cement (AC) pipe values were left as such. About 1,500 feet of pipe have asbestos cement as material and year of installation of 1916 or earlier. These segments would need to be reviewed to adjust either the material or the installation year, since it is unlikely that that material was used so early on. Most AC pipe has unknown installation year (about 18%). Aside from these, the most common year of installation for this material was 1955. About 40% of the total AC pipe were installed between 1950 and 1970. For this reason, pipes with unknown material and year of installation between 1950 and 1970 were assigned AC as material in the risk and financial model.

Cement pipe values were left as such, but Portland Cement was reported as cement pipe. The majority of cement pipe has installation year of 1896. Cement pipe represents only 7.7% of the total. Iron pipe was reclassified as ductile iron pipe.

Unknown material was reclassified as VCP if the year of installation was before 1950, as AC for those installed between 1950 and 1970, and as PVC for those installed after 1970. The majority of PVC pipe was installed in 1983.

Pipes without year of installation nor material that were connected to a pipe segment that had that information were assigned the data from the connected segment. The rest were assigned VCP as material and 1921 as the year of installation, as these are the most common material and year, respectively, within the system. Figure 4 shows normalization between the raw data (received from City) and the adjustments made for purposes of modeling ("Clean" data). Once categories of pipe were normalized according to the categories, the data was able to be consolidated into fewer categories, which made the application of the Risk Framework easier to apply.

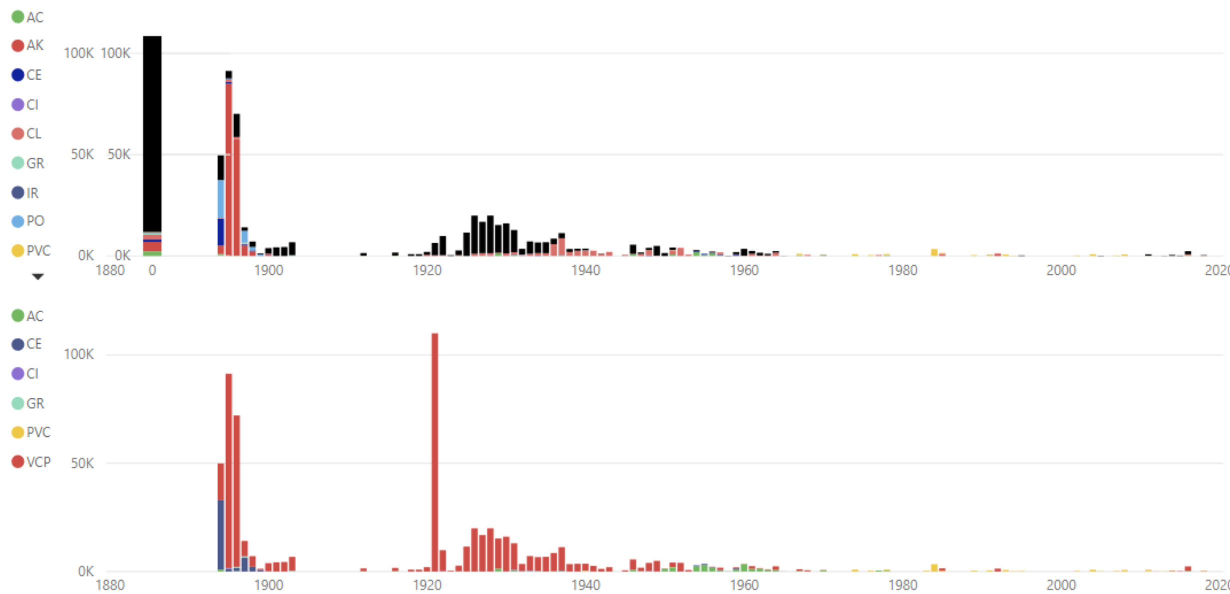



*Figure 4: Comparison between raw and clean data*

An important aspect of any sewer system GIS is the connectivity of the system. This is particularly important if there are infiltration and inflow issues that require a detail analysis. For the purpose of this AMP, connectivity was used to calculate the order of a segment within the network, defined as the number of branches that contribute to that segment. The review of the system connectivity revealed some areas with connectivity issues, which are highlighted in Figures 5 and 6.

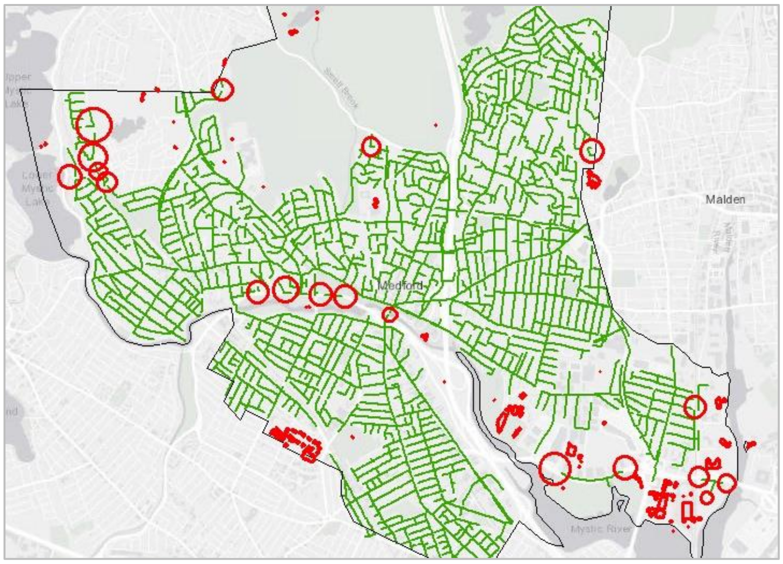



*Figure 5: Sewer System Areas with Connectivity Issues (highlighted in red)*

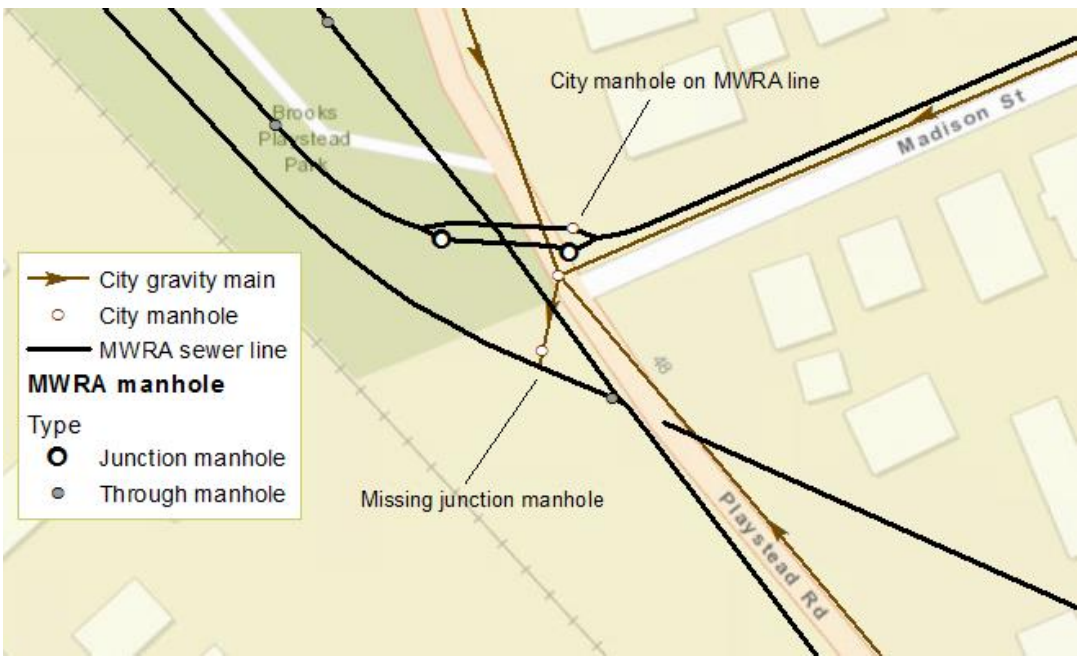



*Figure 6: Example of connectivity issues*

### 4.1.1 Data Recommendations

The sewer system's data could be improved by:

- Addressing the data gaps to the extent possible by reviewing record drawings, particularly material information, since this is missing in about 50% of the system.
- Reviewing record drawings to ensure connectivity of the network is accurate. This is important to create contributing areas or sewer system areas that convey flow into a given connector to the MWRA system.
- Reviewing sewer system subareas.

- Facilitating field data collection so that information about material can be entered from the field during maintenance activities.
- Maintaining a dynamic GIS system that is updated regularly.
- Adding feature classes such as laterals.

## 4.2 Condition

### 4.2.1 Condition Data

Condition is an important aspect of asset management since it serves the purpose of assessing the remaining useful life of the assets. Regulations may also require periodic inspections of certain asset types (for example, tanks). In addition, condition assessment and tracking can help streamline operations by providing data on the performance of assets and therefore the appropriate frequency for maintenance.

There is some condition data available from CCTV inspections conducted between 2011 and 2017. Independently of the actual status of the pipes inspected, the condition data available represents roughly 10% of the entire system, although only 8% have assigned PACP data. Similarly, only 400 manholes from the 3,653 (11%) manholes in the GIS had a condition rating, with no associated inspection date nor details regarding the scoring system used.

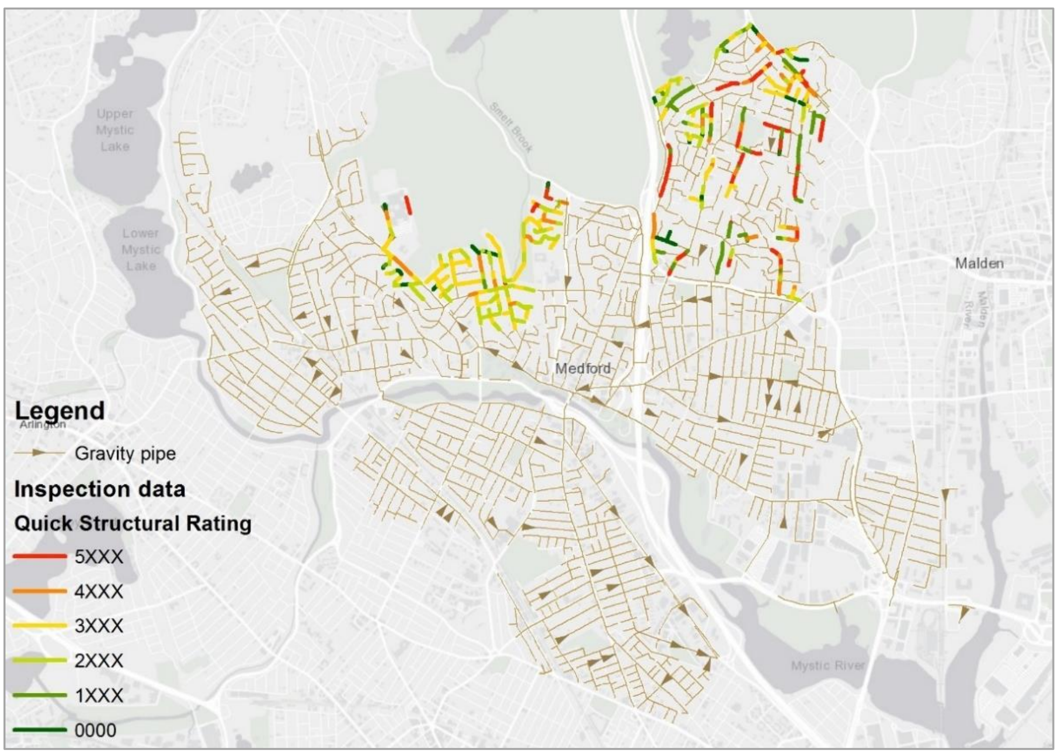



*Figure 7: Condition data available for the sewer pipes*

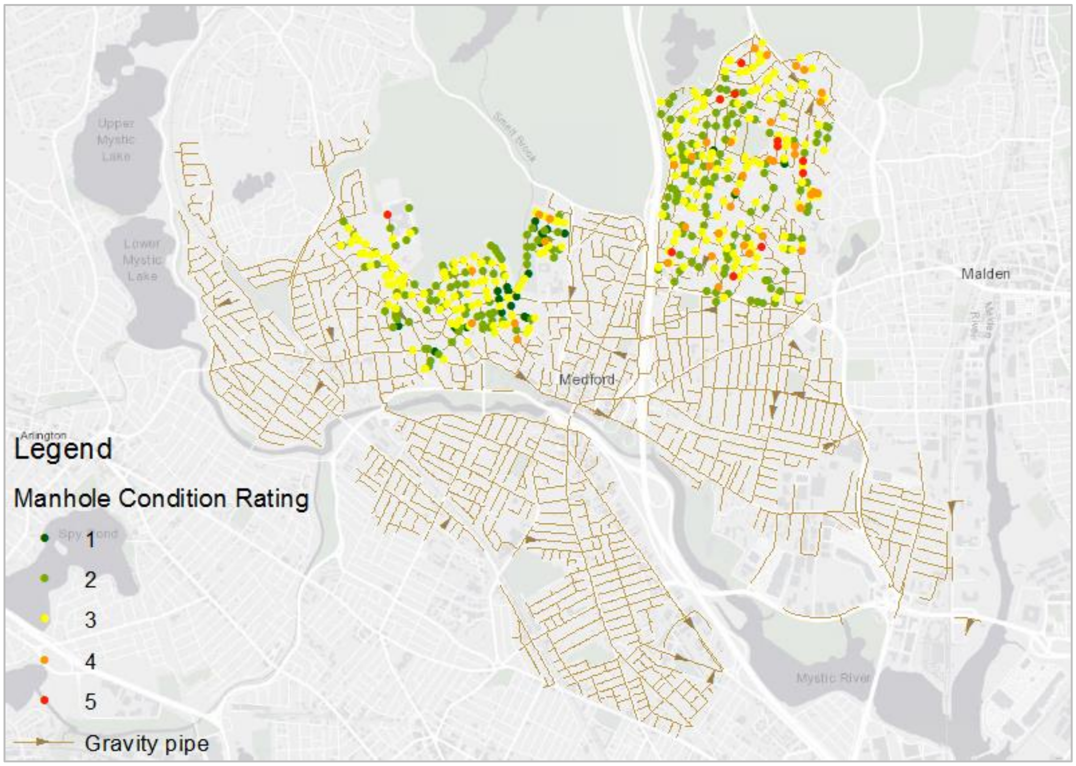



*Figure 8: Condition information available for the sewer manholes*

As depicted in the figures above, the condition information available is clustered in two areas of the system, on the northeast and center-north part of the City.

An additional set of inspection data was provided by the City to be integrated in this AMP. This dataset contained ratings from 1 to 5 for all segments included in the previous set plus 80 additional pipe segments from the same areas depicted in Figure 7. This dataset, in GIS format, didn't contain details about how the final scoring was calculated nor when the inspection was performed, however, for the segments that had both sets of data, the ratings from this dataset showed consistency with the ratings obtained with the more detailed dataset (see Figure 9).

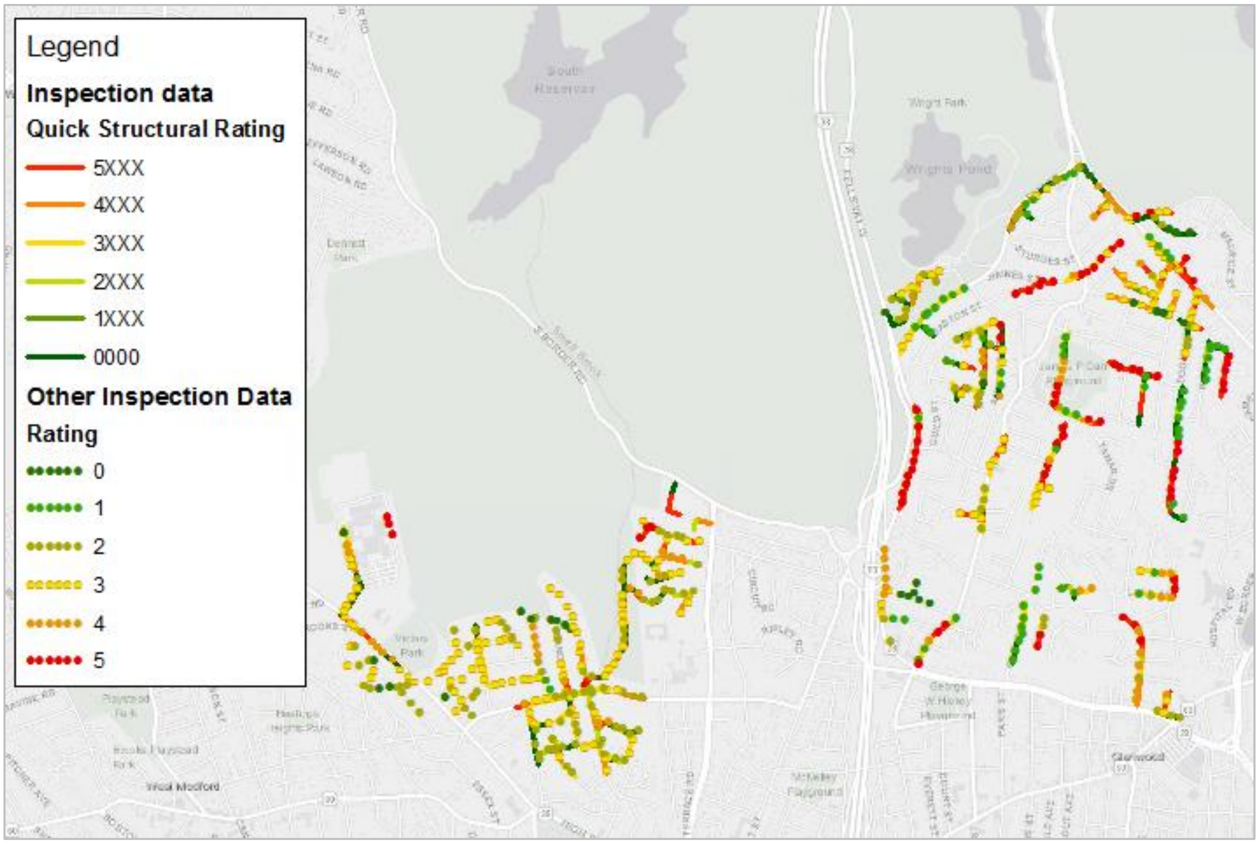



*Figure 9: Comparison between inspection data available*

### 4.2.2 Age and Service Life

According to the data provided, Medford's sewer system dates back to 1894, with most of the City's sewer dating before 1912. The inspection data available, being clustered in two areas of the City, is not representative of the oldest pipe segments, which represent most of the system. Figure 10 below displays the sewer system's age.

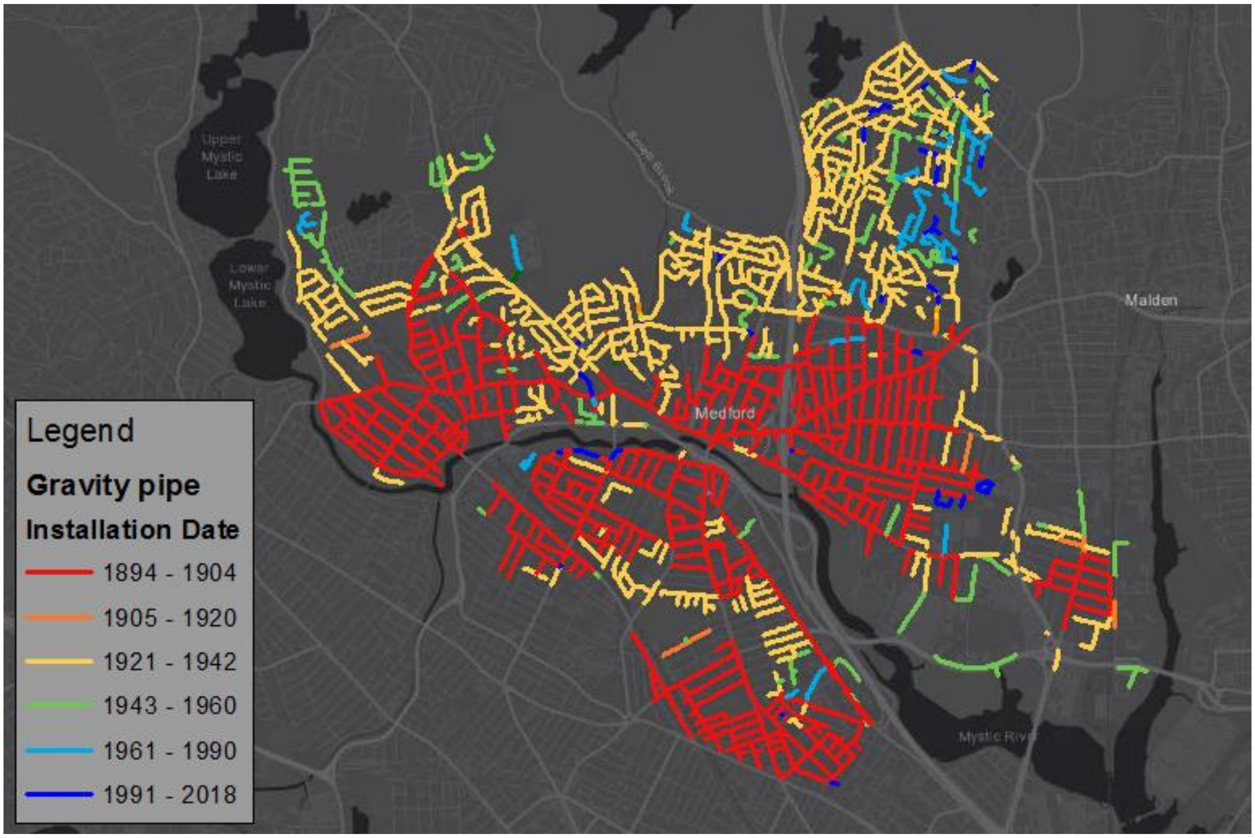



*Figure 10: Sewer System Age*

Considering that most of the system is composed of VCP, which can have a service life of over 100 years, the age of the system should not be the driving force behind a replacement schedule. For the purpose of this analysis, we have considered an estimated service life of VCP of 150 years, which yields the following map of remaining useful life (RUL) across the city (see Figure 111). Most of the segments with RUL values of 5 years or less of remaining useful life have actually 0 years left, and correspond to asbestos cement, or cement pipes, which have a much shorter service life.

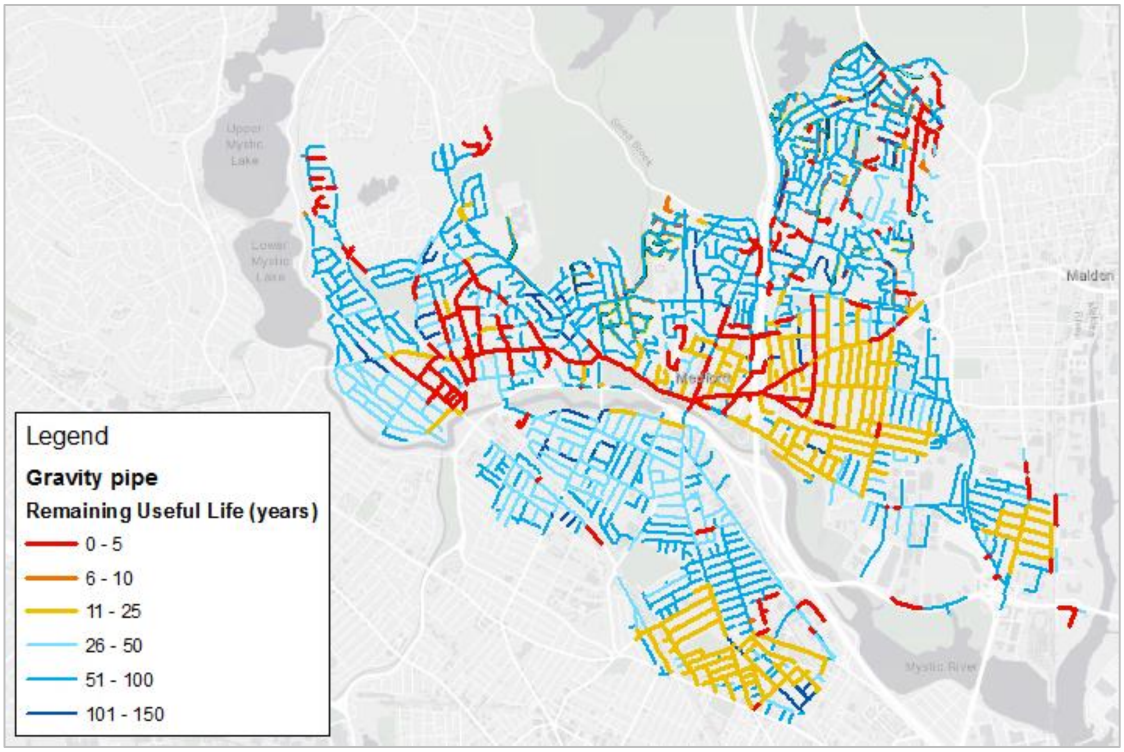



*Figure 11: Remaining Useful Life in Years of Sewer Segments*

### 4.2.3 Condition Recommendations

Having a good understanding of the condition of the sewer system is important for preventing unexpected asset failures that can have undesired consequences for the consumers, the environment, and the organization that maintains those assets. We typically recommend implementing a sewer condition assessment program that will allow for capturing information about the system on a 10-year basis. With a total length of the system of 120 miles, that means implementing a program that CCTVs the system at a rate of 12 miles per year. Since only 8% of the system has condition information available, however, we recommend implementing a more aggressive inspection program in this initial phase that would assess the system completely in 5 years, by inspecting 24 miles of pipe every year. The City has noted that they are have a 5-year CCTV inspection program planned.

# 5 Risk and Financial Forecast

Risk is represented by a numerical value that is used across all managed assets to prioritize their needs. Having a common risk framework across the entire asset portfolio of assets allows for comparison between different asset types.

Risk is defined as the likelihood of failure (LoF) of an asset[1] times the severity and extent of the negative consequences of that failure (CoF).

[1] Also referred to as probability of failure, however *likelihood* is more precise since it is not derived from a statistical analysis.

*Failure* occurs when an asset does not meet its desired or intended purpose. The ***likelihood of failure*** of an asset is the chance of the asset not meeting its intended use. To calculate risk, first we need to identify the ways an asset type might fail, also referred to as *failure modes*. These are specific to each asset type. Typical failure modes for VCP sewer mains are[2]:

- Structural failure, due to cracks, fractures, or the collapse of the pipe
- Operational failures due to sags in the line, deposits, roots, and infiltration, exfiltration of ground water and obstructions
- Joint failures, such as excessive angular deflection, pulled joints, parallel offsets and leakage

Failures in VCP are usually caused by loading, bedding system and foundation, and they will become evident in the first two years after construction. Excessive point loading or impact failure from third-party damage is also possible. Joints are the key weakness in clay pipes. Parallel offsets, pulled joints, excessive angular deflection, and leakage are the main joint failure modes of clay pipes. These joint failures may lead to root intrusions and infiltration and inflow (I&I), which eventually affect the hydraulic capacity and functionality of the pipe.

***Consequences of failure*** are the negative outcomes resulting from the failure of an asset. Consequences represent what is important to prevent. There are three main consequence factors which constitute the triple-bottom-line (TBL): social, environmental and economic although others can be considered (such as impacts to operations, or regulatory non-compliance).

The details about the failure modes and consequence factors for Medford's sewer system are presented in the following sections and constitute the framework for assessing risk for Medford's sewer pipes. This framework has been built side-by-side with the water mains framework and the stormwater framework, so that the City can eventually compare scores from different asset portfolios.

## 5.1 Medford's Risk Framework

Medford's risk framework uses a scale from 1 to 5 both for likelihood of failure and consequence factors, as shown in Table 1.

*Table 1: Risk Scoring System*

| Rating | Condition / Likelihood of Failure (LoF) | Consequence Factor |
|---|---|---|
| 1 | Excellent Condition / Minimal LoF | Insignificant |
| 2 | Good Condition – Low LoF | Minor |
| 3 | Acceptable Condition – Probable, or likely LoF | Moderate |
| 4 | Poor Condition – High LoF | High |

[2] Predicting the Remaining Economic Life of Wastewater Pipes. Phase I: Development of Standard Data Structure to Support Wastewater Pipe Condition and Performance Prediction. Sunil K. Sinha, Ph.D., Thiti Angkasuwansiri, Richard Thomasson. WERF, 2010

| | | |
|---|---|---|
| 5 | Out of Service, not operational – Failed, imminent failure | Very High |

With this rating system, risk scores range between 1 and 25, in a risk *space* as depicted in Figure 12.

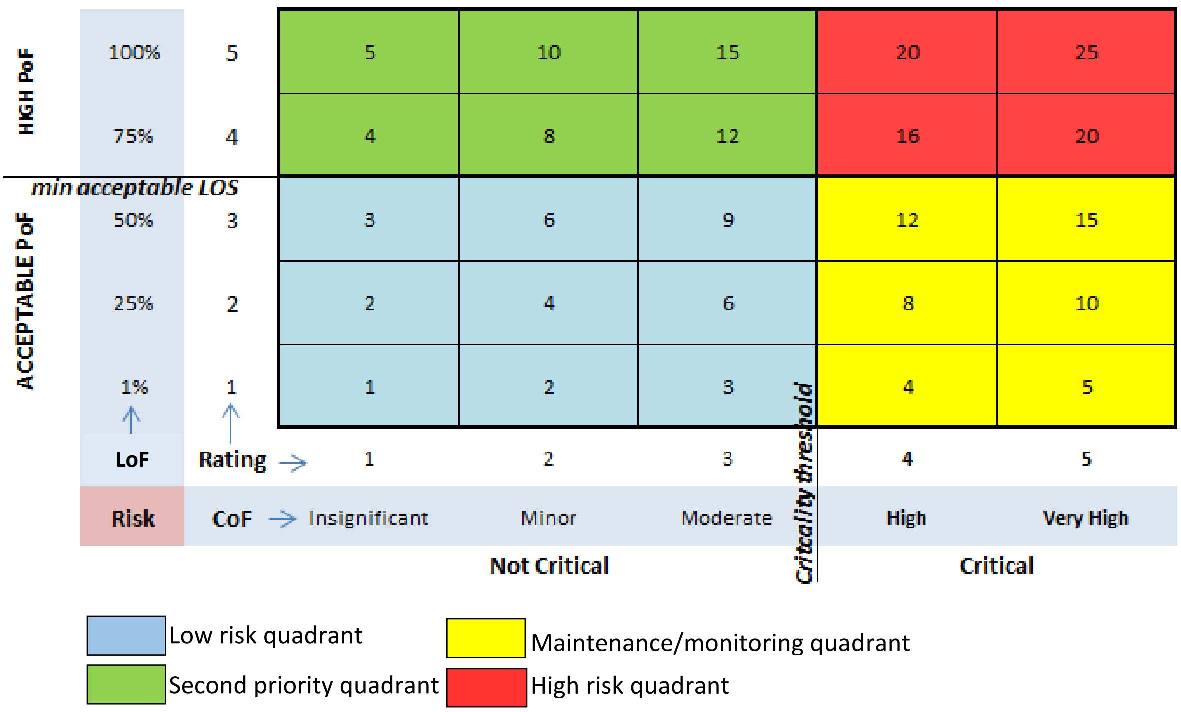



*Figure 12: Medford's Risk Space and Quadrants*

LoF threshold, and a CoF threshold divide the risk space in four quadrants. The LoF threshold represents the minimum acceptable LoS or maximum acceptable likelihood of failure. The CoF threshold represents the limit beyond which criticality is a concern. The top right quadrant, shown in red (Figure 12), is the *high-risk quadrant*. Assets that fall in this quadrant have a LoF greater than the threshold set by the minimum acceptable LoS and represent critical CoF. Assets in this category are the highest priority for repair or replacement.

Below this quadrant, in yellow, is the *maintenance and monitoring quadrant*. Assets that fall into this category have an acceptable LoF but have high consequence. As time progresses and assets deteriorate, the LoF of the assets will increase, and the asset risk score might eventually fall in the high-risk quadrant. For this reason, assets that fall into this category need to be maintained and monitored regularly.

The top left quadrant, in green, corresponds to the assets that have LoF above acceptable levels, but are not critical. These are the *second-priority* items (also referred to as the "Important" quadrant).

Finally, the bottom left quadrant, in blue, corresponds to the assets with acceptable LoF and low criticality: the *low-risk quadrant.*

Note how assets in the maintenance and monitoring quadrants and assets in the second-priority quadrants may have the same risk scores but will need different risk management strategies since the causes of the high-risk values are different.

The next sections outline the methodology to evaluate the LoF scores and the CoF scores.

## 5.2 Likelihood of Failure

This framework considers two **Failure modes**: Failure modes that affect the physical integrity of the asset, and failure modes that affect their capacity.

Physical Integrity, a measure of the "general condition of the pipe", is measured using two proxies:

- **Remaining useful life (RUL):** Calculated as percent of years left from the pipe's estimated service life (ESL), which is assigned to each pipe segment based on its material, according to the following equation.

$$RUL = \frac{ESL - Age}{ESL}$$

  The table below shows the approximate total length (in percentage of total feet) of each material and the approximate ESL for each material type. For the City of Medford, approximately 86% of the sewer pipe is Vitrified Clay Pipe (VCP), which carries a service life of 150 years. Based on the year of installation of a segment, the RUL can be calculated.

*Table 2: Estimated Service Life (ESL) of Sewer Pipes*

| Type | ESL (years) | Total length |
|---|---|---|
| AC | 50 | 4.20% |
| CE | 100 | 7.51% |
| VCP | 150 | 85.91% |
| PVC | 75 | 1.95% |
| CIPP | 75 | 0.00% |
| DI | 100 | 0.20% |
| CI | 100 | 0.02% |
| GR | 100 | 0.21% |

- **Condition**: As administered by the National Association of Sewer Service Companies (NASSCO), the PACP (Pipeline Assessment Certification Program) is the North American Standard for pipeline defect identification and assessment, providing standardization and consistency to the methods in which pipeline conditions are identified, evaluated and managed. Condition ratings are calculated from the PACP Quick Structural Rating (QSR). The QSR is a 4-character rating system - ABCD- where A indicates the highest severity of the defects found, B indicates the number of point defects with that severity (for longitudinal defects, it is the equivalent number of point defects), C is the second greatest level of severity found and D the number of defects with that severity (e.g. 4527 indicates 5 defects of severity 4, and 7 defects of severity 2). Severity ranges between 1 and 5. When the number of defects is greater than 9, a letter is used for quantifying (A: 10-13 defects, B: 14-17 defects... etc.). The QSR is then transformed to a 0-100 metric, using the formula: 100 x (90-(A*B+C*D))/90, which assumes that the worst-case scenario would be 5*10+4*10=90. This factor will be used in the future as the City progresses conducting inspections.

Both RUL and Condition were used in this year's CIP however only 8% of the system had condition information available.

Capacity:

- **Loss of capacity due to obstructions**: This factor was not used this year because most of the inspection data available is not recent and we believe that issues regarding obstructions were addressed after the inspections (database indicated cleaning activities performed on the pipes). This factor will be used in the future as the City progresses conducting inspections.

There are other proxies that can be used in the future to assess capacity, such as freeboard, for example. These might require a hydraulic model, or some other data sources or means of measure.

## 5.3 Consequence Factors

**Consequence** factors, or the negative impacts of a failure, are grouped in two categories: social impacts, and financial impacts. Environmental impacts were not considered for this year's AMP, although they should be considered in the future.

Social impacts represent impacts to the public including health and safety, and loss of service. They are estimated based on:

- **System criticality**: This is defined by how important the pipe segment is as part of the system. For this factor, we used the order of the pipe segment within the network as a proxy (see Figure 13 below).

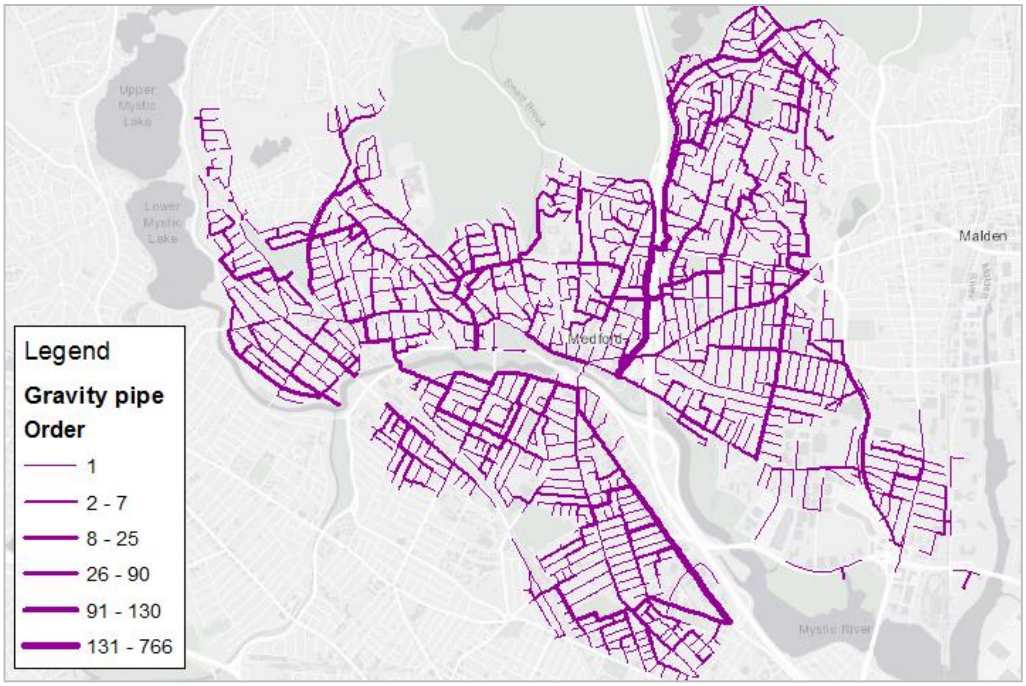



*Figure 13: Order of Magnitude of Medford's Sewer Network Pipes*

- **Customers affected**: This is represented by the land use or the use of the parcel closest to the pipe. The user might give more weight to pipes that service schools or wellness centers than to other land uses.

We modeled financial impacts based on how neighborhood development density that the pipe services (**population density**). This is based on census track information. The metric for this factor is the relative density to Medford's average at the City level, for each census block group. We assigned this value, calculated for each block group, to each pipe segment based on location. The process was as follows:

1. In ArcMap we calculated the City's average population density by dividing the total population by the City's area, based on Census data of 2010
2. In ArcMap, we calculated each census block group population density by dividing their corresponding populations by their areas, using GIS
3. In ArcMap, we calculated the relative population of each census block group to the City's average by dividing the density of each block by the average density of the City.
4. We assigned this last result to each pipe segment by performing a spatial join in ArcMap based on the location of the center of the pipe segment.

Neighborhoods that have Medford's average population density ±25% (so, between 0.75% and 1.25% of the City's average) have a score of 3 (average). Assets in neighborhoods with less than 50% of the population density have the lowest consequence score, and assets in neighborhoods that have twice or more of the average density get the highest score.

The final consequence of failure score is calculated as the weighted average of the scores obtained for each consequence factor. The weighs applied to each factor are model parameters and may be changed by the user. These rules and scoring system for this risk framework are presented in Appendix E - Risk Framework.

The risk framework gives us the rules and exact math needed to calculate risk scores, which are then used to prioritize assets. The next step is to determine what happens to each pipe segment. Does it need to be replaced? Rehabilitated? Inspected? This requires another set of rules that are explained in Section 5.4.3, Decision Model. To effectively calculate risk, preliminary actions, and costs for each pipe segment, Kleinfelder developed a numerical model in Excel that uses the data available at the segment level (length, material, diameter, age, condition, etc.) and user-input parameters such as unit costs, ESLs, budget, etc. to create a list of action items and costs which will constitute the CIP. The mechanics of this model are explained in this section, and the results obtained are explained in Section 5.5.

## 5.4 Sewer Model

Kleinfelder developed a risk-based model for the sewer system that calculates risk scores based on the GIS data available. The model, in Excel, allows for the user to modify some parameters so that the results of the model are representative of the system.

The model performs the following calculations for each sewer main segment:

1. Cleans data-gaps
2. Assigns Estimated Service Life (ESL) based on material
3. Calculates age from today's date and the segment's year of installation
4. Calculates Remaining Useful Life (RUL) based on age and ESL
5. Calculates percent life left from RUL and ESL
6. Calculates LoF based on Percent Life left
7. Transforms QRS ratings to 0-100 condition scale
8. Adjusts condition to current year (or year of analysis) using deterioration curves
9. Calculates LoF based on condition data
10. Calculates final LoF
11. Calculates consequence factors scores for system criticality, customers affected (land use), and population density
12. Calculates a final CoF score based on the three consequence factors used
13. Calculates risk
14. Calculates the corresponding risk box the asset belongs to
15. Calculates the corresponding priority the asset falls into
16. Assigns a preliminary renewal strategy based on decision model (see Section 5.4.3)
17. Calculates preliminary renewal or replacement costs
18. Creates list of CIP actions and assigns CIP year per segment
19. Allows for Action Override: the user might want to change the action selected by the software
20. Calculates final costs

### 5.4.1 Model Inputs

The model requires the following input data:

- Sewer pipe attributes from GIS (for each pipe segment)
    - AssetID or unique identifier
    - Material
    - Diameter
    - Street
    - Year of installation
    - Length
    - Land use associated with the pipe segment - from the assessor's database, based on proximity (closest to the segment centroid)
    - Population density associated with the pipe segment - from census data at the census block group level, based on census of 2010. Population density was normalized to average population density in Medford.
    - Most recent QSR and QMR ratings and their corresponding date
- Deterioration equations[3]
- Unit costs table
- Year of analysis (starting in 2018)
- Default values for missing data
- Prioritization matrix
- Consequence factors parameters and weights

### 5.4.2 Model Parameters

The user may change the model parameters and assess the sensitivity of the model to those. Cells in light yellow are model parameters. These are:

- **Start Year**: Start year is the starting year for the simulation. It is used to calculate the age of the pipe at the beginning of the simulation.
- **Year if Null**: Is the year assigned to those segments that are missing year of installation (after the data cleaning). The default value is 1921, as this is the most common year of installation for the sewer system.
- **Diameter if Null**: is the diameter assigned to those segments with missing diameter data (after cleaning). The default is 8 inches, as this is the most common sewer size.
- **ESL** for each material.
- **Unit costs:** unit costs for pipe replacement and lining by diameter. The costs assume that all segments smaller than 8 inches in diameter would be replaced with an 8-inch pipe.
- **Yearly Budgets:** amount allocated for renewal and replacement of the pipes for the 5-year plan.
- **System Criticality**: By changing the "to order" parameters, the user can define which segments get a rating of 1 (insignificant), 2 (Minor), 3 (Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. The percentages next to each category, which have a

[3] Deterioration equations were built using two linear equations for each material, representing the slow deterioration that occurs first, and a steeper deterioration rate that occurs later in the life of the asset. These equations were built based on best- known estimated service life data.

green bar conditional formatting indicate the percentage of the system that fall in each category. These are dynamic and change as the user changes the parameters. The default values for system criticality are displayed in Table 3, which indicates that 58.6% of the system has order of 1 (and corresponds to the consequence rate *insignificant*).

*Table 3: System Criticality Ratings*

| System Criticality | Weight | 65% | |
|---|---|---|---|
| **Conseq Factor** | **From Order** | **To Order** | |
| Insignificant | 1 | 1 | 58.58% |
| Minor | 2 | 7 | 25.31% |
| Moderate | 8 | 25 | 9.22% |
| High | 26 | 90 | 5.12% |
| Very High | 91 | 130 | 1.77% |
| | | | 100.00% |

The distribution above indicates that all first order segments constitute 58.58% of the system. Segments of order between 2 and 7 are 25% of the system.

- **Financial Impacts**: As explained in Section 5.1, financial impacts are represented by the density of population the pipe is servicing. Therefore, a failure in a high-density neighborhood can cause more disruption due to traffic and other factors than a break in a sparse area. The user can assign consequence of failure ratings based on population density, as displayed in Table 4 below. By changing the "to population density" parameter, the user can define what pipes get a rating of 1 (insignificant), 2 (Minor), 3 (Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. Population density is relative to the average population in Medford, so that a value of 0.5 means "half the average density" while a value of 2 means "twice the average". The default values are represented in Table 4.

*Table 4: Financial Impact Scores*

| Financial Impacts | Weight | 25% | |
|---|---|---|---|
| **Consequence** | **From Pop Dens** | **[To Pop Dens]** | |
| Insignificant | 0.00000 | 0.50000 | 7.40% |
| Minor | 0.49000 | 0.75000 | 5.03% |
| Moderate | 0.74000 | 1.25000 | 17.26% |
| High | 1.24000 | 2.00000 | 54.55% |
| Very High | 1.99000 | 3.85783 | 15.75% |
| | | | 100.00% |

- **Loss of Service**: As explained in Section 5, loss of service impacts are represented by the land use the pipe is servicing. Therefore, a failure in a school, or a residential parcel can cause more disruption than a break in a garage or industrial parcel. The user can assign consequence of failure ratings based on land use, as displayed in Table 5. Ratings are: 1 (insignificant), 2 (Minor), 3

(Moderate), 4 (High) and 5 (Very high). The user may also assign a weight to this criticality factor. The percentages next to each land use indicate the total of the system by length assigned to that land use. 82.2% of the system is residential, 5.3% is on vacant property and 3.1% is in retail.

*Table 5: Consequence Scores Associated with Land Use*

| Loss of Service | Weight | 10% |
|---|---|---|
| **Land Use** | **Consequence** | |
| Automotive Sales and Service | 1 | 1.2% |
| Charitable Services | 1 | 0.1% |
| Clubs/Lodges | 1 | 0.2% |
| DCR Park | 1 | 0.8% |
| Education | 4 | 0.9% |
| Fire Station | 3 | 0.1% |
| Garages | 1 | 0.1% |
| Government | 1 | 0.8% |
| Hospitals | 5 | 0.1% |
| Hotels | 3 | 0.0% |
| Industrial | 1 | 0.4% |
| Nursing Homes | 5 | 0.2% |
| Office Buildings | 2 | 1.5% |
| Open Space | 1 | 0.0% |
| Other | 1 | 0.0% |
| Religious | 1 | 1.3% |
| Residential | 3 | 82.2% |
| Retail | 2 | 3.1% |
| Utility | 1 | 0.0% |
| Vacant | 1 | 5.3% |
| Warehouses | 1 | 1.6% |
| Funeral Homes | 2 | 0.1% |
| | | 100.00% |

- **Likelihood of Failure**: the user might distribute condition ratings (from 0 being "failed" to 100, being "in Excellent condition") to likelihood of failure ratings, as displayed in Table 6. These can be based on percent life left, and on condition.

*Table 6: Likelihood of Failure - Input Parameters Table*

| Likelihood of Failure | | | |
|---|---|---|---|
| **Consequence** | **[% Life Left ]** | **[To Cond]** | |
| Insignificant | 25.0% | 95.0 | 51.22% |
| Minor | 15.0% | 85.0 | 34.69% |
| Moderate | 10.0% | 70.0 | 2.19% |
| High | 1.0% | 50.0 | 1.16% |
| Very High | 0.0% | 0.0 | 10.74% |
| | | | 100.00% |

According to the Table, 51.2% of the system gets assigned the lowest score for LoF, and 10.7% of the system would have the highest score of LoF (very high, or imminent failure).

- **Prioritization Matrix:** This is a 5x5 matrix that represents, as the risk matrix, the combinations of CoF (on the horizontal axis, from 1 to 5), and the LoF (on the vertical axis, from 1 to 5). The values of each cell correspond to the priority assigned to it. Since it is a 5x5 matrix, the values on these cells should be unique and range from 1 to 25. This matrix helps differentiate between cells that have the same risk scores. For example, Asset 1 and Asset 2 could both have a risk score of 8. Asset 1's score results from a CoF of 2 and a LoF of 4. Asset 2's score is due to a CoF of 4 and a LoF of 2. Which one takes priority? The priority matrix allows the user to define it. In this case, the Asset 1 would take priority over Asset 2 (see Figure 6-3).

**Risk Scores**

| | | | | | | |
|---|---|---|---|---|---|---|
| LoF | 5 | 5 | 10 | 15 | 20 | 25 |
| | 4 | 4 | 8 | 12 | 16 | 20 |
| | 3 | 3 | 6 | 9 | 12 | 15 |
| | 2 | 2 | 4 | 6 | 8 | 10 |
| | 1 | 1 | 2 | 3 | 4 | 5 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | | | CoF | | |

**Priority Matrix**

| | | | | | | |
|---|---|---|---|---|---|---|
| LoF | 5 | 17 | 10 | 5 | 2 | 1 |
| | 4 | 19 | 12 | 7 | 4 | 3 |
| | 3 | 21 | 14 | 9 | 8 | 6 |
| | 2 | 23 | 16 | 15 | 13 | 11 |
| | 1 | 25 | 24 | 22 | 20 | 18 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | | | CoF | | |

*Figure 14: Comparison between Risk and Priority*

The default setting for the prioritization matrix is depicted in Figure 15.

| | | | | | | |
|---|---|---|---|---|---|---|
| LoF | 5 | 17 | 10 | 5 | 2 | 1 |
| | 4 | 19 | 12 | 8 | 4 | 3 |
| | 3 | 21 | 14 | 9 | 7 | 6 |
| | 2 | 23 | 16 | 15 | 13 | 11 |
| | 1 | 25 | 24 | 22 | 20 | 18 |
| | | 1 | 2 | 3 | 4 | 5 |
| | | | | CoF | | |

*Figure 15: Prioritization Set for Medford's AMP*

- **Deterioration Function:** These equations are briefly used in this model. Their purpose is to bring outdated condition information to today's expected value, as if the asset had deteriorated over time. As explained in previous sections, condition comes from converting a QSR rating from its alphanumerical format to a numeric format in a scale from 1 to 100. Once that conversion is applied, then the condition values are lowered using two straight line deterioration functions as displayed in Figure 6-5. Obviously, the deterioration function needs to cross the point (0% , 100) – when an asset is new, which has 0% used life, and its condition is perfect (100), and the point (100% , 0) – when an asset has failed, reached the end of its useful life (100% used), and its condition is 0 (failed). The user then may define the vertex that will help shape the deterioration. In the figure below, this point is (80%, 80). That creates a shape for the deterioration that represents smooth decay where the pipe loses 20 points of deterioration over the first 80 percent of its lifetime, followed by an aggressive decay from thereafter where it will lose 80 points in the following 20% of its remaining life.

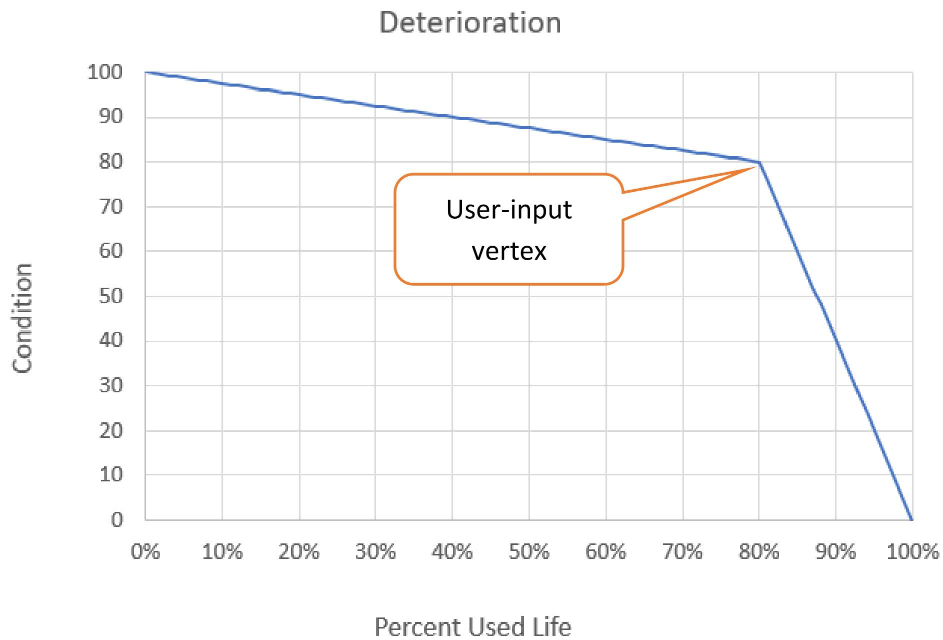



*Figure 16: Example Deterioration Function Curve*

### 5.4.3 Decision Model

The decision model is the algorithm or sets of rules that the model uses to assign rehabilitation strategies to each segment. Each strategy has an associated unit cost (per linear foot), which is used to calculate the cost of applying a given strategy to an asset. A summary of unit costs for sewer pipe is in Table 7. This is a ballpark cost since it is only based on length and diameter and doesn't take into considerations other factors such as permitting costs, depth of the pipe, traffic management and such.

The decision model considers the following strategies:

- Replacement – consists of replacing the entire segment for a new pipe of same diameter. This strategy has unit costs per linear foot associated. The unit costs used are presented in Table 7 and can be changed by the user.
- Lining – consists of lining the pipe using trenchless technology. This strategy has unit costs per linear foot associated based on cement lining. Note, that various lining technologies could be used.
- Spot Rehabilitation – Consists of repairing a point or linear defect on the pipe. This strategy has a unit cost per spot repair. The model generates random numbers between 1 and 5 for those pipes that have a LoF of 4 to estimate future repairs (just for forecasting purposes).
- Assess – Consists of inspecting (CCTV) and cataloging a pipe segment according to the PACP standards. This strategy has unit costs per linear foot associated.

- Flag for assessment – this strategy places a "flag" on a segment because it will likely need to be inspected in the consequent years. This strategy has no costs associated.
- Do nothing.

*Table 7: Unit Costs for Sewer Pipe*

| Diameter | Replace | Lining | Spot Rehab | Assess |
|---|---|---|---|---|
| 6 | $ 251.20 | | $ 2,500.00 | $ 1.50 |
| 8 | $ 321.60 | $ 90.00 | $ 2,666.67 | $ 1.50 |
| 10 | $ 392.00 | $ 100.00 | $ 2,833.33 | $ 1.50 |
| 12 | $ 370.00 | $ 110.00 | $ 3,000.00 | $ 1.50 |
| 14 | $ 425.00 | $ 120.00 | $ 3,166.67 | $ 1.50 |
| 15 | $ 403.00 | $ 130.00 | $ 3,333.33 | $ 1.50 |
| 16 | $ 427.20 | $ 140.00 | $ 3,500.00 | $ 1.50 |
| 18 | $ 485.60 | $ 150.00 | $ 3,666.67 | $ 1.50 |
| 20 | $ 534.00 | $ 160.00 | $ 3,833.33 | $ 1.50 |
| 24 | $ 630.80 | $ 170.00 | $ 4,000.00 | $ 1.50 |

The model uses the following logic to assign preliminary strategies for each segment:

1. If the LoF of a segment is 1 (minimal), then *Do nothing.*
2. If the LoF of a segment is 2 (low), *Flag for assessment.*
3. If the LoF is 3 (probable), *Assess.*
4. If the LoF is 4 (high), *Spot rehabilitation.*
5. If the LoF is 5 (failed or near failure), then if the diameter is less than or equal to 8 inches, *Replace*. Otherwise, if it has been lined before, *Replace*. If the pipe is bigger than 8 inches in diameter, but hasn't been lined before, then *Line*.

The model then creates the CIP action from the preliminary action so that only the segments that have been inspected maintain those preliminary actions. If the pipe has not been inspected, the CIP action defaults to Assess.

## 5.5 Risk Analysis Results

### 5.5.1 Likelihood of Failure

From the parameters and settings described above, the model first calculates LoF as a score from 1 (Insignificant, or very unlikely) to 5 (imminent failure). To do so, it calculates the LoF based on Remaining Useful Life (RUL, also referred to as percent life left) based of the user-entered settings, which reflect the values of the risk framework as indicated in Table 8. The values in this table indicate the lower limit of the bracket: All assets with RUL of 25% or more get an LoF score of 1 (*Insignificant*); all assets with a RUL between 15% and 25% get a LoF score of 2 (*Minor*), and so on.

*Table 8: Likelihood of Failure*

| Likelihood of Failure | [to RUL] | [To Cond] | |
|---|---|---|---|
| Excellent - Very Unlikey | 25.0% | 95.0 | 48.86% |
| Good - Unlikely | 15.0% | 85.0 | 34.33% |
| Acceptable - Moderate | 10.0% | 70.0 | 2.90% |
| Poor - Likely | 1.0% | 50.0 | 1.31% |
| Failed-Imminent | 0.0% | 0.0 | 12.61% |
| | | | 100.00% |

The model also calculates the LoF score from condition information (if available). For example, Quick Structural Rating (QSR) values are converted to a numeric value and "deteriorated" (as demonstrated in Figure 16) to estimate the degradation between the inspection year and current evaluation year (i.e. normalizing the condition rating to present day conditions, if inspections were done in the past). Then LoF values are assigned using the brackets of Table 8, which are also based on the risk framework. As with RUL, the values on the table indicate the lower limit of the bracket. Assets with condition ratings of 95 and above get an LoF of 1 (insignificant); assets with condition between 85 and 95 get an LoF score of 2 (Minor).

The results of the risk analysis show a nice distribution of the LoF, with 49% of the length having a LoF of 1. About 79,000 feet of pipe (12% of the system) have a LoF of 5, which indicates pipes that are near if not passed their service life (see Figure 17).

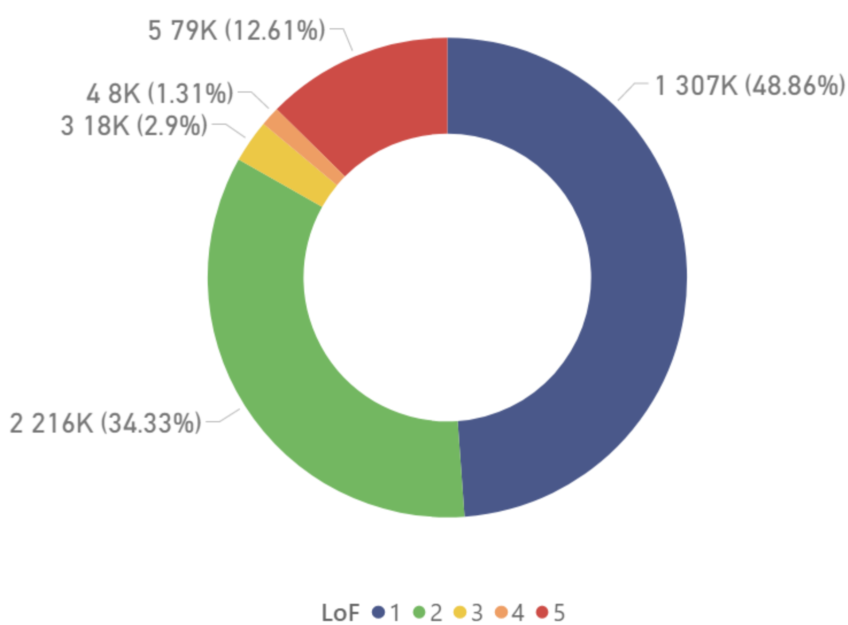



*Figure 17: LoF Distribution by Length*

As explained in Section 5.2, only 8% of the system had QSR ratings. The QSR data was used to calculate a LoF score for inspected data, which resulted to be well-distributed with condition ranging from excellent to very poor (see Figure 18). Since the decision model will identify either renewal strategies (replace, line or spot rehabilitation) for those segments with LoF 4 and above, we calculated the percentage of pipe that had LoF of 4 and 5 over the total length of pipe inspected as a guidance (see section 5.5.4). Of the 49,000 feet of segment that had QSR, 41.5% of those had LoF of 4 or above.

The final LoF score is calculated giving priority to condition data over RUL. Assets with QSR scores get the LoF from the QSR as their final LoF. Assets with non-NASSCO inspection ratings get those as their final LoF. The remaining assets get their scores from their RUL LoF. A summary of LoF scores can be shown geographically in Figure 19.

There was no correlation between age and condition or between RUL and condition.

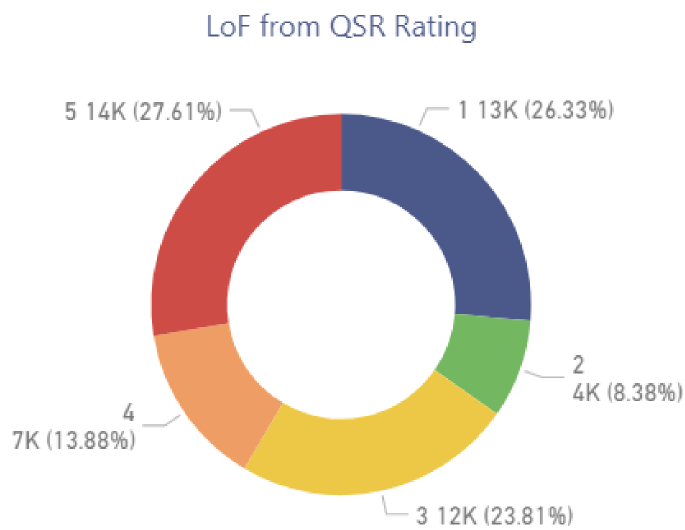



*Figure 18: LoF from QSR (based on 49,000 lf data available)*

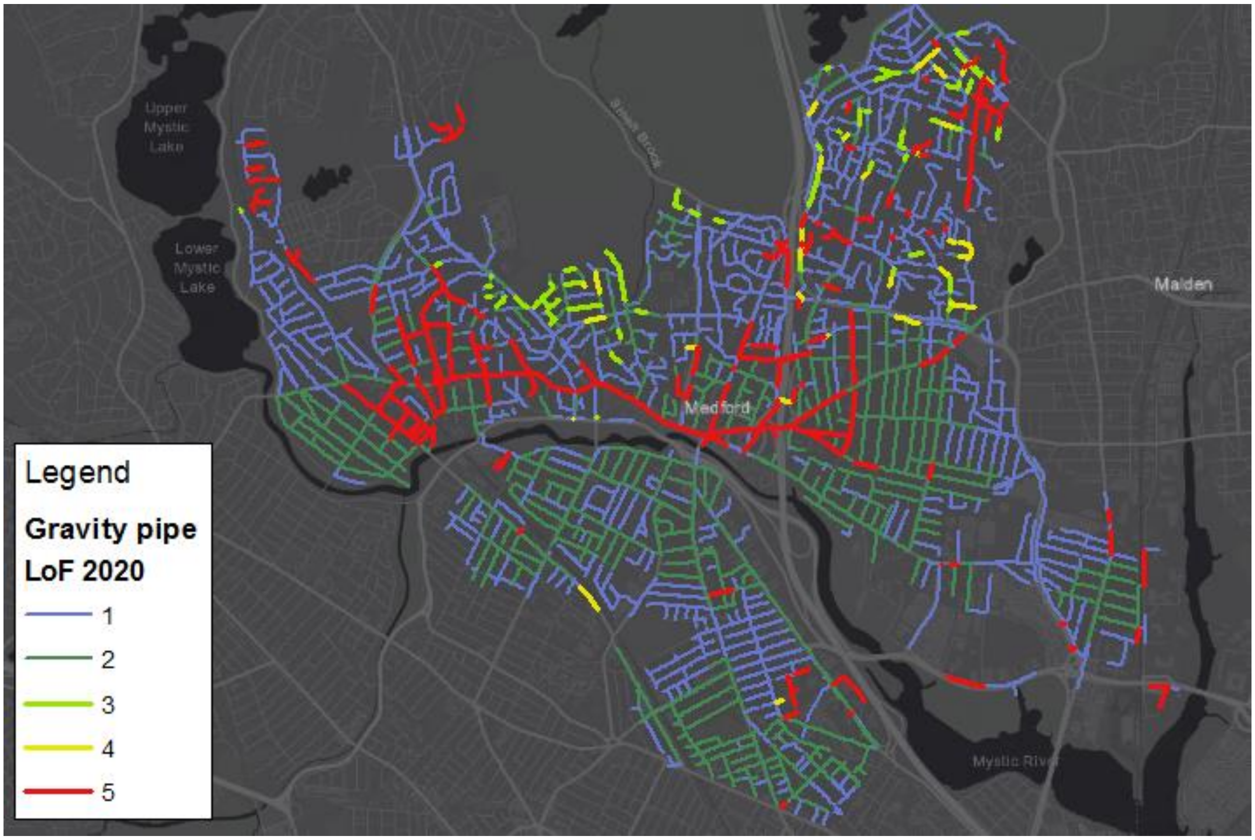



*Figure 19: Likelihood of Failure Map*

### 5.5.2 Consequence of Failure

The model calculates consequence failure (CoF) scores for each consequent factor and uses the weights indicated by the user through the interface to calculate the weighted average of the consequence factors, which is the final consequence score.

The model allows the user to set weight for the three consequence factors described in section 6.2. The default weights used were: 50% for system criticality (or order of the segment within the network), 35% for financial impacts (or population density), and 15% for loss of service (or land use).

The consequence of failure displays a not ideal distribution for prioritization, since most of the system is between CoF scores of 2 and 3 (see Figure 23). More intuitive is the distribution of the System Criticality Impacts, represented in Figure 20. The Consequence Factor Loss of Service, for which Land Use is the proxy, is very poorly distributed, with almost the entire system falling under category 3, which corresponds to residential areas and is shown in Figure 22. Figure 21 represents the Financial and Loss of Service impacts factored into the final CoF calculation, shown in Figure 23.

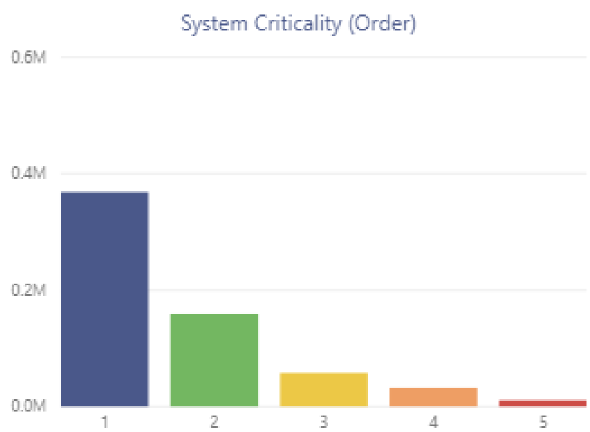



*Figure 20: Distribution of System Criticality Impacts*

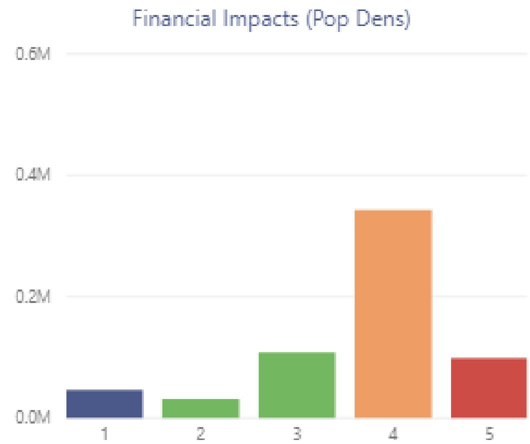



*Figure 21: Distribution of Financial Impacts*

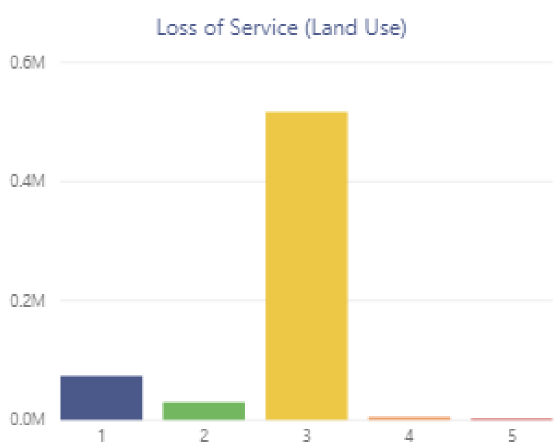



*Figure 22: Distribution of Loss of Service Impacts*


*Figure 23: Final Distribution of Consequence*

### 5.5.3 Risk

With likelihood of failure (LoF) and consequence of failure (CoF) scores calculated, the model then proceeds to calculate risk and express the results in terms of “Risk Box”, “Risk Score”, and “Priority”.

The **Risk Box** is the combination of CoF-LoF expressed as such. It indicates where the asset falls in the risk matrix. For example, an asset with risk box 4-2 has a CoF of 4 and a LoF of 2. This metric is important because it paints a very clear picture of where the system is as a whole, especially after adding the lengths of segments by their risk box and presenting the results in a risk-matrix format as displayed in Figure 24.

| LoF | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | 5,551 | 31,674 | 34,999 | 6,303 | 706 | 15.01 mi | 12.61% |
| 4 | 294 | 3,740 | 3,072 | 1,092 | - | 1.55 mi | 1.31% |
| 3 | 694 | 8,311 | 7,338 | 1,860 | - | 3.45 mi | 2.90% |
| 2 | 3,021 | 89,257 | 100,510 | 22,793 | 100 | 40.85 mi | 34.33% |
| 1 | 24,534 | 165,830 | 102,334 | 14,081 | 152 | 58.13 mi | 48.86% |
| CoF | 1 | 2 | 3 | 4 | 5 | | |
| | 6.46 mi | 56.59 mi | 47.02 mi | 8.74 mi | 0.18 mi | 118.99 mi | |
| | 5.43% | 47.56% | 39.52% | 7.34% | 0.15% | | |

*Figure 24: Risk Distribution by Length*

These results indicate that 706 feet of pipe fall in the highest risk quadrant (5-5). This risk matrix provides very useful information:

- Only 706 feet of pipe fall in the highest risk box (5-5)
  - These areas are located near City Hall: Salem St., City Hall Mall and I-95 Access Ramp.
  - These areas need to be inspected as soon as possible.
- Only 8,101 feet of pipe fall in the High-Risk Quadrant (boxes 5-5, 5-4, 4-5 and 4-4)
- There are 15 miles of pipe that have LoF of 5 - that is 12% of the system
- The majority of the system, 83% by length, has LoF of 2 or 1
- There are 0.18 miles of pipe that have a CoF of 5 and a total of 9 miles can be considered critical (CoF of 4 or 5)

We must emphasize that these results are very dependent on the age of each pipe – which depends on the year of installation, and on the ESL, which in this model, depends on the material. Given the data gaps discussion about missing data and ESL, we must acknowledge the uncertainty associated with the results.

### 5.5.4 Financial Results

The results obtained with the unit costs and decision model as defined in Section 6.3.3 follow:

1. With 119 miles of sewer pipe, the total replacement of the system is $209 million.
2. Considering that the average ESL of the system is 140 years, the average investment should be around $1.5 million/year. We consider this an "upper bound" of the average investment.
3. The preliminary costs identified by the model before overriding to "assess" the actions for those segments that did not have inspection data added up to $9.1 million. Although this number relies heavily on age and ESL versus condition, it provides another estimate of the investment needed, which, if distributed through a 10-year plan, yields $911K/year.
4. The cost for assessing the system entirely is $942,369. It is common practice to have an inspection program on a 10-year schedule, therefore, which would require an investment for condition assessment of $94K/year. However, given that there is condition information for only 8% of the system, we recommend implementing an inspection program that would complete the system in

5 years (inspecting at 24 miles/year, which would require $190K/year), and after that, proceed with a 10-year program.

5. From the subset of pipes already inspected, we determined that about 40% of those would require some sort of renewal strategy for having LoF greater than or equal to 4. To provide another way of assessing the minimum required investment in the system, we applied a factor of 50% to the renewal budget obtained for the pipes as they were inspected. For example, if you choose to inspect at a rate of 12 miles/year, you should dedicate $95K for the inspection plus $460K to address the issues found during those inspections (total of $555K). If you choose to inspect at 24 miles per year, you should dedicate $190K for the inspection plus $920K to address issues from the inspection ($1.11M total).

*Table 9: Estimated Annual Investment Options*

| Description | Estimate |
|---|---|
| Investment needed for sustainable renewal | $1.5 M/year |
| Preliminary system investment (results from model) | $ 0.91 M/year |
| Recommended Investment | $1.11 M /year (Years 1 - 5)<br>minimum of $555K /year after |

### 5.5.5 Recommendations Regarding Risk and Financial Forecast

With the risk framework developed, and after this first year of risk analysis, we recommend reviewing the framework and the analysis over time to incorporate failure modes that might prove to be relevant in the City. That type of information will become more evident as you capture information from daily operations and maintenance tasks in the asset management system.

As stated in previous sections, the quality of the data is very important to obtain significant results, and therefore we recommend minimizing the data gaps addressed in Section 5.1, and also implementing an inspection program for inspecting 24 miles of pipe every year. The inspection information will be useful not only to determine the status of a pipe segment, but also for assessing the service lives of the different materials, specifically for Medford, since they may differ from the typical ESLs found in the literature. The inspection information may also reveal failure modes that could be important and that were not considered in this first year.

In terms of consequence factors, we recommend reviewing the system connectivity, which will affect the *system criticality* score. Although this probably will not change the overall results of the model, it could change the specifics on a single segment, which could end up having a slightly different priority. The most benefit from addressing the connectivity will be to have well defined sewer sheds and a better understanding of the actual flow through the system.

The *financial impacts* consequence factor could also be updated in the future once the census of 2020 data is published, since that is the proxy used.

# 6 Renewal Items

Action items other than "assessment" included in the CIP are the ones related to the segments that had inspection data. Out of the 3,613 segments inspected, 106 had LoF greater than or equal to 4, which triggers a renewal treatment. Table 10 summarizes the activities identified for those segments.

*Table 10: Identified CIP Actions*

| Number of Segments | Length (feet) | CIP Action | CIP Cost |
|---|---|---|---|
| **71** | 12,089 | Line | $1,123,552 |
| **2** | 429 | Replace | $123,009 |
| **33** | 6,252 | Spot Rehab | $124,833 |
| **106** | **18,771** | | **$1,371,484** |

We propose distributing these actions over the first 3 years of the CIP (Table 11, Table 12, and Table 13). The action items have been prioritized based on risk as explained in previous sections. The ten-year summary table is found in Table 14.

*Table 11: CIP Actions - Year 1*

| PRIORITY | STREET NAME | CIP Action | CIP Cost |
|---|---|---|---|
| 2 | BENMOR STREET | Cement Line | $15,572 |
| 2 | GASTON STREET | Cement Line | $18,311 |
| 2 | GASTON STREET | Replace | $47,441 |
| 4 | ELLSWORTH STREET | Spot Rehab | $6,000 |
| 5 | BELLE TO WINSLOW | Cement Line | $29,092 |
| 5 | BENMOR STREET | Cement Line | $29,826 |
| 5 | CLEMATIS ROAD | Cement Line | $35,131 |
| 5 | DOONAN STREET | Cement Line | $53,747 |
| 5 | EAST BORDER ROAD | Cement Line | $24,905 |
| 5 | FELLS AVENUE | Cement Line | $32,396 |
| 5 | FULTON STREET | Cement Line | $4,563 |
| 5 | GROVER ROAD | Cement Line | $12,520 |
| 5 | HIGHLAND AVENUE | Cement Line | $48,720 |
| 5 | HUTCHINS ROAD | Cement Line | $8,942 |
| 5 | LAWRENCE ROAD | Cement Line | $15,452 |
| 5 | MCCORMACK AVENUE | Cement Line | $8,732 |
| 5 | SAUNDERS STREET | Cement Line | $26,675 |
| 5 | SAUNDERS TO ANDREWS | Cement Line | $9,226 |
| 5 | SCOTT STREET | Cement Line | $11,490 |
| 5 | WINTHROP STREET | Cement Line | $18,290 |
| **Total** | | | **$457,030** |

*Note: Cement line is shown as the potential CIP action; this indicates what was assumed at this time to determine CIP costs. Note, other types of lining / rehab could be employed.*

*Table 12: CIP Actions - Year 2*

| PRIORITY | STREET NAME | CIP Action | CIP Cost |
|---|---|---|---|
| 5 | BREWSTER ROAD | Cement Line | $10,650 |
| 5 | BREWSTER TO SAMSON | Cement Line | $10,872 |
| 5 | FULTON STREET | Cement Line | $28,389 |
| 5 | LINCOLN ROAD | Cement Line | $12,779 |
| 5 | LINCOLN TO HUTCHINGS | Cement Line | $29,800 |
| 5 | MCCORMACK AVENUE | Cement Line | $51,005 |
| 5 | MCCORMACK TO WATERVALE | Cement Line | $10,448 |
| 5 | PARK AVENUE | Cement Line | $13,924 |
| 5 | POWDER HOUSE ROAD EXTENSION | Cement Line | $13,216 |
| 5 | SAUNDERS STREET | Cement Line | $17,980 |
| 5 | WINTHROP STREET | Cement Line | $28,512 |
| 8 | AQUAVIA ROAD | Spot Rehab | $5,333 |
| 8 | BREWSTER ROAD | Spot Rehab | $5,333 |
| 8 | BREWSTER TO SAMSON | Spot Rehab | $2,667 |
| 8 | ELMS STREET | Spot Rehab | $2,667 |
| 8 | FELLS AVENUE | Spot Rehab | $16,000 |
| 8 | FULTON STREET | Spot Rehab | $2,833 |
| 8 | HIGHLAND AVENUE | Spot Rehab | $14,667 |
| 8 | LINCOLN ROAD | Spot Rehab | $2,667 |
| 8 | PARK AVENUE | Spot Rehab | $5,333 |
| 8 | SAUNDERS STREET | Spot Rehab | $2,667 |
| 10 | CLEMATIS ROAD | Cement Line | $20,442 |
| 10 | DOONAN STREET | Cement Line | $42,385 |
| 10 | FELLSWAY WEST | Cement Line | $11,551 |
| 10 | FULTON STREET | Cement Line | $26,594 |
| 10 | GASTON STREET | Cement Line | $14,420 |
| 10 | GROVER ROAD | Cement Line | $12,610 |
| 10 | HIGHLAND AVENUE | Cement Line | $22,065 |
| 10 | LOOKOUT ROAD | Cement Line | $18,523 |
| **Total** | | | **$456,332** |

*Table 13: CIP Actions -- Year 3*

| PRIORITY | STREET NAME | CIP Action | CIP Cost |
|---|---|---|---|
| 10 | BREWSTER ROAD | Cement Line | $15,590 |
| 10 | CARBERRY STREET | Replace | $75,658 |
| 10 | CEDAR CLIFF TERRACE | Cement Line | $23,969 |
| 10 | DAMON ROAD | Cement Line | $18,853 |
| 10 | DOONAN STREET | Cement Line | $11,094 |
| 10 | ELMS STREET | Cement Line | $15,750 |
| 10 | FULTON STREET | Cement Line | $7,270 |
| 10 | GASTON STREET | Cement Line | $33,372 |
| 10 | GREENHALGE STREET | Cement Line | $13,586 |
| 10 | HARRISON STREET | Cement Line | $11,055 |
| 10 | JEREMIAH CIR (OFF) | Cement Line | $12,881 |
| 10 | JEREMIAH CIRCLE | Cement Line | $15,469 |
| 10 | JOYCE ROAD | Cement Line | $9,226 |
| 10 | MCCALL STREET | Cement Line | $15,842 |
| 10 | MORGAN AVENUE | Cement Line | $15,384 |
| 10 | MORRISON STREET | Cement Line | $25,807 |
| 10 | RITA DRIVE | Cement Line | $47,592 |
| 10 | TUCKER STREET | Cement Line | $13,920 |
| 10 | UPTON TERRACE | Cement Line | $17,135 |
| 12 | CHARLEMONT ROAD | Spot Rehab | $5,333 |
| 12 | ELMS STREET | Spot Rehab | $2,667 |
| 12 | HIGHLAND AVENUE | Spot Rehab | $10,667 |
| 12 | HOLMES ROAD | Spot Rehab | $8,000 |
| 12 | LAWRENCE ROAD | Spot Rehab | $2,667 |
| 12 | LINCOLN ROAD | Spot Rehab | $8,000 |
| 12 | MACKLIN ROAD | Spot Rehab | $5,333 |
| 12 | PARK AVENUE | Spot Rehab | $2,667 |
| 12 | POND CIRCLE | Spot Rehab | $2,667 |
| 12 | SAMSON ROAD | Spot Rehab | $2,667 |
| 12 | TRAINCROFT NORTHWEST | Spot Rehab | $2,667 |
| 12 | WADDELL STREET | Spot Rehab | $2,667 |
| 19 | WINTHROP STREET (OFF) | Spot Rehab | $2,667 |
| **Total** | | | **$458,122** |

In addition to these, the inspection program recommended should include $190,080/year for inspection, for years 1 through 5, and $95,040/year for the following years. We estimate that for years 1-5 about $919,750/year would be needed to address issues found during the inspection, and from there, you would need a minimum of $459,600/year. This estimate will need to be adjusted as inspection data is available and we gain understanding of the actual condition of the system.

This schedule yields:

*Table 14: Forecasted 10-Year Capital Plan*

| | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|
| CIP Renewal: | $625,621 | $287,742 | $458,122 | $0 | $0 |
| CIP Inspection: | $150,802 | $191,491 | $190,462 | $193,698 | $186,023 |
| **Minimum Needed:** | **$776,423** | **$479,233** | **$648,583** | **$193,698** | **$186,023** |
| Renewal from Inspection: | $921,161 | $921,161 | $921,161 | $921,161 | $921,161 |
| **Potential Needed:** | **$1,697,584** | **$1,400,393** | **$1,569,744** | **$1,114,858** | **$1,107,184** |

| | 6<br>2026 | 7<br>2027 | 8<br>2028 | 9<br>2029 | 10<br>2030 |
|---|---|---|---|---|---|
| CIP Renewal: | $0 | $0 | $0 | $0 | $0 |
| CIP Inspection: | $94,382 | $94,571 | $94,878 | $94,988 | $87,907 |
| **Minimum Needed:** | **$94,382** | **$94,571** | **$94,878** | **$94,988** | **$87,907** |
| Renewal from Inspection: | $460,278 | $460,278 | $460,278 | $460,278 | $460,278 |
| **Potential Needed:** | **$554,660** | **$554,849** | **$555,155** | **$555,266** | **$548,185** |

The complete list of segments with corresponding actions by year is presented in an Excel spreadsheet accompanying this document.

# APPENDIX C:

# Stormwater System AMP

# Medford, MA
# Stormwater System
# Asset Management Plan

September 2020

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KLEINFELDER
Bright People. Right Solutions.

# Medford Stormwater System
# Asset Management Plan (SW-AMP)

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## Acronyms and Abbreviations

AMP: Asset Management Plan
AWWA: American Water Works Association
CIP: Capital Improvement Plan
CoF: Consequence of Failure
DPW: Department of Public Works
EPA: Environmental Protection Agency
GIS: Geographic Information System
gpm: gallons per minute
LoF: Likelihood of Failure
LoS: Levels of Service or Level of Service
MS4: Municipal Separated Storm Sewer System
NOI: Notice of Intent for Stormwater Discharges

# 1 Introduction

In 2019 the City of Medford's Department of Public Works was awarded an Asset Management Grant issued by the Massachusetts Clean Water Trust (the Trust). The awarded grant funds are to help the City kick off an Asset Management Program that will be first adopted by the Water and Sewer Division – which manages the water and wastewater assets - and the Highway Division for the stormwater assets. Eventually, the City's vision for asset management is to have a centralized system that can be used by other departments to also manage their pavement, park assets, trees, street lighting, vehicles (fleet), and signage.

Under this grant, the City, with the assistance of Kleinfelder, is to:

1. Assess the current asset inventory and condition for their water, stormwater and wastewater assets.
2. Develop a risk-based prioritization process that will allow the City to compare assets from the different systems and their needs.
3. Identify system recommendations and formalize a 5-year capital plan.
4. Assist the City with the selection of an Enterprise Asset Management Software; and,
5. Document the process and findings in the form of an asset management plan.

This document constitutes the first Asset Management Plan (AMP) for the stormwater system. It is accompanied by the Water System AMP and the Sewer System AMP. Each of these documents can be read independently, however, they all share a common risk framework. The common framework will be used in the future to compare needs arising from the different assets and consequently prioritize investments appropriately.

# 2 Overview

The City of Medford owns and maintains a 120-mile stormwater collection network that conveys stormwater to over 260 outfalls. The stormwater infrastructure consists of 8,200 segments of stormwater pipe, and over 3,300 stormwater manholes.

They have interconnections from the neighboring Towns of Winchester, and the Cities of Malden and Somerville as well as other state organizations such as Department of Conservation and Recreation (DCR), Massachusetts Department of Transportation (MassDOT), Massachusetts Bay Transportation Authority (MBTA), and private connections.

To maintain and ensure the reliability of these assets, the Highway Division typically conducts the following activities related to the stormwater system:

- Street Sweeping
- Catch basin repair, cleaning and inspection
- Stormwater manhole inspection and repair
- Repair of stormwater pipe breaks

- Installation of new stormwater connections
- Coordination and supervision of stormwater inspection projects

Under this phase of work, the City identified an Asset Management Software product that helps the Highway Division conduct the tasks listed above efficiently. The City evaluated the products based on type of activities typically conducted by the Division staff and the IT infrastructure and resources available to the City. They cited the following characteristics as critical for the preferred software:

- Can integrate with ESRI's GIS technology
- Is a subscription-based online application
- Requires no additional licensing for products other than the asset management software and, at the most, ArcGIS Online
- Has a desktop and a mobile interface to support planning and dispatching tasks, and field tasks
- Accepts any types of assets at no additional cost
- Offers reliable technical support
- Is easy and user-friendly

Other preferred (but not essential) characteristics are:

- Integrates with See-Click-Fix
- Integrates with Micro-Paver or specific pavement-management capabilities
- Has resource or storage inventory capabilities

The City invited software demonstrations from three different vendors and interviewed current users for feedback regarding their experience with the software in terms of:

1. Implementation;
2. Satisfaction with the product; and,
3. Satisfaction with technical support.

The three vendors evaluated were Cityworks, Dude Solutions and Cartegraph. A table outlining the specifics on the asset management selection process is presented in Appendix D. The City decided to acquire and implement Cartegraph as their asset management software. Implementation will start in mid-late 2020.

# 3 Levels of Service

The term "Levels of Service" (LoS) refers to the standards to which a service is delivered to the customer. LoS are a key component of an asset management program:

1. They allow for departmental performance assessment from actual data;
2. They help to convey information to stakeholders, justify expenses, and measure return-on-investment which rationalizes funding requests;
3. They help to identify areas of improvement, and areas of over-performance for optimal resource allocation; and,

4. They help to align operations with departmental goals.

LoS have a definition, a performance measure, and a target. For stormwater systems, LoS typically address customer satisfaction (e.g. “no roadway flooding”), compliance with regulatory standards (e.g. “no illicit discharges”), and organizational goal (e.g. “response time to an emergency break of 2 hrs. or less”).

## 3.1 Levels of Service Recommendations

Defining LoS for utilities is critical for assessing performance. It is important to know what the customers expect from the service for which they are paying, what the regulatory standards require, and what the *actual* performance of the system is. Utilities have the main purpose of servicing people efficiently while minimizing impacts to the environment. As such, LoS should be measurable and defined with the *triple bottom line* (TBL) in mind; that is, considering **social and economic as well as environmental demands**. LoS is most useful when defined with a long-term perspective. Reaching a sustainable LoS is the ideal for any utility.

LoS can be defined at the system level, and at the asset level, although at the asset level we refer to it is as *performance*. Factors considered for the LoS include regulatory compliance, reliability of service, availability of service, customer services, operations and maintenance, environmental impact, and cost. Under the TBL, these areas can be considered Health and Safety, Customer Service, Environmental, and Financial. Examples of such LoS include:

- Annual MS4 cleaning and inspection requirements
- Flooding event response time/surface flooding level
- Water quality benchmarking and monitoring
- Return on investment for drainage improvements

These LoS represent performance targets for each system that the City sees as important and reasonable to strive for. The LoS should be revisited annually to track performance and make adjustments to the LoS parameters as appropriate. As the program is more fully developed, the City may consider sharing or publicizing the LoS and performance results with its customers and other stakeholders.

During this first year of Medford’s Asset Management Program implementation, LoS was not defined at the system level for stormwater. We recommend developing LoS next year and their corresponding tracking tools in the upcoming years, focusing on meeting regulatory compliance first. In accordance with the City of Medford’s Municipal Separated Storm Sewer System (MS4) Permit, there are several items to be completed within the five-year permitting period. The following items can be tracked using the asset management software workflows and measured as a metric of LoS, as discussed in later sections.

- Catch Basin Cleaning
- Outfall Identification
- Outfall Sampling
- Manhole and Piping Inspection
- Public Education

- Disconnection of Storm Drains from Sewer or an Illicit Discharge Detection and Elimination (IDDE) program

As more data is compiled on these workflows, setting annual goals and appropriate LoS can be achieved.

# 4 Asset Inventory

Asset management starts with an inventory of the assets. It is important to know what you own and in what condition it is to identify asset needs. Furthermore, once an asset management program is implemented, other information about the assets might reveal inefficiencies or other asset priorities. For example, an asset that still works but needs constant repairs may be more costly to the organization than a new one; a critical asset that is obsolete, although still operational, could be too much of a risk for the City if it were to fail and no replacement part were available.

The stormwater system inventory of assets is maintained in GIS format. The inventory consists of:

- 8,212 stormwater pipe segments, representing 117 miles in length
- 3,033 manholes
- 4,674 catch basins
- 260 outfalls
- 57 Best Management Practices or treatment facilities
- 18 catchments
- 855 storm fittings, including tide gates, flap valves, and weirs

This project provided a Data Gap Inventory analysis to capture some information about these assets, just to ensure that 1) their value is captured correctly 2) their estimated replacement date is calculated correctly, and that 3) operations against those assets are supported by the system (for example, knowing the diameter of the pipe before replacing the pipe). Different asset types require storing different information. The information collected about the assets is usually compiled over time, as work gets done on assets. The information about assets is stored as part of the attribute table in the GIS. The fields names and data types in each feature class in the database constitutes the database schema.

At a minimum, the stormwater pipe feature class (or database) should contain the following information:

- Location and length in GIS
- Material
- Diameter
- Year of installation

A secondary set of attributes to further enhance the stormwater pipe inventory should capture:

- Whether the pipe is lined or not and when it was lined
- Capacity
- Depth

- Upstream structure or manhole
- Downstream structure or manhole
- Condition (as PACP quick rating code)
- Condition date

## 4.1 Data Gap Analysis

The City of Medford appears to have captured enough data to perform an initial assessment or Data Gap Analysis. However, there is not enough information to complete a comprehensive Risk Analysis or Financial Model based on the lack of detailed information required to complete the risk assessment.

### 4.1.1 Condition Data

Condition is an important aspect of asset management since it serves the purpose of assessing the remaining useful life of the assets. Regulations may also require periodic inspections of certain asset types (for example, catch basins or other stormwater BMPs). In addition, condition assessment and tracking can help streamline operations by providing data on the performance of assets and therefore the appropriate frequency for maintenance.

For pipe and inlet/outlet structures, there is limited or no condition data. For drain manholes, there is some condition data available from manhole inspections conducted between 2009 and 2017. Approximately 2,000 (70%) of manholes in the GIS had a condition rating, with a Good, Fair or Poor rating system (Figure 1). No NASSCO MACP standard ratings nor associated inspection follow-up information was included.

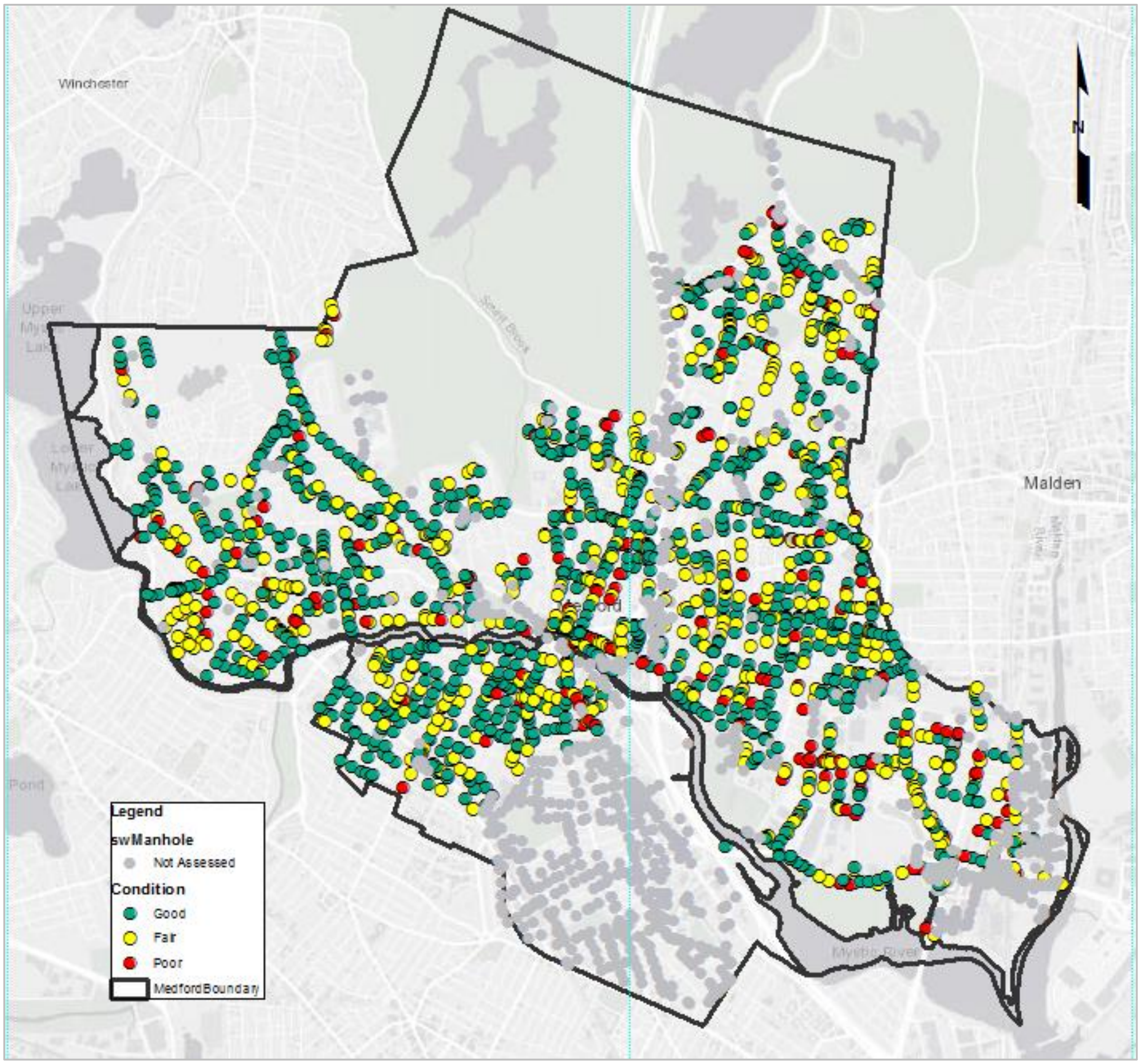



*Figure 1: Condition information available for the stormwater manholes*

As depicted in the figure above, the condition information available is outdated (over 10 years old) and several areas of the City remain uninspected. Poor conditions may have degraded further, and Fair or Good conditions may have lowered to Poor or Fair ratings since 2010.

### 4.1.2 Age Data

According to the data provided, Medford's stormwater system dates to 1959, in contrast with the City's sewer system dating before 1912. The inspection data available is limited and represents less than 10% of the entire piping system.


*Figure 2: Stormwater System Age*

Considering most of the system is composed of concrete, which can have a service life of 50 to 75 years, the age of the system should not be the driving force behind a replacement schedule. Therefore, focusing on collecting more condition inspection data will allow greater accuracy in estimating remaining useful life (RUL) across the city's stormwater system.

### 4.1.3 Data Recommendations

For MS4 compliance purposes, we recommend reviewing the requirements and incorporating the information needed for mapping and reporting in this geodatabase, since some activities that will be required by the MS4 permit and can be set-up in the asset management system. As part of this effort, we recommend:

- Fixing / completing the Asset ID (or FacilityID) for all features to be included in the asset management plan where this information is missing (not including fittings which will be accounted for with drain pipes);

- Reviewing system connectivity, including intermunicipal connections;
- Adding receiving waters (suggested feature classes in the Stormwater MS4 dataset);
- Adding integrated waters (suggested feature classes in the Environmental dataset);
- Completing inventory of BMPs for stormwater treatment (if needed);
- Creating initial catchment delineations for the outfalls (suggested feature classes in the Stormwater MS4 dataset);
- Categorizing Outfalls and MS4/Non-MS4, with priority ranking, and receiving water body in the GIS.

Having a good understanding of the condition of the stormwater system is important for preventing unexpected asset failures that can have undesired consequences for the customers, the environment, and the organization that maintains those assets. We recommend implementing a typical stormwater assessment program that will allow for capturing information on a 10-year basis. With a total system length of about 117 miles, the CCTV program will be conducted at a rate of 12 miles per year.

# 5 Risk

Risk is numerical value that is used across all managed assets to prioritize their needs. Having a common risk framework cross the entire asset portfolio of assets allows for comparison between different asset types. Risk is defined as the likelihood of failure of an asset[1] times the severity and extent of the negative consequences of that failure.

*Failure* occurs when an asset does not meet its desired or intended purpose. The ***likelihood of failure (LoF)*** of an asset is the chance of the asset of not meeting its intended use. To calculate risk, first we need to identify the ways an asset type might fail, also referred to as *failure modes*. These are specific to each asset type. Typical failure modes for concrete gravity mains are structural failures due to cracks caused by excessive external loading or corrosion[2]. As concrete is mineral based, softening of the pipe material can occur over time when in contact with certain water and soil types, including reacting with the reinforced rebar typically installed inside a reinforced concrete pipe (RCP).

***Consequences of failure*** **(CoF)** are the negative outcomes resulting from the failure of an asset. Consequences represent what is important to prevent. There are three main consequence factors which constitute the triple-bottom-line (TBL): social, environmental and economic, although others can be considered (such as impacts to operations, or regulatory non-compliance.).

## 5.1 Risk Framework

Medford's' risk framework uses a scale from 1 to 5 both for likelihood of failure and consequence factors, as shown in Table 1.

[1] Also referred to as probability of failure, however *likelihood* is more precise since it is not derived from a statistical analysis.

[2] Predicting the Remaining Economic Life of Wastewater Pipes. Phase I: Development of Standard Data Structure to Support Wastewater Pipe Condition and Performance Prediction. Sunil K. Sinha, Ph.D., Thiti Angkasuwansiri, Richard Thomasson. WERF, 2010

Table 1: Risk Scoring System

| Rating | Condition / Likelihood of Failure (LoF) | Consequence Factor |
|---|---|---|
| 1 | Excellent Condition / Minimal LoF | Insignificant |
| 2 | Good Condition – Low LoF | Minor |
| 3 | Acceptable Condition – Probable, or likely LoF | Moderate |
| 4 | Poor Condition – High LoF | High |
| 5 | Out of Service, not operational - Failed | Very High |

With this rating system risk scores range between 1 and 25, in a risk *space* as depicted in Figure 3.

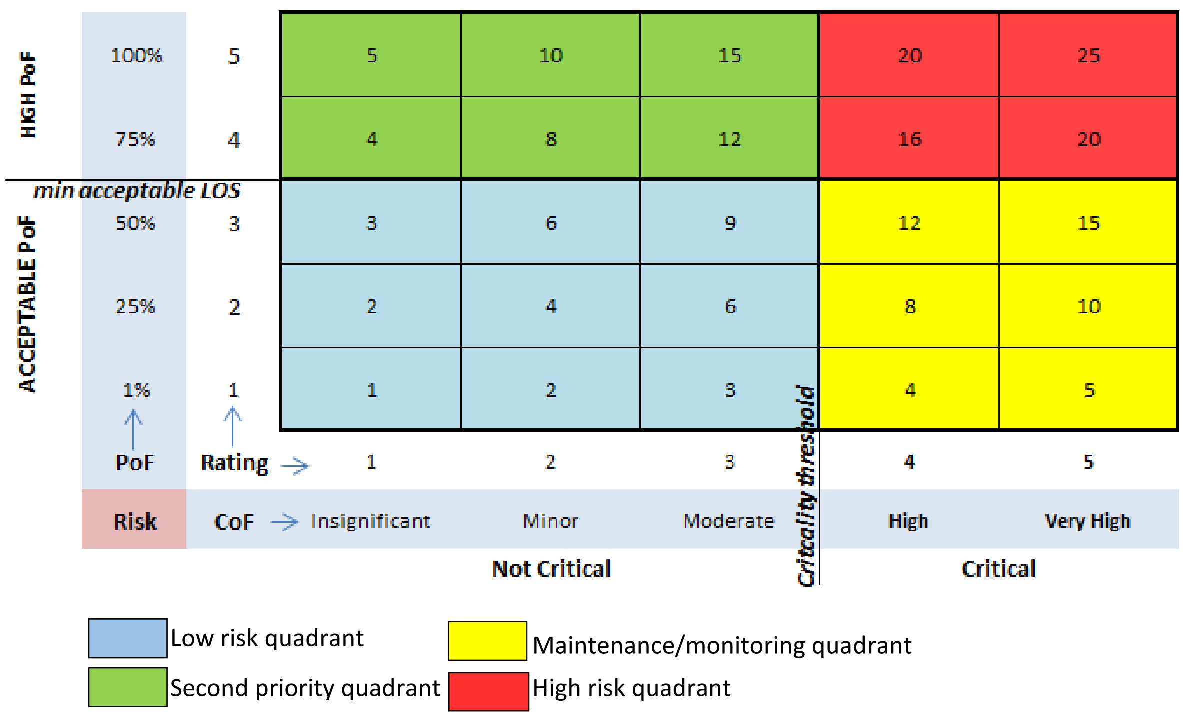



Figure 3: Risk Quadrants

An LoF threshold, and a CoF threshold divide the risk space in four quadrants. The LoF threshold represents the minimum acceptable LoS or maximum acceptable likelihood of failure. The CoF threshold represents the limit beyond which criticality is a concern. The top right quadrant, shown in red (Figure 3), is the *high-risk quadrant*. Assets that fall in this quadrant have LoF greater than the threshold and critical CoF. Assets in this category are prioritized over the rest.

Below this quadrant, in yellow, is the *maintenance and monitoring quadrant*. Assets that fall into this category have an acceptable LoF but have high consequence. As time progresses and assets deteriorate, the LoF of the assets will increase, and the asset risk score might eventually fall in the high-risk quadrant. For this reason, assets that fall into this category need to be maintained and monitored regularly.

The top left quadrant, in green, corresponds to the assets that have LoF above acceptable levels, but are not critical. These are the *second-priority* items (also referred to as the "Important" quadrant).

Finally, the bottom left quadrant, in blue, corresponds to the assets with acceptable LoF and low criticality: The *low-risk quadrant.*

Assets in the *maintenance and monitoring quadrants* and assets in the *second-priority quadrants* may have the same risk scores but will need different risk management strategies since the causes of the high-risk values are different.

### 5.1.1 Risk Framework Recommendations

The risk framework for water and sewer is fully developed and provides acceptable, defendable results. However, for stormwater, the framework has not been tested as the full extent of data is not incorporated. As the software is utilized and additional data becomes available about the system, it is expected to change or fine-tune a risk model. To improve the risk analysis of Medford's stormwater system we recommend:

- Development of forms for capturing relevant information from planned and unplanned maintenance, inspections and MS4 compliance activities to ensure they are logged in the asset management software.
- Review consequence factors and fine-tune customer impacts by using actual historical flooding loss information from FEMA.

## 5.2 Likelihood of Failure and Consequence Factors for Stormwater Pipes

**Failure modes** have been classified into two major categories: Failure modes that affect the physical integrity of the asset, and failure modes that affect their capacity.

<u>Physical Integrity:</u>

- **Remaining useful life (RUL):** Calculated as percent of years left from the pipe's estimated service life (ESL), which is assigned to each pipe segment based on its material. Typically, the ESL is assigned by pipe material, but can be variable based on existing site conditions and installation techniques. Therefore, a more reliable method of calculating RUL is by assessing conditions within the pipe itself. Below is the typical RUL calculation based on material ESL assumptions and known pipe ages:

$$RUL = \frac{ESL - Age}{ESL}$$

- **Condition**: As administered by the National Association of Sewer Service Companies (NASSCO), the PACP (Pipeline Assessment Certification Program) is the North American Standard for pipeline defect identification and assessment, providing standardization and consistency to the methods in which pipeline conditions are identified, evaluated and managed. Condition ratings are calculated from the PACP Quick Structural Rating (QSR). The QSR is a 4-character rating system - ABCD- where A indicates the highest severity of the defects found, B indicates the number of point defects with that severity (for longitudinal defects, it is the equivalent number of point defects), C is the second greatest level of severity found and D the number of defects with that severity (e.g. 4527 indicates 5 defects of severity 4, and 7 defects of severity 2). Severity ranges between 1 and 5. When the number of defects is greater than 9, a letter is used for quantifying (A: 10-13 defects, B: 14-17 defects... etc.). The QSR is then transformed to a 0-100 metric, using the formula: 100 x (90-(A*B+C*D))/90, which assumes that the worst-case scenario would be 5*10+4*10=90. This factor will be used in the future as the City progresses conducting inspections.

<u>Capacity:</u>

- **Loss of capacity due to obstructions**: This will be calculated from PACP Quick Maintenance Rating (QMR). This factor will be used in the future as the City progresses conducting inspections.

Both RUL and Condition **are unknown for 99% of the stormwater assets.** Therefore, physical integrity and capacity as it pertains to Risk cannot be calculated at this time. Instead, additional data should be collected as recommended in Section 5.1.

**Consequence** factors are grouped in two categories: social impacts, and financial impacts. Environmental impacts were not considered for this year's AMP.

<u>Social impacts</u> represent impacts to the public including health and safety, and loss of service. They are estimated based on:

- **System criticality**: Or how important is the pipe segment as part of the system. For this factor, the order of the pipe segment, or how many upstream connections feed this pipe, is typically used as a proxy for criticality. **However, there is insufficient networking and flow path data to accurately estimate this method for the stormwater system.**

- **Customers affected**: based on land use or the use of the parcel closest to the pipe. The user might give more weight to pipes that service schools or wellness centers than to other land uses.

  As an example, Figure 4 shows the housing density from 2010 Census data with flooding impacts overlaid. The circled areas in black show the areas which may be most critically impacted during a flooding event, as they are medium to high density areas which may have flooding impacts greater than 1.0 foot. The circled areas could be prioritized for implementing initial system inspections to help with determining the LoF of these pipes. By starting with areas of Highest Risk, then working to lower risk, the greatest number of customers affected can be reduced.
- <u>Financial impacts</u> were modeled based on development density within the neighborhood that the pipe services (i.e. population density). This is based on census track information. The metric for this factor is the relative density to Medford's average at the City level, for each census block

group. We assigned this value, calculated for each block group, to each pipe segment based on location.

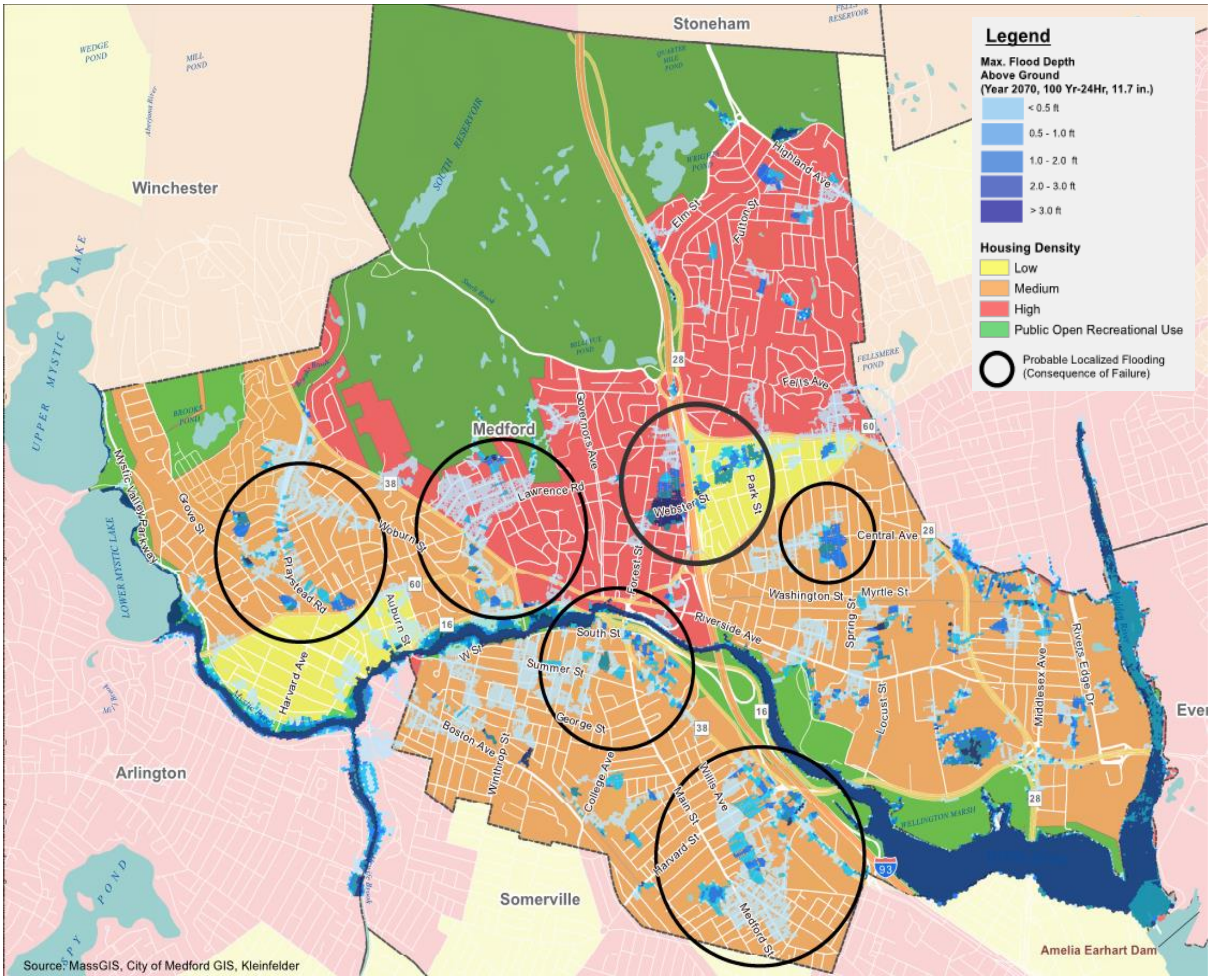



*Figure 4: Stormwater System Estimated CoF*

# 6 Financial Forecast and Capital Planning

## 6.1 Short-Term Financial Forecast

The City expressed concern with the corrugated metal (CM) stormwater piping and noted that it had a higher deterioration rate than the other pipe materials in the system. There is approximately 8,400 linear feet (lf) of CM pipe currently in the system, with a range of diameters, that could possibly need replacement or repair (there is no age information to determine how long this pipe has been in use). The following figure shows these segments of pipe across the system.

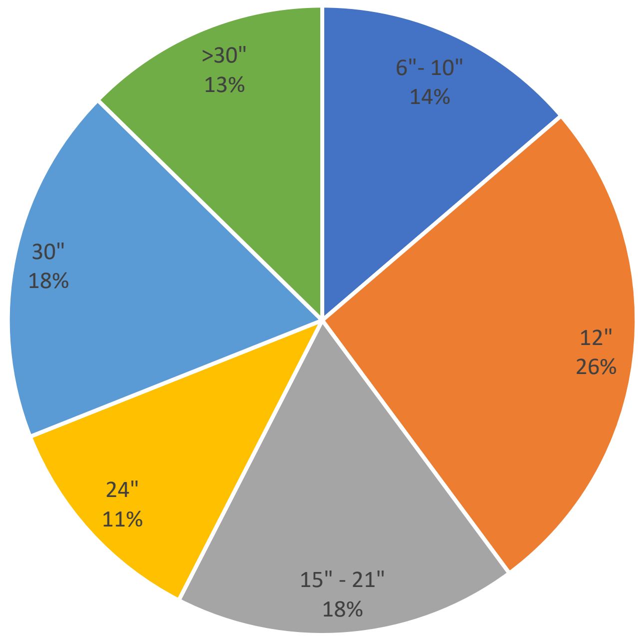



*Figure 5: Medford Corrugated Metal Pipe Sizer Breakdown (by Percentage)*

The approximate cost to replace corrugated metal pipe in urban environments is varied and depends on the diameter, location and pipe thickness upon installation. MassDOT weighted Bid Prices were used as the basis of pipe calculations, and installation considerations included trench width cost calculation information (8 – 10 ft. trench widths and approximately $5 per foot of width). A contingency of 30% and design assumption of 18% were applied to the total estimated installation cost. The total cost for replacement of all CM pipe in the system is over $2.3M, with an annual 10-year investment of approximately $256K. Table 2 summarizes these costs and shows the 5- and 10- year replacement annual cost breakdown.

*Table 2: Medford Corrugated Metal Pipe Replacement Costs*

| Pipe Diameter | Approximate Length | Pipe Cost per Length[3] | Total Cost per Length | Contingency (30%) & Design (18%) | Total Cost |
|---|---|---|---|---|---|
| 6" – 10" | 1,176 ft. | $ 56.67 | $ 113,680.00 | $ 54,566.40 | $ 168,246.40 |
| 12" | 2,184 ft. | $ 85.00* | $ 273,000.00 | $ 131,040.00 | $ 404,040.00 |
| 15" – 21" | 1,512 ft. | $ 127.50 | $ 268,380.00 | $ 128,822.40 | $ 397,202.40 |
| 24" | 924 ft. | $ 170.00 | $ 203,280.00 | $ 97,574.40 | $ 300,854.40 |
| 30" | 1,512 ft. | $ 212.50 | $ 396,900.00 | $ 190,512.00 | $ 587,412.00 |
| >30" | 1,092 ft. | $ 250.00 | $ 38,520.00 | $ 162,489.60 | $ 501,009.60 |
| **Grand Total** | **8,400 ft.** | **-** | **$ 1,593,760** | **$ 765,005** | **$ 2,358,765** |
| | | | **5-Year Replacement** | | **$471,753** |
| | | | **10-Year Replacement** | | **$235,877** |

*Note: For 12" CM Pipe, only 14-gauge sizing information was available ($7.08/in-dia.).

While certain pipe materials are known to have a longer lifetime than other materials, applying this type of blanket replacement cost is the worst-case scenario. A better way to identify more accurate annual capital spending is through the creation of a longer-term risk model, using inputs such as condition and age, to determine the effective replacement strategies and capital spending.

## 6.2 Long-Term Financial Forecast

Kleinfelder developed an Excel and GIS-based tool to identify future water and sewer main renewal or replacements needs over a 100-year period. This model can be adapted to the stormwater system; however, it requires additional data to make an accurate capital planning assessment. The model can perform the following calculations for each stormwater pipe segment, with additional data per pipe segment:

1. Assign estimated service life (ESL) based on material
2. Calculate age based on current date and year of installation
3. Calculate Remaining Useful Life (RUL) based on age and ESL
4. Calculate remaining life
5. Calculate LoFs based on remaining life and C values
6. Calculate Risk factors based on LoFs and CoFs (inputs):
    a. Risk from Physical Integrity and Social Impacts

[3] MassDOT Weighted Base Bid Records. Web. https://hwy.massdot.state.ma.us/CPE/WeightedAverageCriteria.aspx

b. Risk from Physical Integrity and Economic Impacts
c. Risk from Capacity and Social Impacts
d. Maximum Risk Score
e. Dominant Risk Factor
f. Risk Box (where in the risk space the asset falls)
g. Risk Quadrant

7. Assign a renewal strategy (clean and line) or replacement (replace with same diameter or with larger diameter) based on LoF and CoF data, which can be overridden by the user
8. Calculate renewal or replacement costs based on replacement strategies
9. Deteriorate segments with actions starting during the following time-step
10. Repeat steps 2 through 10 for Years 2022 and 2027

The model requires the following inputs:

- Stormwater main attributes from GIS: AssetID, Material, Diameter, Street, Year of installation and length
- Stormwater Consequence factor ratings from risk analysis
- Estimated Service Life
- Unit cost table
- Deterioration rate
- Year of analysis
- Default values for missing data

The model uses a decision-making algorithm that allows the user to change the renewal strategies for any given LoF/CoF combination. The decision model is dynamic and allows the user to change inputs such as replacement unit costs, estimated service lives, and renewal/replacement strategies. Example model outputs included:

- Yearly total investment and risk scores (see Figure 6)
- Risk distribution of water mains over Medford's risk space by feet, and by investment needs per year (see Figure 7)
- Assigned strategies per segment and year

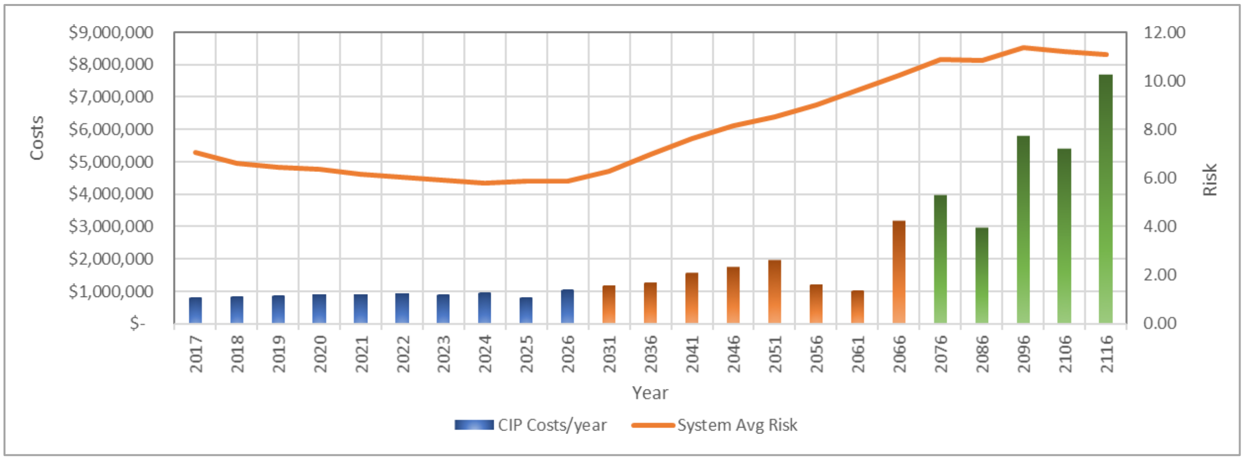



*Figure 6: Example of Long-Term Expenditures and Average Risk Scores*

**Length (ft)**

**2036**

661,518 feet

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 126,862 | | | | | | 10,775 |
| 90,023 | 5 | - | 7,791 | 82,232 | - | - | |
| 47,613 | 4 | 369 | 5,342 | 31,128 | 10,775 | - | |
| 126,026 | 3 | 18,512 | 40,552 | 36,731 | 22,748 | 7,482 | |
| 101,071 | 2 | - | 11,871 | 54,288 | 32,218 | 2,694 | |
| 296,784 | 1 | - | 1,604 | 149,526 | 145,655 | - | |
| | 313,084 | 1 | 2 | 3 | 4 | 5 | 210,797 |
| | | 18,881 | 67,160 | 353,905 | 211,395 | 10,176 | |

**Replacement Costs (no inflation)**

**2036**

$ 75.00 Million

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $13.33 M | | | | | | $1.41 M |
| 9,295,245 | 5 | - | 791,908 | 8,503,337 | - | - | |
| 5,445,384 | 4 | 39,449 | 555,354 | 3,444,089 | 1,406,493 | - | |
| 15,695,691 | 3 | 1,946,625 | 4,916,609 | 4,179,681 | 2,894,430 | 1,758,346 | |
| 12,437,796 | 2 | - | 1,329,597 | 6,421,701 | 4,055,753 | 630,745 | |
| 32,127,154 | 1 | - | 172,394 | 15,730,109 | 16,224,651 | - | |
| | $34.70 M | 1 | 2 | 3 | 4 | 5 | $25.56 M |
| | | 1,986,073 | 7,765,862 | 38,278,916 | 24,581,326 | 2,389,091 | |

*Figure 7: Example Risk Distribution by Length and Replacement Costs*

In order to calculate risk, a better understanding of the LoF (Condition) is needed. CoF can be calculated based on housing density and other land-use figures, but until structural condition is identified, the model cannot determine whether segments are operating at or below their designed capacity.

The recommendations for capital spending are NOT accurately estimated at this time, however, within the next MS4 permit cycle (2023 – 2028), this could be possible. By continuing to track compliance and maintenance using Software, more data will be available for analysis.

Also, for consideration, tracking damages related to storms or flooding, and integrating other customer/citizen requests may help with understanding future capacity concerns or identifying potential projects. Consider areas circled in Figure 4 as appropriate starting points.

# 7 Recommendations

The following recommendations have been summarized from previous sections of the report and are to be used as a guideline for data collection over the course of the next year. By walking through each of the following categories, the City of Medford will be in better position to set up for the following year of their Asset Management program, and one step closer to implementing a fully operational financial risk model.

*Table 3: Summary of Recommended Actions for Stormwater System*

| Category | Objectives | Cost Considerations |
|---|---|---|
| Level of Service (LoS) | • Set LoS metrics using MS4 Permit Requirements<br>• use AM Software to track related activities and workflows | No cost; already in program |
| Asset Inventory | • Fix / complete the Asset ID (or FacilityID) for all features to be included in the asset management plan where this information is missing (not including fittings which will be accounted for with drain pipes);<br>• Review system connectivity, including intermunicipal connectivity.<br>• Add receiving waters feature class<br>• Adding integrated waters feature class<br>• Complete inventory of BMPs<br>• Create/confirm catchment delineations for the outfalls<br>• Categorizing Outfalls and MS4/Non-MS4, with priority ranking, and receiving water body in the GIS. | No cost if performed by City; an outside contractor may cost $75,000 to $200,000 to complete all assessments. |
| Risk Model | • Update model using data exported from Asset Inventory<br>• Adjust benchmarks and assumed values (e.g. default year and service life requirements) | Can be incorporated in Year 2 AMP Grant |
| Financial Forecast and Capital Planning | • Revise material replacement costs based on known values (e.g. use City capital information to adjust assumed replacement costs)<br>• Update deterioration curves based on City replacement/repair data | Can be incorporated in Year 2 AMP Grant |

By answering some outstanding stormwater system data questions, workflows will be able to identify metrics which will help to prioritize system improvements, both applicable to MS4 and in addition to MS4. The City of Medford has already taken great strides in expanding their institutional stormwater knowledge through climate resiliency planning and construction projects, and this type of work compliments those goals.

## 7.1 Next Steps for the City

For immediate next steps, the following software implementation steps can be adapted to fit the City's needs with the software vendor:

1. Finalize the list of activities from the water and sewer division to be implemented in the asset management software, with their corresponding fields, default values, drop-down menus, recurrence settings etc. This can be done by reviewing the preliminary work order dictionary provided by Kleinfelder to the City as a starting point for this task.
2. Configure the software for these activities.
3. Identify key personnel involved in the resolution of these activities, both from the dispatcher end (task assigner), and the resolution end (task assignee).
4. Start using the software for conducting the work.

This process might require a couple of rounds of configuration until the workflows are fully adopted by the City staff and 100% supported by the software. From there, to take the implementation further we recommend:

5. Configuring operation management dashboards for each division head
6. Configuring reports
7. Configuring dashboards for level of service tracking
8. Integrating software with other systems such as See Click Fix
9. Expanding the software with other modules, if necessary, such as fleet, or storeroom inventory

It is highly recommended that the stormwater plan be revisited after workflows are setup using the software. Applying for a second round of Clean Water Trust Asset Management Plan Grant funding is a great vehicle to continue planning using the framework and assess next steps after the implementation begins. Other avenues such as Coastal Zone Management Resiliency Funding and MVP Assistance may also provide avenues to fund investigation and feature class updates to the stormwater data.

# APPENDIX D:

# Risk Framework

# Medford Risk Framework

Risk = LoF x CoF

| | LoF | | | | | |
|---|---|---|---|---|---|---|
| Failed | **5** | 5 | 10 | 15 | 20 | 25 |
| Poor | **4** | 4 | 8 | 12 | 16 | 20 |
| Fair | **3** | 3 | 6 | 9 | 12 | 15 |
| Good | **2** | 2 | 4 | 6 | 8 | 10 |
| Excellent | **1** | 1 | 2 | 3 | 4 | 5 |
| | | **1** | **2** | **3** | **4** | **5** |
| | CoF | Not Critical | | | Critical | |

# LoF Score Cards

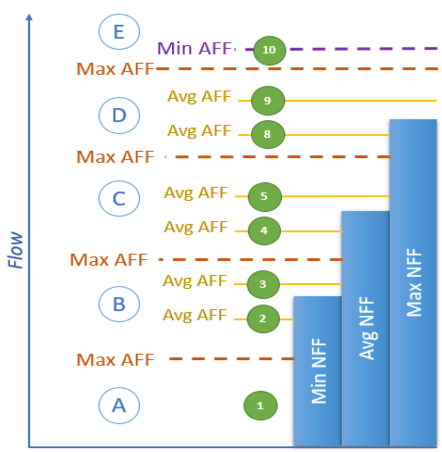
## Water Mains

| Failure Modes | Criteria | Measure or Proxy | Ratings | | | | |
|---|---|---|---|---|---|---|---|
| | | ***Condition:*** | **Excellent** | **Good** | **Fair** | **Poor** | **Failed** |
| | | ***LoF:*** | **Very unlikely LoF** | **Unlikely LoF** | **Moderate LoF** | **Likely LoF** | **Imminent failure** |
| | | | 1 | 2 | 3 | 4 | 5 |
| **Physical Integrity** | Age* | % Life left: calculated as (ESL-Age)/ESL | >= 25% | 25-15 % | 15-10 % | 5%-1% | 1%- 0% |
| | Condition | % Corrosion | <5% | <10% | 10-15% | >20% | >30% |
| | | **Final Score:** | **Maximum obtained** | | | | |
| **Capacity** | Pressure | Hydraulic model or field meassurements | (90-100) psi | (60-90) psi | (45-60) psi | (45-35) psi | <35 psi or >100 psi |
| | Reduction of Pipe diameter | Change of C-Value from Calibrated Hydraulic Model | <5% | <10% | 10-15% | >20% | >30% |
| | Fire Flow Adequacy | Available Fire flow (AFF) and Needed Fire Flow (NFF)* | Min AFF > Max NFF (Zone E) | Max AFF> Max NFF (Zone D) | Avg NFF< Max AFF< Max NFF (Zone C) | Min NFF< Max AFF< Avg NFF (Zone B) | Max AFF < Min NFF (Zone A) |
| | | **Final Score:** | **Maximum obtained** | | | | |

Factors included in Year 1

Age: Age failure mode depends on the Estimated Service Life (ESL) of a pipe, which depends on many factors including material and size. This failure mode can be fine-tuned by looking at the history of water main breaks.

NFF: Estimated from building total area from building footprints and number of stories based on ISO estimate for fireflow. This assigns a NFF to each building. Use geoprocessing NEAR tool to assign Min, Avg, and Max NFF to eacg pipe segment. This calculation is an ESTIMATE not an actual fireflow assessment.



## LoF Score Cards

### Sewer Pipes (Gravity)

| | | | Ratings | | | | |
|---|---|---|---|---|---|---|---|
| | | ***Condition:*** | **Excellent** | **Good** | **Fair** | **Poor** | **Failed** |
| | | ***LoF:*** | **Very unlikely LoF** | **Unlikely LoF** | **Moderate LoF** | **Likely LoF** | **Imminent failure** |
| **Failure Modes** | **Criteria** | **Measure or Proxy** | 1 | 2 | 3 | 4 | 5 |
| **Physical Integrity** | Age* | % Life left: calculated as (ESL-Age)/ESL | >= 25% | 25-15 % | 15-10 % | 5%-1% | 1%- 0% |
| | Condition | PACP Quick Structural Rating (QSR)* | >=95 | (85-95] | [70-85) | [50-70) | <50 |
| | | **Final Score:** | **Minimum obtained** | | | | |
| **Capacity** | Loss of Capacity due to obstructions | PACP Quick Structural Rating (QMR)* | >=95 | (85-95] | [70-85) | [50-70) | <50 |
| | | **Final Score:** | **Maximum obtained** | | | | |

Factors included in Year 1

Age: Age failure mode depends on the Estimated Service Life (ESL) of a pipe, which depends on many factors including material and size. This failure mode can be fine-tuned by looking at the history of water main breaks.

QSR: The QSR is a 4-character rating system - ABCD- where A indicates the highest severity of the defects found, B indicates the number of point defects with that severity (for longitudinal defects, it is the equivalent number of point defects), C is the second greatest level of severity found and D the number of defects with that severity (e.g. 4527 indicates 5 defects of severity 4, and 7 defects of severity 2). Severity ranges between 1 and 5. When the number of defects is greater than 9, a letter is used for quantifying (A: 10-13 defects, B: 14-17 defects... etc.). To transform the QSR to a 0-100 metric, we used the formula: 100 x (90-(A*B+C*D))/90, which assumes that the worst case scenario would be 5*10+4*10=90. For this math, any number of defects greater than 9 will count as 10.

QMR: The QMR follow the same logic as the QSR, but counting maintenance defects such as grease and root intrusion. Similarly to the QSR, the QMR is transformed to a scale of 1-100.

# LoF Score Cards

## Stormwater Drains

| | | Ratings | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Condition:* | **Excellent** | **Good** | **Fair** | **Poor** | **Failed** |
| | | *LoF:* | **Very unlikely LoF** | **Unlikely LoF** | **Moderate LoF** | **Likely LoF** | **Imminent failure** |
| **Failure Modes** | **Criteria** | **Measure or Proxy** | 1 | 2 | 3 | 4 | 5 |
| **Physical Integrity** | Age* | % Life left: calculated as (ESL-Age)/ESL | >= 25% | 25-15 % | 15-10 % | 5%-1% | 1%- 0% |
| | Condition | PACP Quick Structural Rating (QSR)* | >=95 | (85-95] | [70-85) | [50-70) | >50 |
| | | **Final Score:** | **Maximum obtained** | | | | |
| **Capacity** | Capacity Adequacy (or Safety factor, SF) | Drainage capacity from hydraulic model | Structure has sufficient capacity with a 200% SF | Structure has sufficient capacity with a 150% SF | Structure has sufficient capacity with a 125% SF | structure has sufficient capacity with a 100% SF | structure doesn't have sufficient capacity |
| | | **Final Score:** | **Capacity Score** | | | | |

Factors included in Year 1

Age: Age failure mode depends on the Estimated Service Life (ESL) of a pipe, which depends on many factors including material and size. This failure mode can be fine-tuned by looking at the history of water main breaks.

## Consequence Factors

| Category | Factor | Definition | System | Measure or Proxy | Ratings: Insignificant 1 | Minor 2 | Moderate 3 | High 4 | Very High 5 |
|---|---|---|---|---|---|---|---|---|---|
| **Social Impacts** Impacts to the public and customers | **System Criticality** | How important is the asset as a part of the system | Water | Diameter | <8" | [10"-12"] | (12" -16"] | Transmission mains | Facilities |
| | | | Wastewater | Order | 1-10 | 10-60 | >60 | Facilities | |
| | | | Stormwater | Asset Type | Smaller drains | Big drains | Flooding Control Structures | | |
| | | | | Drainage Area | | | | | |
| | **Loss of Service** | Number of people affected by the failure of an asset AND imporatnce of the customers affected | Water | Land Use/Parcel Use | Services residential, comercial customers | | | Services schools | Services hospital, acute care facilities |
| | | | Wastewater | Land Use/Parcel Use | Services residential, comercial customers | | Services schools | Services hospital, acute care facilities | |
| | | | Stormwater | Number of people affected | Will need to be developed based on flooding area and number of people affected in the area. In this case flooding would be caused by the failure of the asset (such as blockage) and not due to external factors (such as excess of precipitation). | | | | |
| | | | | **Final Score:** | **Maximum** | | | | |
| **Environmental** | **Pollution** | Asset failure causes pollution on environmental resources | Water | N/A | All assets here | | | | |
| | | | Wastewater | Proximity to water body, vernal pool, or habitat | > 500 ft | 500-100 ft | 100-50 ft | <50 ft | |
| | | | Stormwater | Type of asset and MS4 | Rest of assets | Assets within MS4 catchment area | WQ Structures | | |
| | | | | **Final Score:** | **Maximum** | | | | |
| **Financial Impacts** Impacts to the DPW and to the community | **Property damage and other costs assumed by customer** | water loss, property damage, impacts to industry, costs from loss of service etc | Water | Population Density* (expressed relative to Medford's average) | < 0.5 | [-0.5 - 0.75) | [0.75 - 1.25] | (1.25 - 1.5] | > 1.5 |
| | | | Wastewater | Population Density* (expressed relative to Medford's average) | < 0.5 | [-0.5 - 0.75) | [0.75 - 1.25] | (1.25 - 1.5] | > 1.5 |
| | | | Stormwater | Population Density* (expressed relative to Medford's average) | < 0.5 | [-0.5 - 0.75) | [0.75 - 1.25] | (1.25 - 1.5] | > 1.5 and all flooding control structures |
| | | | | **Final Score:** | **Weighted average** | | | | |

Factors included in Year 1

Population Density: Population density is calculated as: (CENSUS BLOCK GROUP POPULATION/CENSUS BLOCK GROUP AREA) / (TOT POPULATION IN MEDFORD/MEDFORD AREA). So this factor is the relative density of population with respect to Medford's density. The assumption is that assets that fail in higher density neighborboods can potentially cause damage to more individuals.