**MASSDEP BRP2017-02**

**WATER INFRASTRUCTURE ASSESSMENT & PLANNING GRANT**

**YARMOUTH, MA**

**WATER DIVISION**

# ASSET MANAGEMENT PLAN


**REVISION DATE: JUNE 20, 2017**

KLEINFELDER
Bright People. Right Solutions.

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# ACRONYMS AND ABBREVIATIONS

AM – Asset Management

AMP – Asset Management Plan

AWWA – America Water Works Association

C value – Hazen-Williams roughness coefficient "C"

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

KPI – Key Performance Indicator

LoF – Likelihood of failure

LOS – Level of Service or Levels of Service

MassDEP – Massachusetts Department of Environmental Protection

O&M – Operations and Maintenance

PLA – Priority List of Assets

ROI – Return on Investment

RPA – Recommended Plan of Action

RTCR – Revised Total Coliform Rule

RUL – Remaining Useful Life

SCADA – Supervisory Control and Data Acquisition System

SDWA – Safe Drinking Water Act

SLA – Secondary List of Assets

TBL – Triple Bottom Line

WMA – Water Management Act

# 1 EXECUTIVE SUMMARY

The Town of Yarmouth's Water Division (Division) has taken the first steps towards enterprise asset management, and is in the midst of implementing an Asset Management Software solution as part of an initiative from the Town's Department of Public Works (DPW). This document is their first Asset Management Plan (AMP), which has been partially funded by the Massachusetts Department of Environmental Protection (MassDEP). The Water Division engaged Kleinfelder to help them through the process, instruct them about the principles of Asset Management, engage with their staff, and write the AMP. This AMP has been completed following requirements from MassDEP, and guidelines about Asset Management published by EPA in several of their publications, including Fundamentals of Asset Management[1] and Asset Management: A Best Practices Guide[2]. With input from the Division, Kleinfelder followed the process of developing an AMP, including:

- Gathering and compiling data to create an asset register,
- Conducting a data gap analysis to identify and estimate values for critical data gaps,
- Evaluating condition based on existing data for the water network and the facilities,
- Developing a risk framework for mains and facilities, and
- Conducting a risk analysis and developing an interactive financial model for a 10-year time horizon to identify potential system needs in the next five and 10 years.

These steps are explained in this AMP in sections 3 through 8. Recommendations are presented in section 9 and summarized here:

1. Most of the water system data is outdated.
2. The Division currently has no way of assessing their performance or needs based on daily operations data. Data from a work order management system should be leveraged for for planning and self-assessment.
3. The Division's last Water Master Plan was developed in 2007. The Division is in need of an update to their Master Plan, which should include a new hydraulic model and an inspection and assessment of their wells, pump stations, corrosion control facilities and tanks.
4. Yarmouth's water rates have been the same since 1995. The Division should conduct a rate study to review the water rates and pair them with the findings from the financial plan presented here to assess potential rate increases.
5. The Division is overdue for painting Sandy Pond Tank. Prospect Hill tank should be painted within the next 5 years and German Hill within the next 10 years.
6. The Division should conduct a long-term plan (50 years or longer) to ensure that water main replacement needs are addressed proactively, avoiding major unexpected system failures.
7. The Division should update this AMP once items 1 and 3 have been addressed.

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[1] *Training materials on Asset Management provided by EPA and available here: https://www.epa.gov/sustainable-water-infrastructure/asset-management-workshops-training-slides*

[2] *EPA Office of Water (4606 M) EPA 816-F-08-014, April 2008*

# 2 INTRODUCTION

## 2.1 BACKGROUND

Located in Barnstable County, Massachusetts, the Town of Yarmouth is home to a permanent population of about 24,000 (2010 census); As with many towns in Cape Cod, the Town experiences a considerable increase in population during the summer, which nearly triples to an estimated population of 72,500. As part of the Town's Department of Public Works (DPW), the Water Division (the Division) is committed to providing quality drinking water to their customers throughout the year, while also ensuring that adequate water flow and pressure is available for fire protection.

Yarmouth's water system is comprised of extensive infrastructure with about 340 miles of water mains, more than 2,000 hydrants, and 3,400 gate valves. The system draws water from 24 groundwater wells, through 24 pump stations. Water treatment is conducted via 17 corrosion control facilities. There are 3 storage tanks.

With an extensive asset inventory to manage, the Division recognizes the need for adopting asset management principles, with the goal of optimizing their resources to progressively move from reactive maintenance to proactive maintenance.

## 2.2 PURPOSE OF THE ASSET MANAGEMENT PLAN

The practice of asset management enables organizations to make smarter investments and deliver greater efficiency while reducing the risks associated with reactive management. During this past month, Yarmouth's DPW has gone through the process of selecting and purchasing asset management software (in the form of Software as a service or SaaS), and is starting asset management system implementation throughout the DPW's, including the Water Division.

This Asset Management Plan (AMP) was created to help the Water Division meet its objective of starting an asset management program. The AMP was developed in accordance with Good Engineering Practices and the EPA issued "Asset Management – A Best Practices Guide, April 2008", and includes the following required information (specified in the grant RFP):

1. Complete inventory of assets for Yarmouth's water distribution system;
2. For each asset, an evaluation table that includes; replacement cost, useful life, material & integrity (if applicable) and criticality;
3. A Priority List of Assets (PLA) that includes AMP line item costs outlined for each of five (5) annual budget years. The PLA will summarize the annual cost to replace prioritized assets for that year;
4. For each year of the PLA total budget line items (years 1 – 5), an annual cost impact to the existing water charge and rate system shall be provided for the governing public entity to consider and act upon;

5. A Secondary List of Assets (SLA) Priority list for each of the following 5 years for years (6 through 10) with total estimated annual costs for each year;
6. Training for the public entities staff. Training will include data entry and other asset management duties. A Written Plan will be provided in the AMP for the management team to utilize;
7. A Recommended Plan of Action (RPA) for the governing authority to consider.

Additionally, this AMP documents:

8. The Levels of Service (LOS) identified by the Division, and
9. A preliminary risk framework for the system's critical asset types.

For the Division, establishing and implementing a sound asset management program will allow for:

- Increasing the efficiency of operations and maintenance activities, managing work and resources to extend the life of the system's assets through preventive maintenance;
- Formalizing operations so that knowledge can be transferred easily to new staff members;
- Leveraging investments in GIS, SCADA and Asset Management Software;
- Supporting cost-effective decisions justified through a strategic, data-driven process;
- Replacing or rehabilitating critical assets before a costly failure occurs;
- Tracking and reporting levels of service over time;
- Defining capital projects strategically, based on established goals and constraints, and prioritized based on risk and opportunity;
- Maintaining the value of the system as time progresses and assets deteriorate, depreciate, get updated, repaired, or replaced;
- Adjusting the water rate structure to support long-term infrastructure needs.
- Be responsive to customer requests with a system that provides ability to self-improve;
- Manage work, staff, and resources to extend the life of the Division assets through strategic maintenance.

## 2.3 DEVELOPMENT OF THIS ASSET MANAGEMENT PLAN

Asset management is a combination of procedures, technology and management practices undertaken with the goal of achieving financial sustainability of a system (in this case a water system) while maintaining the desired level of service for the customers, at an acceptable level of risk.

Asset management strategies are designed to minimize costs, estimate and manage risk, extend the life of assets, track levels of service, optimize operations and forecast expenditures. According to EPA's Fundamentals of Asset Management, asset management strategies are designed to answer these five core questions while following seven principles:

***Five core questions:***

1. What's the current state of my assets?
2. What's my required Level of Service?
3. Which assets are critical to sustained performance?
4. What are my best operations and maintenance and capital investment strategies?
5. Which is my best long-term funding strategy?

These core questions have been addressed during the completion of this plan. Answers to question 1, *what's the current state of my assets* are addressed in Sections 4–*Asset Register* and 6–*Evaluation of Condition and Performance*. Section 5 addresses Levels of Service. Criticality is addressed in Section 7. The basis for answering questions 4 and 5 is presented in section 8, Financial Planning.

***Seven principles of Asset Management:***

1. *Level of Service (LOS) Principle*: Assets exist to deliver services. There is a minimum LOS below which a given service is not perceived as adding value. For example, a customer would see little value in having water if that water is not safe to drink.
2. *Life Cycle Principle*: All assets go through a life cycle. Managing assets consists of deciding what and when to perform tasks on each asset and how those actions will alter the asset's life cycle.
3. *Failure Principle*: Failure occurs when an asset cannot perform its purpose at its required level of service.
4. *Failure Modes Principle*: Failure modes define how assets fail.
5. *Probability Principle*: Probability of failure depends on factors other than age.
6. *Consequence Principle*: Not all asset failures have the same consequences.
7. *Total Cost of Ownership Principle*: There exists a minimum optimal investment over the life cycle of an asset that best balances performance and cost given a target level of service and a designated level of risk

This AMP has been created following these principles, and the guidelines provided by the EPA.

The Division established ownership of the development of this Plan through active engagement in a series of three workshops on Asset Management, as described in Table 1.

**Table 1– Workshops Conducted During AMP Development, 2017**

| Workshop | Description |
|---|---|
| **Kick-off meeting and Overview** (3/09/2017) | • Discussed project goals and process<br>• Identified stakeholders<br>• Gathered asset inventory and condition information |
| **Workshop 1 - Asset Management Principles and Levels of Service** (5/18/2016) | • Presented introduction to asset management, concepts and principles.<br>• Discussed Level of Service (LOS) principles and importance in AM planning implementation and evaluation<br>• Completed a series of exercises to determine how existing values and system performance aligns with LOS goals.<br>• Created draft LOS definitions and targets. |
| **Workshop 2 - Condition and Risk** (5/18/2017) | • Reviewed inventory and status of GIS. Reviewed data gaps.<br>• Presented concepts of criticality, risk, failure modes, likelihood of failure, and consequence of failure and risk analysis<br>• Presented draft risk framework for Yarmouth's water system.<br>• Discussed rating system, failure modes and consequence factors.<br>• Reviewed preliminary risk analysis results |
| **Workshop 3 - Financials** (6/8/2017) | • Reviewed draft AMP<br>• Review risk-based prioritization process<br>• Review Financial Model<br>• Conducted sensitivity analysis to reveal range of outcomes<br>• Discussed financial strategies |

The Supplemental Documentation (Appendix A) includes materials covered in each workshop, including presentations and exercises.

# 3 ASSET REGISTER

## 3.1 DATA COLLECTION AND ASSESSMENT

The Division has a comprehensive asset portfolio that has been documented over time in different file formats. As part of this task, Kleinfelder gathered water-system data from different sources and formats and compiled it in a geodatabase format, with feature classes representing different asset types. Data sources included:

- GIS line shapefile with water main geometry and diameter data.
- GIS point shapefile from a Trimble export. This shapefile contained a field called *class,* of which values were asset types for most of the features, and hydrant IDs for hydrant features. It also contained a field named *hydrant-type* with hydrant manufacturer data.
- Excel spreadsheet with hydrant IDs and hydrant attribute information.
- Hard copy of pump station database with year of construction and details about pump capacity and years of installation and renewal of pumps and motors.
- Water Master Plan of 2007 by SEA Consultants.
- MassGIS parcels and roads layers.
- GIS shapefile with water distribution system and Hazen Williams "C" values. Dated 2007, this is an output from a hydraulic model.
- Well schematics with information about pump installation and renewal dates.
- Well reports for some of the water supply wells with pre- and post-cleaning specific capacities.

Kleinfelder developed a preliminary **data model** for Yarmouth's water system and created a comprehensive asset register from the information gathered.

## 3.2 ASSET SUMMARY

The water system assets that the Division maintains include:

- 282 miles of water mains
- 2,113 hydrants
- 2,075 hydrant valves
- 3,428 gate valves
- 9 butterfly valves
- 338 shut-off valves (in the GIS, probably more to be identified)
- 24 Pump Stations with their wells
- 15 Corrosion Control Facilities
- 3 Water Storage Tanks

Information about the distribution system assets (attributes) is presented below. During the production of this AMP, the distribution system data has been managed in GIS. Facilities data has been managed in Excel.

## 3.3 WATER MAINS

### *3.3.1 Diameter*

Diameters of the water main segments range from 1 inch to 20 inch. The distribution of length by diameter is represented below:

**Table 2 – Distribution of pipe (length, in miles) by diameters**

| Diameter (in) | 1 | 2 | 4 | 6 | 8 | 10 | 12 | 16 | 20 | Total (>2in) |
|---|---|---|---|---|---|---|---|---|---|---|
| Miles | 0.15 | 17.97 | 0.15 | 79.23 | 118.96 | 16.90 | 41.44 | 3.67 | 3.59 | **281.92** |
| % | | 6.38% | 0.05% | 28.11% | 42.20% | 5.99% | 14.70% | 1.30% | 1.27% | |

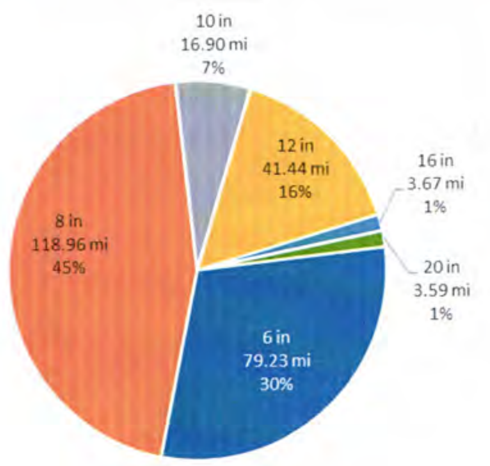



**Figure 1 - Distribution of pipe diameter by length of water main**

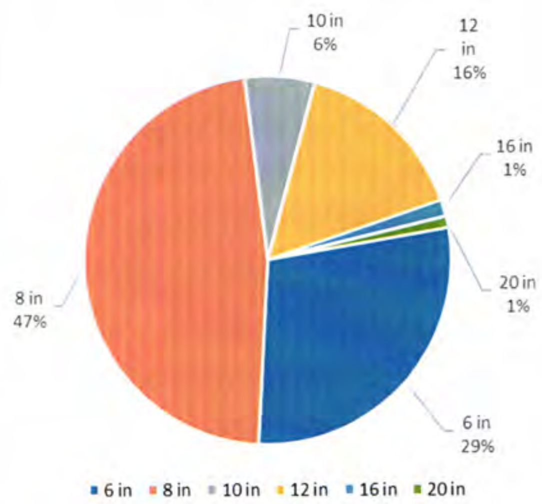



**Figure 2 - Distribution of pipe diameter by hydrant count**

The Hydrants feature class had data indicating the size of the main they are connected to. The distribution of diameters by hydrant count to distribution is very similar to the distribution from the GIS feature class. (see Figures 1 and 2) which indicates consistency on the data. Figure 3, System Map, displays the same information. Except for few spots that need to be checked in the field, hydrant size and water main size data are consistent.

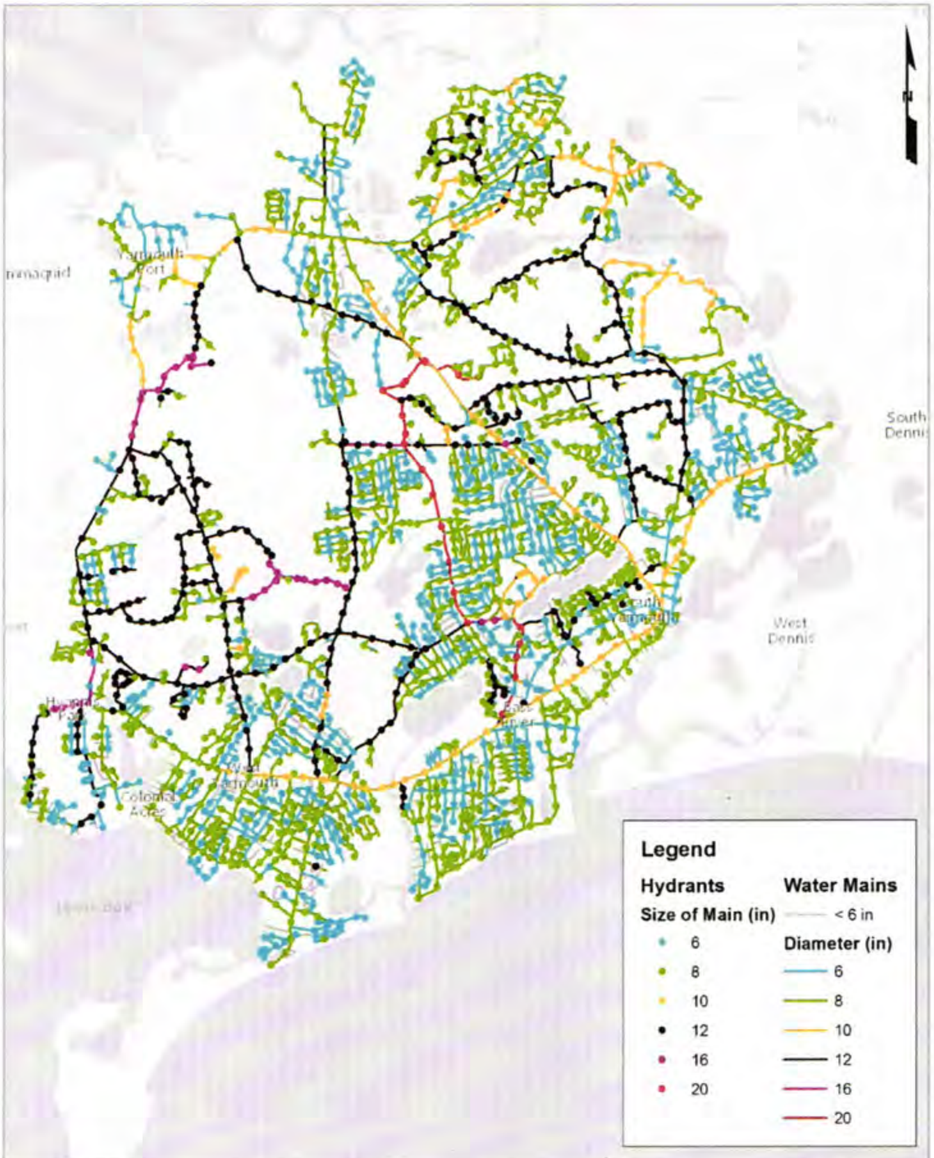



**Figure 3 - System Map with Sizes**

### *3.3.2 Year of Installation and Material*

Material is assumed to be ductile iron pipe throughout the system, based on institutional knowledge from the Division staff. This needs to be confirmed on an asset basis as inspections and field activities proceed.

There was no information about installation year in the GIS.

There are very few record drawings available that can help identify the year of installation of the system's assets.

Having installation year is important because is used to estimate remaining useful life for assets. Additionally, year of installation can be used to verify the material information by comparing it to the historical production and use of water pipe materials (see Figure 7). To start gaining understanding of installation dates, Kleinfelder looked at census information. Census 2010 data indicates that the population in Yarmouth was steady from the 1800s and experienced some growth during the 1940s and 1950s. The most abrupt growth took place during the 1960s and 1970s.

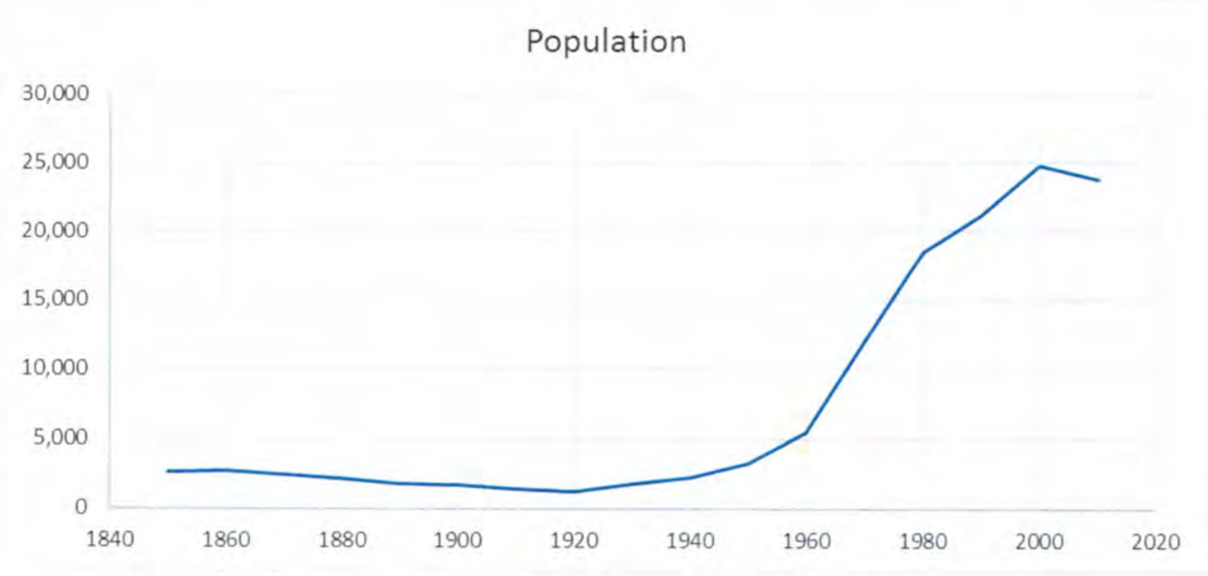



**Figure 4– Population Growth in Yarmouth (Census 2010)**

The hydrant database contained information about system year. By plotting the accumulated number of hydrants over time from the hydrant spreadsheet, we see a similar trend, with an abrupt growth during the 1960s and a steady increase right after the 170s into the 2000s.

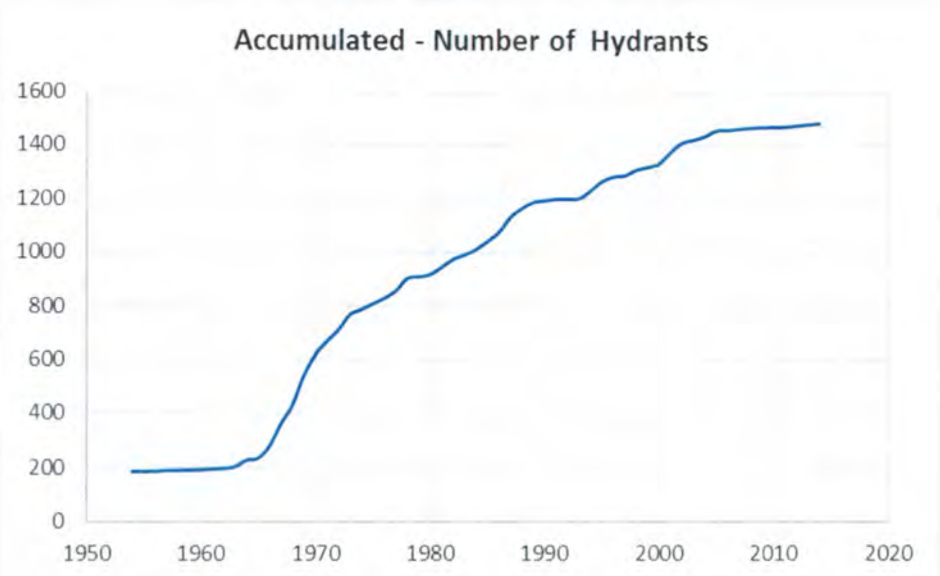



**Figure 5– Accumulated number of hydrants by year installed**

The assessor's database contained information about year built per parcel.

To assign year of installation to each water main segment in GIS Kleinfelder performed a GIS analysis that transferred the system installation dates from the hydrant dataset to the corresponding mains. The parcels dataset was used to fill-in the gaps. The distribution of water main length by year built is presented in Figure 6.

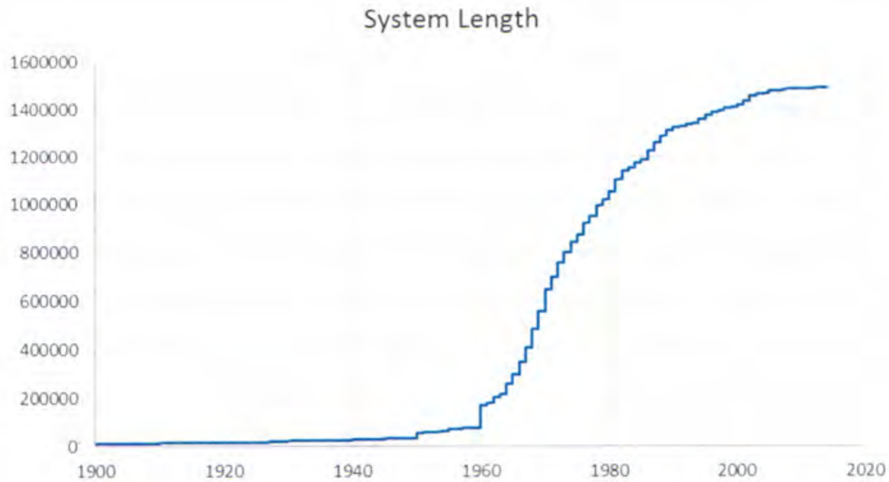



**Figure 6– Accumulative length (feet) of water mains installed over time**

Having looked at this trend, we expect to have only a small percentage of the system with material other than ductile iron in the system. Per AWWA *Buried No Longer: Confronting America's Water Infrastructure Challenge* (see Figure 7), ductile iron was predominantly in use after the 1960s, and therefore is reasonable to accept the hypothesis that most the water mains are of this material.

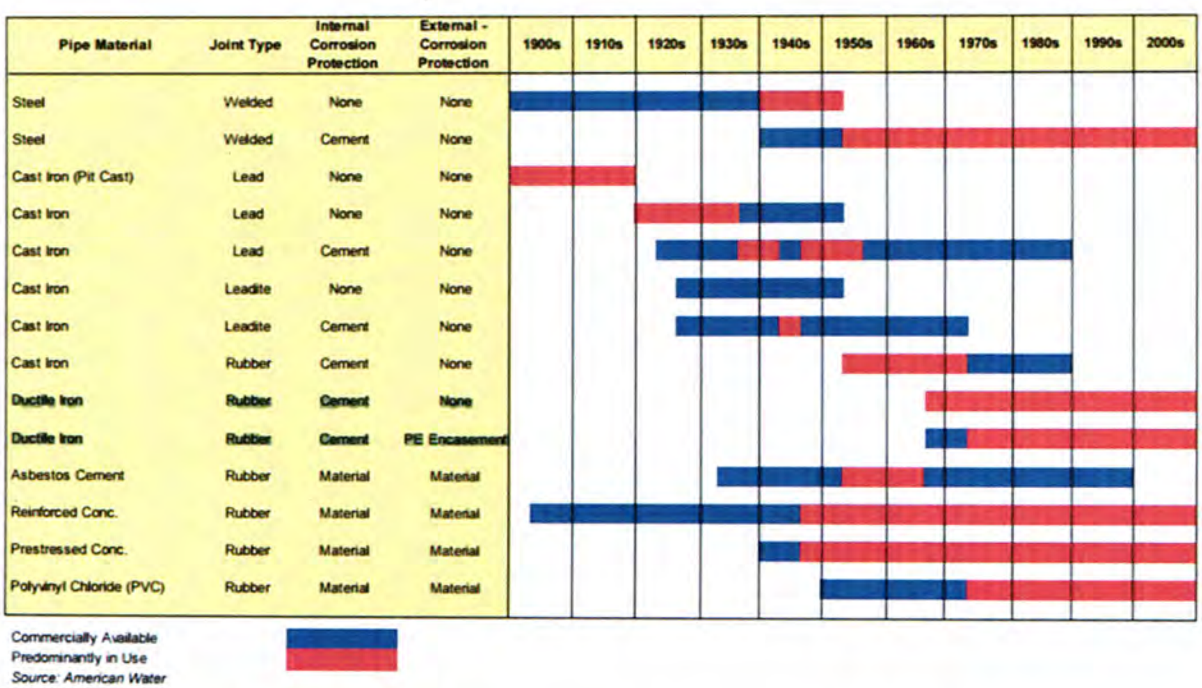



**Figure 7 – Historic Production and Use of Water Pipe by Material**

### *3.3.3 Hazen Williams C Values*

The Hazen Williams roughness coefficients (C values) used for the calibration of the hydraulic model (dated 2007) were added to the water mains feature class. This roughness coefficient can be used as a proxy for condition since pipes become rougher over time. Segments without C values (segments that weren't part of the hydraulic model) were assigned the average C value from segments with data that were installed during the same period and had the same diameter.

### *3.3.4 Spatial Accuracy and Segment Lengths*

Water mains features are aligned correctly and connected to other features such as valves and hydrants. This indicates good spatial accuracy of this feature class. However, the length of the segments varies considerably, and the segments vertices of most segments don't match with street intersections or valves. This can lead to inaccurate results when using this data set for life-cycle cost analysis.

To provide better understanding of the wide range of lengths through the system, Kleinfelder grouped the segments by the order of magnitude of their lengths (which is the number of digits of each length value). Fifty-eight percent of the system (by length) is represented by segments that are between 1,000 and 9,999 feet long, while 40% is composed by segments between 100 and 999 feet of length (3 digits). 1% is represented by 1 segment that have 5 digits of length (see inner circle in Figure 8).

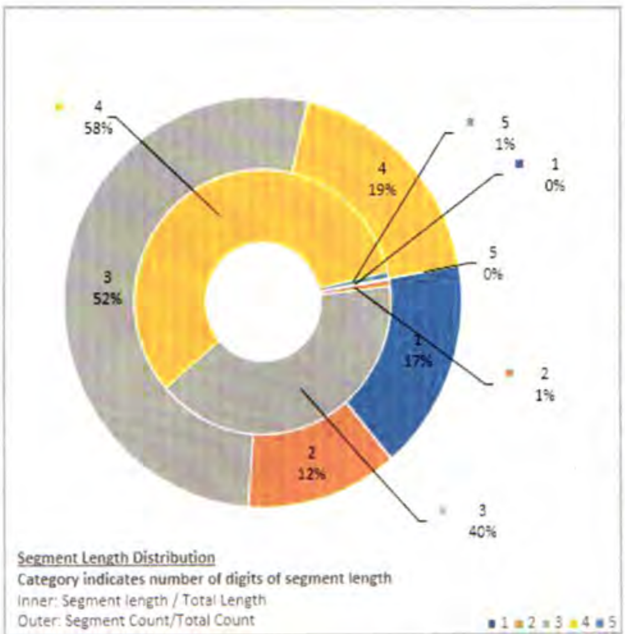



**Figure 8 – Water Mains Segment Length Analysis**

There is a considerable number of assets - 17% in asset count- of short lengths (less than 10 feet), as shown in the outer circle of Figure 8.

To ensure proper management of each asset, the water mains segments need to be adjusted in terms on length to represent a manageable unit.

The data cleanup effort should include removing shorter segments that represent service lines instead of distribution lines, or merging them if they indeed correspond to the distribution system. This effort should also include breaking long segments into shorter segments. The breaks should be placed at street intersections, or at the location of water valves.

## 3.4 OTHER DISTRIBUTION SYSTEM ASSETS

### *3.4.1 Hydrants*

There is a small discrepancy between the total number of hydrants in the GIS (2,113) and in the spreadsheet (2,118). Since the spreadsheet and the GIS had a hydrant ID field, we used it to link the two and create a hydrant feature class. This feature class is populated with make, year of installation, size of main, location, last inspection date and comments data. It appears that all the hydrants were inspected in 2002. The most common hydrant models are Eddie (1,261) and Darling (833).

### *3.4.2 Valves*

The valves inventory is extensive although the GIS contains no attribute information. The following table shows the valve count. Spatially, the location of these assets seems accurate. There is good connectivity of the valves to the water mains feature class. We suspect some errors on the identification of the type of valve. Some curb stop (curb cock valves) seem to represent a service valve, and the quantity should be higher. There must be a few missing hydrant valves given the difference between the number of those and the number of hydrants.

**Table 3 – Water System Valves**

| Valve Type | Count |
|---|---|
| 2 inch Valves | 205 |
| Butterfly Valves | 9 |
| Gate Valves | 3428 |
| Curb Cock Valves | 338 |
| Hydrant Valves | 2075 |
| Service Valves | 88 |

## 3.5 FACILITIES

The Division maintains 24 pump stations, 17 corrosion control facilities and 3 tanks. As part of this AMP, a data model for the entire system including facilities was developed. That means that asset types and hierarchy for facilities have been identified. This AMP contemplates facilities at the facility level, and the Division should utilize the provided data model as a living document to be updated over time.

**Table 4 – Summary of Facilities Information**

| Pump Station | Year Built | Aux Power | Pump Capacity (GPM) | AVG Daily Withdrawal (GPM, 2007) |
|---|---|---|---|---|
| PS-001M | 1931 | NO | 920 | 444 |
| PS-1 | 1953 | NO | 250 | 250 |
| PS-2 | 1953 | NO | 350 | 245 |
| PS-3 | 1953 | NO | 400 | 425 |
| PS-4 | 1960 | YES | 350 | 300 |
| PS-5 | 1960 | YES | 350 | 300 |
| PS-6 | 1963 | YES | 250 | - |
| PS-7 | 1963 | YES | 250 | - |
| PS-8 | 1963 | YES | 250 | - |
| PS-9 | 1936 | YES | 600 | - |
| PS-10 | 1969 | YES | 300 | 278 |
| PS-11 | 1969 | YES | 300 | 278 |
| PS-13 | 1974 | YES | 500 | 333 |
| PS-14 | 1974 | YES | 350 | 350 |
| PS-15 | 1975 | YES | 500 | 444 |
| PS-16 | 1975 | YES | 500 | 444 |
| PS-17 | 1976 | YES | 600 | 400 |
| PS-18 | 1976 | YES | 450 | 300 |
| PS-19 | 1976 | YES | 450 | 300 |
| PS-20 | 1979 | YES | 350 | 350 |
| PS-21 | 1981 | YES | 450 | 444 |
| PS-22 | 1981 | YES | 550 | 444 |
| PS-23 | 1989 | UNK | 500 | 550 |
| PS-24 | 1989 | NO | 350 | 350 |

| Corrosion Control Facility | Year Built | Treatment Capacity (GPM) |
|---|---|---|
| CCF-1M | 1993 | 920 |
| CCF-1 | 1993 | 250 |
| CCF-2-3 | 1993 | 750 |
| CCF-4-5 | 1993 | 700 |
| CCF-6-7-8 | 1993 | 750 |
| CCF-9 | 1993 | 600 |
| CCF-10 | 1993 | 300 |
| CCF-11 | 1993 | 300 |
| CCF-13 | 1993 | 500 |
| CCF-14 | 1993 | 350 |
| CCF-15-16 | 1993 | 1000 |
| CCF-17 | 1993 | 600 |
| CCF-18-19 | 1993 | 900 |
| CCF-20 | 1993 | 350 |
| CCF-21-22 | 1993 | 1000 |
| CCF-23 | 1993 | 500 |
| CCF-24 | 1993 | 350 |

# 4 LEVELS OF SERVICE

Levels of Service (LOS) criteria is a core element of an Asset Management Program, which defines the goals and standards that an organization will strive to maintain. Defining LOS for utilities is critical to allow the organization to assess its own performance. It is important to document customers' expectations, regulatory demands, and actual performance of the system. Because utilities have the main purpose of servicing people efficiently while minimizing impacts to the environment, 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 goal for any utility or system owner.

As infrastructure systems deteriorate with age, the LOS provided by those systems will decline as well. For example, if a water tank is left unmaintained, corrosion and bacteria build-up will eventually affect the quality of the water. Maintaining a desired LOS requires an investment. Asset management, and long-term sustainability consist of investing the right amount of money, at the right time to maintain the desired LOS at an acceptable level of risk.


**Figure 9 – LOS, Risk and Investment**

Levels of Service reflect the mission and values of the Division and are grouped into the following three categories: Social, Environmental and Economic. Metrics are expressed in terms of quality, quantity, reliability, responsiveness, cost, and environmental impact. They must be measurable and attainable.

During the Asset Management Principles and Level of Service Workshop, the Division examined the strengths, challenges, opportunities, and external factors influencing the Division's decision making and capabilities. In a group setting, this exercise engaged stakeholders by encouraging all participants to contribute their perspectives.

The Division identified the following strengths:

- Customer Service responsiveness and quality (they provide service 24 hours/day)
- Water quality and pressure

- Protection of the water sources (by scheduled pumping times and rates)

In terms of water quality, quantity, value and responsiveness and reliability of the Division towards their customers, the Division considered their service on a rating of 4.5 on a scale of 1 (poor) to 5 (excellent).

However, the Division faces challenges and recognizes areas of improvement. Most of their challenges come from the large number of assets that need to be maintained, and from the lack of an updated mapping that can help the staff identifying assets in the field accurately.

The Yarmouth Water Division Preliminary Levels of Service are presented in Tables 5, 6, and 7.

**Table 5 – Preliminary Level of Service: Social Focus**

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **Water Quality** | Compliance with Safe Drinking Water Act (SDWA) primary and secondary standards | Number of violations per year | 0 |
| | Compliance with Revised Total Coliform Rule (RTCR) | Number of violations per year | 0 |
| **Fire Protection** | There will be fire flow available for 100% of customers within the system | Meet Insurance Service Office's (ISO) requirements | |
| | | • Frequency of hydrant inspections | Annual |
| | | • Frequency of hydrant flushing | Biannual |
| | | • Distance between hydrants | 500-750 feet |
| **Water Availability** | No adverse event will cause the customer to be without water | Time without water (location based) | No more than 8 hours at a time |
| **Water Pressure** | A minimum pressure will be maintained in the distribution system | Monthly average of daily minimum values | More than 20 psi |
| **Response Time** | Respond to customer complaints/requests in a timely manner | • Emergency (water main breaks) | Within 1 hour |
| | | • Leaks | Within 1 hour |
| | | • New connection | 15 calendar days |
| | | • Meter repairs or replacement | 1 to 5 days |
| | | • Customer complaints (color, odor, bad taste) | 4 hours |
| **Complaints** | Customer complaints will be tracked and monitored on a regular basis (weekly) | Number of complaints due to unplanned or unanticipated issues such as water outages, poor pressure, colored water, or water with bad taste, odor. | Tracked weekly |
| **Communication** | Customers will be notified of planned shutdowns. | Number of days before shutdown | 3 days |

**Table 6 – Preliminary Level of Service: Economic Focus**

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **System Performance** | Main break frequency per year | Number of breaks per 100 miles per year | ≤ 20 /100 miles |
| **Financial Capability** | Revenues are reviewed on an annual basis to determine adequacy for operational needs | Financial analysis | Yearly |

**Table 7 – Preliminary Level of Service: Environmental Focus**

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **Aquifer Protection** | Compliance with Water Management Act (WMA) Permit Conditions | Number of violations per year | 0 |
| **Water Conservation** | Minimize water loss through leaks | Frequency of system-wide leak detection[3] survey | Every 3 years |

With these LOS identified and targets defined, the next step for the Division is to establish or modify existing workflows and systems (such as the newly acquired asset management software) to ensure information required to assess and track the LOS is captured. Over the long-term, this information will be useful to assess the Return on Investment (ROI) in adopting an asset management system and modus operandi.

[3] *The legal responsibility of leaks on private services and properties should be clearly defined in the by-laws, or the utilities rules and regulations. The Division will encourage customers to consider installing permanent leak detection equipment in their water system.*

# 5 EVALUATION OF CONDITION AND PERFORMANCE

Condition assessment is one of several methods for assessing the state of an asset. Performance monitoring, is a second method. The purpose of monitoring asset condition and performance is to determine its likelihood of failure. Additionally, tracking condition information over time is crucial for developing deterioration curves, which are the basis of long-term planning.

Currently, asset condition data is captured primarily through institutional knowledge of the Division's staff or through periodic inspection reports issued by vendors.

Kleinfelder reviewed records of pump station inspections from 2007. Additionally, the Division provided inspection data for the pump stations, corrosion control facilities and Water Division Headquarters building from 2015. This information was compiled and used as input for calculating likelihoods of failure for the facilities. Most pump stations were found to have condition ratings falling within the *fair* category. Pump maintenance and replacement information was also incorporated.

We identified performance data for some of the water supply wells, and records of well maintenance. The Division indicated that they conduct well-cleanings every five years. Two inspection reports were identified for the German Hill Tank (dated 2015) and the Prospect Hill Tank (dated 2009). Data sources are summarized in Table 8.

**Table 8 – Condition Data Sources**

| Asset Type | Existing Data Source & Tracking |
|---|---|
| **Supply Wells** | Flow Test report for well 21 (2015).<br>No flow tests identified for rest of the wells |
| **Pump Stations** | Inspection reports from 2007 and 2015. |
| **Corrosion Control Facilities** | Inspection reports from 2015. |
| **Storage Tanks** | Inspection report for German Hill tank (2015) and inspection report for Prospect Hill tank (2009). |
| **Distribution System** | C-values from 2007 hydraulic model. |
| **Hydrants** | No condition data. Latest inspections date back to 2003. |
| **Valves** | No data. |

## 5.1 CURRENT CONDITION AND PERFORMANCE OF ASSETS

### *5.1.1 Water Distribution System*

C values from the 2007 hydraulic model were assigned to the GIS water mains feature class. These C values range between 60 and 130. New ductile iron pipe exhibits a C value of 140, according to industry standards. Considering the distribution of C values by system age presented in Table 8, we mapped the water mains and compared it with the system age information in the hydrants database to see if there was a correlation.

**Table 9 – Condition Scores for Water Mains from C Values**

| C value | Age Range | Condition |
|---|---|---|
| **99-130** | Less than 28 | Very Good |
| **70-95** | 29-55 years | Good |
| **60-67** | 56-62 years | Fair |


**Figure 10 – C Values of the Water Distribution System**

Figure 10 shows C values from the modeling results of 2007 along with the hydrants, color-coded following the scale indicated in Table 9. Except for few areas, the two data sets are consistent with each other.

In any case, except for very isolated areas with somewhat low C values the system seems to be in good to very good condition, although we need to keep in mind that the modelling dates to 2007 and C values might have changed slightly in the past 10 years.

### *5.1.2 Water Supply Wells*

A common key performance indicator (KPI) for wells is the change of the well's specific capacity over time. This metric is calculated as the current specific capacity of the well divided by its original specific capacity. A flow test conducted in 2015 at Well 21 indicates that the original specific capacity when the well was developed in 1981 was 17.5 GPM/ft. The specific capacity in 2015 was 9.3 GPM/feet, which is 53% of the original. Original specific capacity data for the rest of the wells was not available and therefore this KPI could not be calculated for the rest of the wells.

Regular well maintenance activities have been conducted for the wells since 2006. Table 10, below shows the maintenance schedule history since 2010. In general, the Division conducts periodic well maintenance activities for the wells on a 5-year cycle.

**Table 10 – Well Maintenance History since 2010 (highlighted rows indicate well is overdue for maintenance)**

| Well | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|
| 1-Main | | | | | ● | | | |
| 1 | | | | | | ● | | |
| 2 | ● | | | | | ● | | |
| 3 | | | | | | ● | | |
| 4 | | | | | | ● | | |
| 5 | | | | | | ● | | |
| 6 | | | | | ● | | | |
| 7 | | | | | ● | | | |
| 8 | | | | | ● | | | |
| 9 | | ● (presumably) | | | | | | |
| 10 | | ● | | | ● | | | |
| 11 | | | | | | | | ● |
| 13 | | ● | | | | | | |
| 14 | | | | | | | | ● |
| 15 | | | | | | | | |
| 16 | | ● | | | | | | |
| 17 | | | | | ● | | | |
| 18 | | | | | ● | | | |
| 19 | | ● | | | | | | |
| 20 | | | | | | | | ● |
| 21 | | | | | ● | | | ● |
| 22 | | ● | | | | | | |
| 23 | | ● | | | | | | |
| 24 | | | | | | | | ● |

Most wells have undergone maintenance in the last 5 years, except for wells 13, 16, 19 and 23. There are no records of maintenance for Wells 9 and 15.

Kleinfelder reviewed the inspection reports from 2007 and 2015 to assess the condition of the pump stations. However, these reports include more information on the building systems more than the pumping equipment. The assessment used data from the well schematics reports to assign condition scored based on the year when the pump and motor where last maintained. This information is presented below:

**Table 11 – Pump Station Data and Condition Ratings**

| Pump Station | Facility Year Built | Pump and Motor Last Installation Year | Auxiliary Power | Pump Capacity (GPM) | Last Pump and Motor Maintenance | Building Condition Rating (2015) | Pump and Motor Condition |
|---|---|---|---|---|---|---|---|
| 001M | 1931 | 2014 | NO | 920 | Unk | 2.26 | Poor |
| 1 | 1953 | 2015 | NO | 250 | 2015 | 2.70 | Excellent |
| 2 | 1953 | 2010 | NO | 350 | 2015 | 2.57 | Good |
| 3 | 1953 | 2008 | NO | 400 | 2015 | 2.62 | Good |
| 4 | 1960 | 2008 | YES | 350 | 2015 | 2.81 | Good |
| 5 | 1960 | 2008 | YES | 350 | 2015 | 2.62 | Good |
| 6 | 1963 | 2014 | YES | 250 | 2006 | 2.52 | Poor |
| 7 | 1963 | 2014 | YES | 250 | 2006 | 2.50 | Poor |
| 8 | 1963 | 2014 | YES | 250 | 2006 | 2.48 | Poor |
| 9 | 1963 | 2008 | YES | 600 | 2008 | 2.67 | Fair |
| 10 | 1969 | 2014 | YES | 300 | 2011 | 2.62 | Fair |
| 11 | 1969 | 2009 | YES | 300 | 2009 | 2.77 | Fair |
| 13 | 1974 | 2014 | YES | 500 | 2011 | 2.57 | Fair |
| 14 | 1974 | 2009 | YES | 350 | 2009 | 2.44 | Good |
| 15 | 1975 | 2009 | YES | 500 | 2009 | 2.62 | Good |
| 16 | 1975 | 2011 | YES | 500 | 2011 | 2.55 | Fair |
| 17 | 1976 | 2014 | YES | 600 | 2006 | 2.56 | Poor |
| 18 | 1976 | 2014 | YES | 450 | 2006 | 2.61 | Poor |
| 19 | 1976 | 2011 | YES | 450 | 2011 | 2.40 | Fair |
| 20 | 1979 | 2009 | YES | 350 | 2009 | 2.74 | Good |
| 21 | 1981 | 2009 | YES | 450 | 2009 | 2.65 | Good |
| 22 | 1981 | 2011 | YES | 550 | 2011 | 2.45 | Fair |
| 23 | 1989 | 2011 | UNK | 500 | 2011 | 2.31 | Fair |
| 24 | 1989 | 2009 | NO | 350 | 2009 | 2.30 | Good |

**Table 12 – Corrosion Control Facilities Data**

| Corrosion Control | Year Built | Condition Rating (2015) | Condition Rating Description (2015) |
|---|---|---|---|
| CCF-001M | 1993 | 2.35 | Very Good |
| CCF-1 | 1993 | 2.23 | Very Good |
| CCF-2-3 | 1993 | 2.33 | Very Good |
| CCF-4-5 | 1993 | 2.46 | Very Good |
| CCF-6-7-8 | 1993 | 2.42 | Very Good |
| CCF-9 | 1993 | 2.37 | Very Good |
| CCF-10 | 1993 | 2.31 | Very Good |
| CCF-11 | 1993 | 2.35 | Very Good |
| CCF-13 | 1993 | 2.42 | Very Good |
| CCF-14 | 1993 | 2.31 | Very Good |
| CCF-15-16 | 1993 | 2.26 | Very Good |
| CCF-17 | 1993 | 2.27 | Very Good |
| CCF-18-19 | 1993 | 2.27 | Very Good |
| CCF-20 | 1993 | 2.32 | Very Good |
| CCF-21-22 | 1993 | 2.26 | Very Good |
| CCF-23 | 1993 | 2.31 | Very Good |
| CCF-24 | 1993 | 2.30 | Very Good |

In general, the corrosion control facilities were in very good condition at the time of the inspection (2015). Pumps stations buildings were in good to fair condition at the time of the inspection (2015). The estimated condition ratings for pump and motors estimated based on the year of their last inspection are fair or good for most of the pump stations.

### *5.1.3 Storage Tanks*

Condition information for two of the three the tanks was available from tank Inspection reports. The field inspection report of the German Hill tank from 2015 assesses the quality of the tank painting activities conducted. A summary of the storage tank condition is presented below.

**Table 13 – Summary of Tank Condition**

| Tank Name | Type | Capacity | Exterior | Interior | Structural | Safety |
|---|---|---|---|---|---|---|
| German Hill Tank (2015 inspection report) | Standpipe | 3.7 MG | Excellent (Painted in 2015) | Excellent (Painted in 2015) | Not rated | Not rated |
| Prospect Hill Tank (2009 inspection report) | Welded Steel | 4.0 MG | Failed (Coatings) | Failed (Coatings) | Fair | Good |
| Sandy Pond Tank | Elevated Tank | 1.5 MG | No data | No data | No data | No data |

# 6 ASSET CRITICALITY AND RISK

## 6.1 DEFINITION OF RISK

In the context of asset management, risk is defined as the likelihood of failure (LOF) of an asset multiplied times the severity and extent of the consequences of that failure (CoF).

Risk =Likelihood of Failure x Consequence of Failure

Consequences are negative outcomes that result from failures. There are three main consequence factors: social impacts, environmental impacts, and economic impacts. Sometimes regulatory compliance is considered a consequence factor (even when most regulations are in place to protect people or the environment). Failure of an asset may have all or only some of the consequence factors considered. Consequence factors should be applicable to any asset type. They are what matters to the asset owner. The consequence of failure score for a given asset is also referred to as the asset's criticality (how important is the asset without considering its likelihood of failure). Since consequence factors are common across asset types, and measured consistently through the asset portfolio, risk becomes the metric that allow us to compare and prioritize between different asset types.

Reaching long-term financial sustainability can be interpreted as investing sufficient resources in the water system so that the desired levels of service are maintained, at an acceptable level of risk. This concept is represented in Figure 11: With time, assets deteriorate and their condition ratings diminish (blue line). That affects the required level of service from the asset, which also decreases since the asset might require repairs more often, for example, or starts consuming more energy (green line). Deterioration increases the likelihood of failure of an asset, which translates into higher risk (purple line).

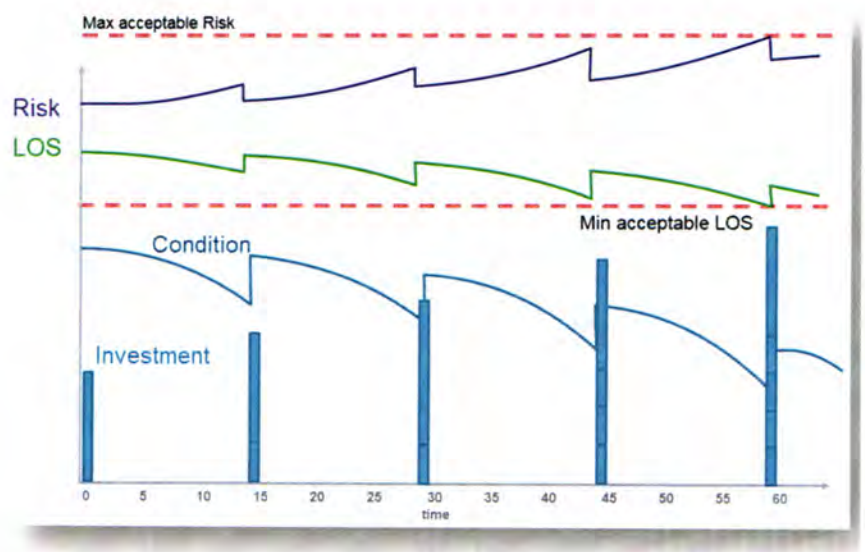



**Figure 10 – Long Term Sustainability as Minimum Investment to Maintain LOS and Risk**

Investments in assets (such as asset renewal or replacement) re-set the condition of the asset, which translates into higher LOS and lower risk. Long-term sustainability is achieved by making the right investments at the optimal time, keeping LOS and Risk within their acceptable boundaries.

## 6.2 FAILURE MODES AND LIKELIHOOD OF FAILURE

Failure refers to the state of not meeting design intent. Failure doesn't mean strictly structural or catastrophic failure. Failure modes are the different ways an asset can fail. To define failure modes one must think about the intended purpose or purposes of each asset. The objective or purpose of many different infrastructure assets types such as water mains, valves, roads, beams, etc. is to withstand a certain load or capacity while maintaining their physical integrity. Pipes are designed to convey a certain flow at certain valid range of velocities, roads are designed to accept traffic loads, and beams are designed for a nominal load capacity with an acceptable deflection. Capacity (understood as one or a group of design criteria) is therefore a failure mode. Failure modes are specific to each asset type.

To determine the likelihood of failure of an asset under each failure mode it's necessary to establish metrics. These are rating systems that will match, for example, the condition of an asset to its likelihood of failure under the physical integrity failure mode. For example, an asset that is in excellent condition would be assigned a very low likelihood of failure.

During the Risk workshop, the Division adopted the following ratings for condition and likelihood of failure:

**Table 14 – Condition Ratings and Likelihood of Failure Values**

| Rating | Condition | Description | Likelihood of Failure | Remaining Useful Life |
|---|---|---|---|---|
| **1** | Excellent | In very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Very Unlikely (LoF=2%) | More than 25 years |
| **2** | Good | Aged, but in good condition providing an adequate service. No signs of immediate or short term obsolescence | Unlikely (LoF =7%) | 10 to 25 years |
| **3** | Fair | Providing an adequate level of service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the medium term. May be signs of obsolescence in short to mid-term. | Likely (LoF=10%) | 5 to 10 years |
| **4** | Poor | Needs to be renewed, upgraded or replaced in the near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | Very Likely (LoF=20%) | 2 to 4 years |
| **5** | Very Poor/Failed | No longer providing an acceptable level of service. Requires immediate renewal or replacement. | Certain (LoF>=95%) | Less than a year |

Failure modes considered were physical integrity, performance and efficiency.

**Physical Integrity**: represents the likelihood of the asset to become inoperable due to deterioration. Physical Integrity is assessed using proxies that refer to the age of the asset (such as age, remaining useful life or percent life left) and condition. Condition is assessed via physical inspections, or other proxies such as the C value.

**Performance**: represents the likelihood of the asset to not meet their design criteria or not conduct the function that is intended to. For most fixed infrastructure assets, performance means capacity. For certain assets, performance also involves obsolescence, or high repair/maintenance needs.

**Efficiency**: This failure mode represents the performance of the asset as intended, such as with a pump or generator. If the asset is operating outside of its designed range then it is using more energy than designed and its efficiency is lower than expected. This failure mode typically applies to mechanical or power-operated asset types.

In Yarmouth, failure modes were defined for water supply wells, water tanks, pumps and motors, water mains, and corrosion control facilities (at the facility level). Failure modes were broken into their corresponding proxies (for example, age). We defined unit of measures and ranges for each corresponding likelihood of failure rating, which have been compiled in a scoring system (see Supplemental Documentation). Figure 12 shows the score card for assessing likelihood of failure for water mains.

**Likelihood of Failure Score Card**

| | | Likelihood of Failure | Extrem. Unlikely | Unlikely | Likely | Very Likely | Sure |
|---|---|---|---|---|---|---|---|
| | | Condition | Excellent | Good | Fair | Poor | Very Poor/Failed |
| | | Remaining life left | >25 years | 10-25 years | 5-10 years | 2-4 years | 0-months |
| | | Rating | 1 | 2 | 3 | 4 | 5 |
| **Failure Modes** | **Criteria** | **Measure or Proxy** | 2% | 7% | 10% | 20% | 95% |
| **Water Mains** | **Water Mains** | **Water Mains** | | **Water Mains** | | **Water Mains** | |
| Physical Integrity | Remaining Useful Life (opt 1) | Life Left (yrs) | 25 years or more | 24-11 years | 10 -5 years | 2-4 years | 1 year or less |
| | % Life Left (opt. 2) | % Life left equivalent for DI pipes (ESL=100) | >=25% | 10-25% | 10-5 % | 2-5% | <2% |
| | | | Excellent | Good | Fair | Poor | Very Poor/Failed |
| | | Condition Assessment (Field Data Inst. Knowledge) | New or in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. |
| | Breakage History | #Breakages/ 100 mi pipe (pipes grouped by cohorts) | 0-5 | 5-10 | 15 | 15-20 | >20 |
| | **Physical Integrity Score = Max (Remaining useful life, Condition, Breakage Hist.)** | | | | | | |
| Performance (= Capacity) | Capacity | C-Value from Calibrated Hydraulic Model | >100 | 100-81 | 80-61 | 31-60 | 30 or less |
| | Fire Flow | Fire Flow Adequacy from hydraulic model AND | >3500 gpm | (1500-3500) gpm | (750-1500) gpm | (750-500) gpm | <500 gpm |
| | | Available Fire Flow (hydraulic Model) and Needed Fire Flow (NFF) | Avg AFF > Avg NFF and min AFF > max NFF | Avg AFF > Avg NFF and min AFF > Avg NFF | Avg AFF > Avg NFF and min AFF > min NFF | Max AFF < min NFF and Avg AFF < Avg NFF | max AFF < min NFF |
| | **Performance Score = Maximum (Pressure, FireFlow)** | | | | | | |

**Figure 11 – Likelihood of Failure Score Card for Water Mains**

## 6.3 ASSET CRITICALITY AND CONSEQUENCE OF FAILURE

Consequences are direct negative outcomes resulting from a particular failure mode. For example, for a water utility it is important to maintain high quality water to protect the health of the consumers. In the framework of risk analysis, the emphasis is on the negative: outcomes that should be avoided such as regulatory infractions, health and safety hazards, or economic losses. The three main consequence factors are what constitute the triple-bottom-line (TBL): social, environmental and economic, however they can be broken down in categories that speak to those three such as health and safety, quality of life, operational cost, regulatory environmental compliance, etc.

When developing a consequence framework for risk analysis, one must consider the consequence factors as they fall into one of each of those categories, accepting that the failure of an asset may very well cause impacts in all three. The difficulty again lays on determining how to measure those impacts.

Potentially, all consequences could be measured as an economic loss, with all possible outcomes valued in dollar amounts. However, when it comes to measuring health and safety impacts, for example, this level of analysis can be daunting and overly complex for most purposes. For that reason, consequence factors are in practice usually estimated qualitatively and relatively amongst assets. Rating scales are set up with values such as negligible, low, moderate, high, and very high, and the values are assigned by comparison with the asset which failure would cause the most severe consequence. When building consequence ratings (or severity table), one must assess the extent and severity of consequences of different natures (and measuring units), and ensure that the same rating means the same across consequence factors.

The Division started developing a risk framework for their assets during this grant project through the risk and criticality workshop. Items addressed were the concepts of criticality, identifying critical assets, and developing a failure mode framework for different types of critical assets. This workshop also addressed how to prioritize assets based on risk and on consequence of failure and likelihood of failure values. Criticality was incorporated in the asset prioritization process with the understanding that the most critical assets are the assets with the highest consequence of failure.

The consequence of failure ratings adopted by the Division were from 1 to 5:

- 1: Minor
- 2: Low
- 3: Moderate
- 4: High
- 5: Very high

Being this the first round of asset management planning embraced by the Division, consequence was addressed as *assigned criticality*. That is, criticality scores (instead of consequence failure ratings) were assigned to the different asset types based on institutional knowledge of the asset. The Division reviewed the criticality scores during the Risk and Criticality workshop. These are presented in Figure 13.

**Assigned Criticality**

| | | Extent and Severity | Minor | Low | Moderate | High | Very High |
|---|---|---|---|---|---|---|---|
| | Reasoning/criteria | Measure or Proxy | Rating 1 | 2 | 3 | 4 | 5 |
| **Criticality** | | | | | | | |
| Water Mains | Larger diameters convey more flow--> serve more customers or could impact more people. Also, larger diameters are more expensive. A break in a larger main could result in more water loss. | Diameter | Less or equal to 6 inch | 8 and 10 inch | 12 inch | 16 and 20 inch | N/A |
| Pump Stations and Corrosion Control Facilities | Impact to Customers | Pumping/Serving Capacity | NA | NA | <=350 GPM | 400 -600 GPM | >600 GPM |
| Wells | | Pumping/Serving Capacity | NA | NA | <=350 GPM | 400 -600 GPM | >600 GPM |
| Tanks | Impact to Customers | | | | | All tanks get this score | |

**Figure 12 – Criticality Scores**

## 6.4 RISK-BASED PRIORITIZATION

To prioritize needs based on risk, one must take into consideration not only risk scores, but consequences and likelihood scores as well. The three numbers matter because risk mitigation strategies depend on where each asset "falls" within the risk space (see Figure 14). It is possible to have assets with the same or very similar risk scores, but one could be due to higher likelihood of failure and lower consequence than the other. To do so, the organization must define where does it "draw the line" that separates high criticality from low criticality (criticality threshold), and where does it draw the line that separates unacceptable likelihood of failure from acceptable (likelihood of failure or level of service threshold).

The criticality threshold can be adopted by an organization by looking at the consequence factor rating system, and deciding the rating that will mark that line.

The likelihood of failure threshold represents the minimum level of service (LOS) acceptable by the organization. One can use Table 13 – Likelihood of Failure Ratings to see the return periods corresponding to each rating to help with that decision. An easy way for visualizing risk scores based on these three numbers (risk score, criticality and likelihood of failure) is to use the risk space diagram, which is shown below in Figure 14. This plots criticality on the horizontal axis, and likelihood of failure on the vertical axis. Each risk score can be then represented by a point in this space using its two scores for LoF and criticality. Risk scores increase diagonally from the bottom left corner to the top right corner.

The criticality threshold divides the risk space vertically in two, representing more critical (on the right) and less critical (on the left). The LoF threshold divides the risk space horizontally in two, representing high probabilities of failure (above the minimum acceptable LOS) on the top, and acceptable LoFs on the bottom. With these two thresholds in place, the risk space is then divided in four quadrants:

- High-Risk Quadrant: The top right corner (in red) corresponds to the space representing critical assets that have high LoF. Assets with scores that fall into this quadrant need to be first priority. To further refine priorities within this quadrant, strict risk scores may be used.

- Maintenance and Monitoring Quadrant: The right bottom corner (in orange), corresponds to assets that are critical, but have acceptable probabilities of failure. Assets in this quadrant will eventually move to the high-risk quadrant if not maintained, as deterioration will increase their LoF over time. For this reason, maintenance and inspection of these assets is highly recommended.
- Important Quadrant: Assets that fall into this quadrant (top left corner in yellow) are failed or about-to-fail but are not critical. Issues here need to be addressed as a secondary priority after the high-risk assets, as budget allows.
- Low-Risk Quadrant: Assets that fall on the bottom left corner (in green), are not critical and have acceptable LoF. Issues in this section should be addressed last.

With the scoring system adopted by the Division, the lowest risk score is 1 and the highest is 25. The criticality threshold was set at 4 (included) and the minimum required LOS threshold at 3 (included). Those thresholds divide the risk space in the quadrants defined above which have risk scores as depicted in Figure 14.

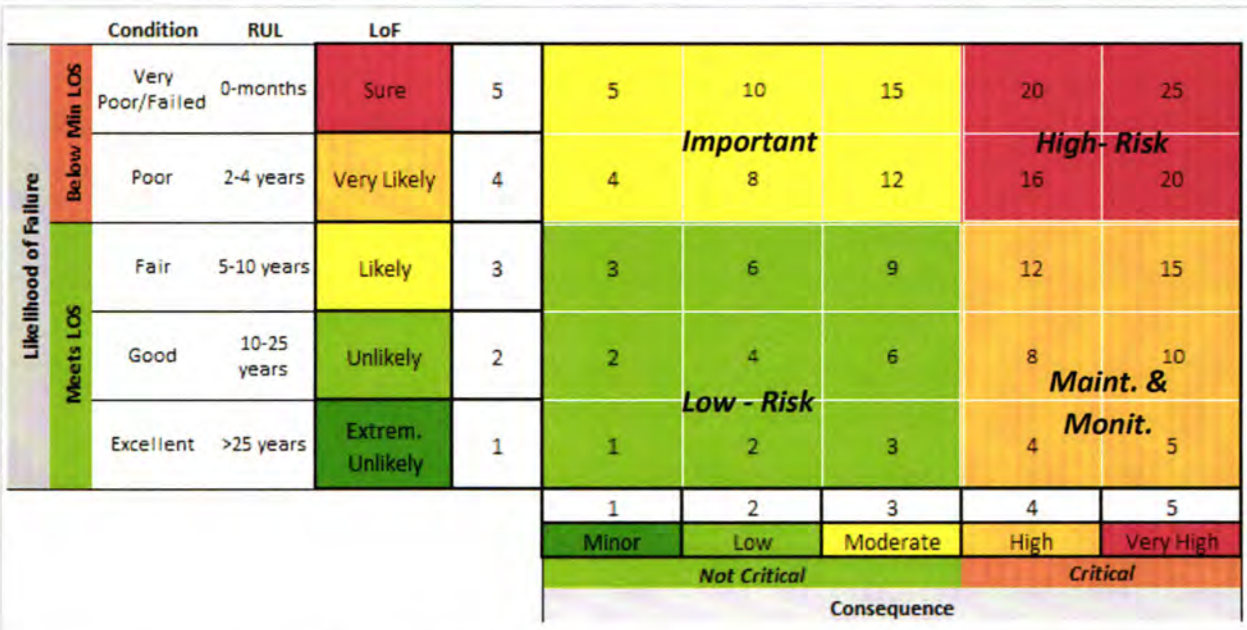



**Figure 13 – Risk Space and Quadrants with Risk Scores**

## 6.5 RISK ANALYSIS

### *6.5.1 Distribution System*

The risk analysis for the water mains was conducted in Excel. The dataset included:

- PipeID: Unique identifier for each pipe segment
- Material
- Diameter

- Year built
- C value

We considered all segments to be ductile iron (as discussed in section 4).

We assigned C values to the segments that didn't have C values (because they weren't originally included in the hydraulic model) by assigning them the values of other segments with the same diameter and decade of installation to reflect a similar deterioration rate.

The estimated service life (ESL) of ductile iron pipe is a model variable. The model changes dynamically when this value is changed.

With the data above the model calculates:

1. Age: difference between the analysis year (2017) and the year built.
2. RUL: Remaining useful life, RUL=ESL-Age and it is set to 0 when that difference is negative
3. LoF_RUL: Likelihood of failure score based on RUL (physical integrity), as defined in the risk framework (see Supplemental Documentation and Figure 12)
4. LoF_C: Likelihood of failure based on C value (performance), as defined in the risk framework (see Supplemental Documentation and Figure 12)
5. CoF: Criticality score. In this case is driven by the pipe diameter, as defined in the risk framework (see Supplemental Documentation and Figure 13)
6. R (RUL x CoF): Physical Integrity risk score. Product of LoF_RUL and CoF.
7. R (C x CoF): Performance risk score. Product of LoF_C and CoF.
8. Max R: Maximum of the 2 risk scores
9. Max LoF: LoF associated with the Maximum risk score (since there is only one CoF, it's the Max Risk/CoF)
10. Risk Box: The model finds where in the risk space each segment lays.

| OBJECTID | Material | Diam | Year Installed | C | Length | Assigned C | ESL | Age | RUL | LoF_RUL | LoF_C | CoF | R (RUL x CoF) | R (C x CoF) | Max R | Max LoF | Box | Repl. Unit Cost ($/LF) | Replacement Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ductile Iron | 6 | 1970 | 0 | 17.7 | 75 | 110 | 47 | 63 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 1,068 |
| 2 | Ductile Iron | 6 | 1957 | 0 | 106.2 | 75 | 110 | 60 | 50 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 6,413 |
| 3 | Ductile Iron | 6 | 1950 | 0 | 601.5 | 70 | 110 | 67 | 43 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 36,325 |
| 4 | Ductile Iron | 8 | 1860 | 0 | 2.3 | 75 | 110 | 157 | 0 | 5 | 3 | 2 | 10 | 6 | 10 | 5 | V | $ 71.29 | $ 164 |
| 5 | Ductile Iron | 8 | 1945 | 0 | 402.1 | 80 | 110 | 72 | 38 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 28,666 |
| 7 | Ductile Iron | 6 | 1950 | 70 | 1266.7 | 70 | 110 | 67 | 43 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 76,497 |
| 8 | Ductile Iron | 6 | 1927 | 0 | 7.9 | 80 | 110 | 90 | 20 | 2 | 3 | 1 | 2 | 3 | 3 | 3 | K | $ 60.39 | $ 480 |
| 9 | Ductile Iron | 8 | 1973 | 0 | 43.9 | 80 | 110 | 44 | 66 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 3,127 |
| 10 | Ductile Iron | 8 | 1935 | 0 | 41.6 | 80 | 110 | 82 | 28 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 2,964 |
| 11 | Ductile Iron | 8 | 1960 | 0 | 42.1 | 80 | 110 | 57 | 53 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 3,000 |
| 12 | Ductile Iron | 10 | 1988 | 0 | 38.9 | 100 | 110 | 29 | 81 | 1 | 2 | 2 | 2 | 4 | 4 | 2 | G | $ 100.31 | $ 3,903 |
| 13 | Ductile Iron | 8 | 1946 | 0 | 753.0 | 80 | 110 | 71 | 39 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 53,681 |
| 15 | Ductile Iron | 12 | 1965 | 0 | 105.0 | 110 | 110 | 52 | 58 | 1 | 1 | 3 | 3 | 3 | 3 | 1 | C | $ 106.77 | $ 11,211 |
| 16 | Ductile Iron | 6 | 1965 | 0 | 108.5 | 75 | 110 | 52 | 58 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 6,554 |
| 17 | Ductile Iron | 6 | 1949 | 0 | 25.5 | 70 | 110 | 68 | 42 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | K | $ 60.39 | $ 1,543 |
| 18 | Ductile Iron | 8 | 1949 | 80 | 2218.2 | 80 | 110 | 68 | 42 | 1 | 3 | 2 | 2 | 6 | 6 | 3 | L | $ 71.29 | $ 158,133 |
| 19 | Ductile Iron | 12 | 1930 | 0 | 75.0 | 110 | 110 | 87 | 23 | 2 | 1 | 3 | 6 | 3 | 6 | 2 | H | $ 106.77 | $ 8,005 |

**Figure 14 – Water Distribution Risk Analysis Model**

Details of the simulation are presented in the Supplemental Documentation.

The risk spaces in the following figures are color-coded to highlight the "high density" areas, or the density of the assets. These risk spaces are represented as LoF (the vertical axis) versus CoF (horizontal axis). Therefore, a box identified as 2-3 represents a risk value of 6 (Consequence is 2 and LoF is 3). Ideally, we'd like to see blue on the top left corner (indicating smaller quantities falling in the *high-risk* quadrant) and red in the bottom right corner (indicating greater quantities falling in the low risk quadrant). The value in each box represents the total quantities with risk scores (as LoF and CoF) as depicted in Figure 16. The four boxes in the corners of the risk space contain the sum of quantities for each of the four quadrants. Values along the Likelihood axis are the totals per each row, and along the CoF axis, the totals per each column.

### *Simulation A: Using ESL of 110 years*

Ductile iron pipe has a ESL that can range between 55 and 110 years. The first simulation was done using ESL of 110 years (which is the "optimistic" simulation). Figure 16 a) displays the distribution of risk by total length. The model adds the lengths of the segments based on what risk "box" they fall into (by matching the CoF with the maximum LoF). In this simulation, there are 0 feet of pipe that fall into the *High-Risk* quadrant, 13,301 feet in the *Important* quadrant, and 38,313 feet in the *Maintenance /Monitoring* quadrant, while the rest lay in the *Low-Risk* quadrant.

Figure 16 b) Displays the same results but expressed as %. Here we can see that 96.53% of the system by length falls in the *Low-Risk* quadrant.

**a) Risk Distribution by Length (in feet)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 13,301 | | | | | | 0 |
| 12,033 | LoF 5 | 7,602 | 4,054 | 377 | - | - | |
| 1,268 | 4 | - | 1,268 | - | - | - | |
| 705,685 | 3 | 439,919 | 257,838 | 7,928 | - | - | |
| 493,847 | 2 | 61,154 | 425,196 | 7,497 | - | - | |
| 275,690 | 1 | 5,377 | 28,983 | 203,017 | 38,313 | - | |
| | 1,436,908 CoF | 1 | 2 | 3 | 4 | 5 | 38,313 |
| | | 514,052 | 717,338 | 218,819 | 38,313 | 0 | |

**b) Risk Distribution by Length as % of Total**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.89% | | | | | | 0.00% |
| 1% | LoF 5 | 1% | 0% | 0% | 0% | 0% | |
| 0% | 4 | 0% | 0% | 0% | 0% | 0% | |
| 47% | 3 | 30% | 17% | 1% | 0% | 0% | |
| 33% | 2 | 4% | 29% | 1% | 0% | 0% | |
| 19% | 1 | 0% | 2% | 14% | 3% | 0% | |
| | 96.53% CoF | 1 | 2 | 3 | 4 | 5 | 2.57% |
| | | 35% | 48% | 15% | 3% | 0% | |

**Figure 15– Risk distribution of water mains by a) length in feet and b) length as % of total considering ESL of DI is 110 years**

This simulation reveals a very healthy system with 99% of the system below the LoF threshold of 4.

### *Simulation B: Using ESL of 55 Years*

This is a conservative simulation that uses ESL for ductile iron pipe of 55 years. Figure 17 displays the results. With the ESL cut in half, we see a shift towards the top of the chart. That means, the physical integrity (as measured by the RUL) is driving the highest LoF. 10,696 feet of main now fall in the *High-Risk* quadrant. 22% of the system is in the *Important* quadrant.

**a) Risk Distribution by Length (in feet)**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 336,819 | | | | | | 10,696 |
| 295,262 | LoF 5 | 177,379 | 83,094 | 24,093 | 10,696 | - | |
| 52,254 | 4 | 33,818 | 13,893 | 4,543 | - | - | |
| 649,502 | 3 | 297,801 | 289,982 | 57,405 | 4,314 | - | |
| 447,280 | 2 | 5,055 | 323,175 | 100,791 | 18,260 | - | |
| 44,225 | 1 | - | 7,194 | 31,988 | 5,042 | - | |
| | 1,113,390 | CoF 1 | 2 | 3 | 4 | 5 | 27,617 |
| | | 514,052 | 717,338 | 218,819 | 38,313 | 0 | |

**b) Risk Distribution by Length as % of Total**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22.63% | | | | | | 0.72% |
| 20% | LoF 5 | 12% | 6% | 2% | 1% | 0% | |
| 4% | 4 | 2% | 1% | 0% | 0% | 0% | |
| 44% | 3 | 20% | 19% | 4% | 0% | 0% | |
| 30% | 2 | 0% | 22% | 7% | 1% | 0% | |
| 3% | 1 | 0% | 0% | 2% | 0% | 0% | |
| | 74.80% | CoF 1 | 2 | 3 | 4 | 5 | 1.86% |
| | | 35% | 48% | 15% | 3% | 0% | |

**Figure 16 – Risk distribution of water mains by a) length in feet and b) length as % of total considering ESL of DI is 55 years**

### *Simulation C: Using ESL of 90 Years*

We conducted a third simulation using 90 years of ESL. The results are presented in Figure 18.

**a) Risk Distribution by Length (in feet)**

| | | 22,140 | | | | | 0 |
|---|---|---|---|---|---|---|---|
| 20,138 | LoF 5 | 14,139 | 5,548 | 452 | - | - | |
| 2,002 | 4 | - | 1,907 | 95 | - | - | |
| 697,143 | 3 | 433,382 | 255,833 | 7,928 | - | - | |
| 494,067 | 2 | 61,154 | 425,452 | 7,327 | 135 | - | |
| 275,172 | 1 | 5,377 | 28,599 | 203,017 | 38,179 | - | |
| 1,428,069 | CoF | 1 | 2 | 3 | 4 | 5 | 38,313 |
| | | 514,052 | 717,338 | 218,819 | 38,313 | 0 | |

**b) Risk Distribution by Length as % of Total**

| | | 1.49% | | | | | 0.00% |
|---|---|---|---|---|---|---|---|
| 1% | LoF 5 | 1% | 0% | 0% | 0% | 0% | |
| 0% | 4 | 0% | 0% | 0% | 0% | 0% | |
| 47% | 3 | 29% | 17% | 1% | 0% | 0% | |
| 33% | 2 | 4% | 29% | 0% | 0% | 0% | |
| 18% | 1 | 0% | 2% | 14% | 3% | 0% | |
| 95.94% | CoF | 1 | 2 | 3 | 4 | 5 | 2.57% |
| | | 35% | 48% | 15% | 3% | 0% | |

**Figure 17 – Risk distribution of water mains by a) length in feet and b) length as % of total considering ESL of 90 years**

This simulation still depicts a very healthy system with 0% of the mains in the high-risk area and only 1.5% of the system in the Important quadrant.

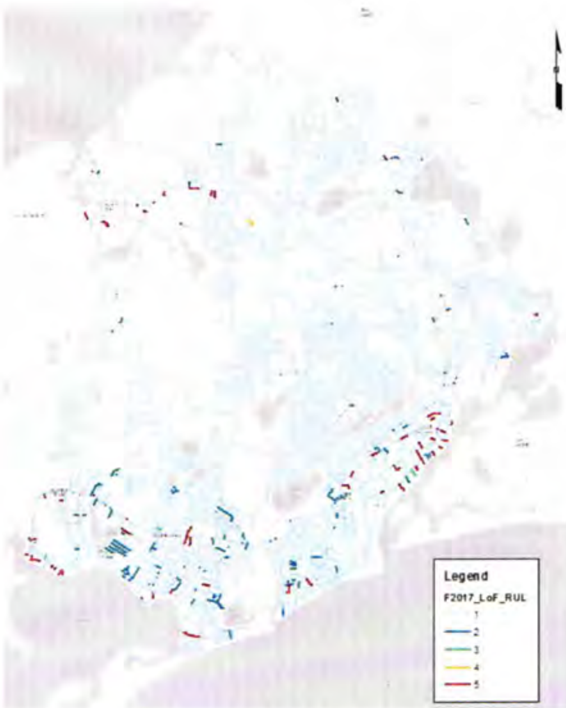



**Figure 18 – LoF RUL Map**


**Figure 19– LoF C Map**

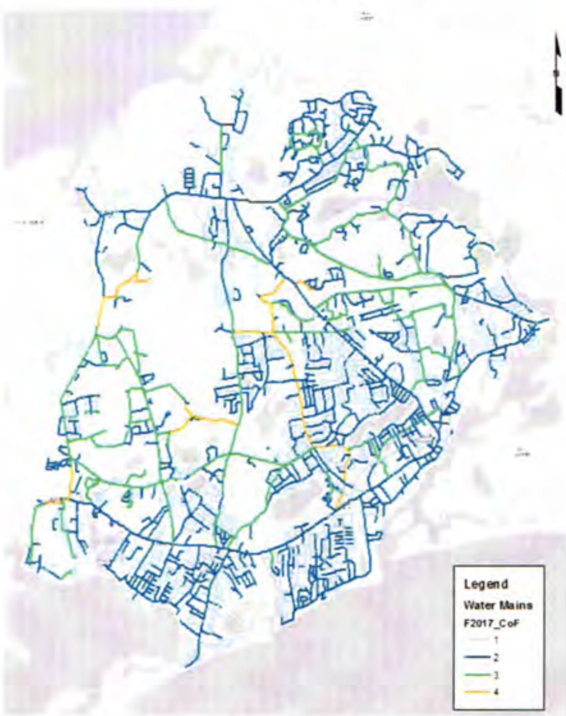



**Figure 20 – Criticality Scores**


**Figure 21 – Risk Quadrants**

### *6.5.2 Facilities*

The process for calculating risk scores for facilities is like the process followed for the water mains. Likelihood of failure scores and consequence factors are calculated following the parameters defined in the risk framework.

The model uses the following information:

- Facility name
- Facility Type (PS: pump station, CCF: Corrosion Control Facility and Tank)
- Year built
- Service capacity in GPM
- Pump Installation Year
- Building Condition Rating (see section 6)
- Pump Condition Rating

The model also uses the following input variables that can be changed by the user to run different scenarios:

- Estimated Service Life (ESL) for pumps, corrosion control facilities and tank coatings
- Costs for pump replacement, corrosion control facilities rehabilitation and tank painting

Risk is calculated differently for these three asset types:

***Pump Stations:***

Risk is calculated at the asset level. The critical assets within this type of facility are the pumps and motors (looking at these facilities as part of a system, the water system, and considering their purpose: to pump water). The Risk factors for pump stations are calculated considering the remaining useful life of the pump and motor (LoF_RUL), and their condition (LoF_Cond). Consequence rating is based on the pumping capacity (see Figure 13, and Supplemental Documentation).

***Corrosion Control Facilities:***

Risk for these facilities is calculated at the facility level considering the remaining useful life of the equipment. In the future, this approach could be fined-tuned by developing an asset register for each of these facilities and calculating risk based on the most critical assets in these facilities, which should be the chemical feel pumps.

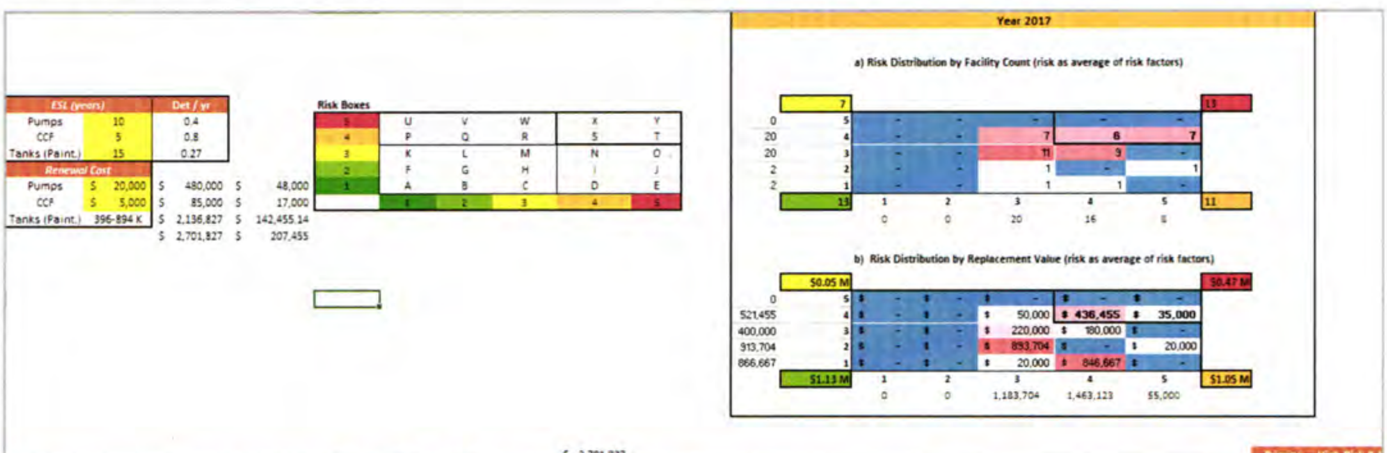
**Tanks:**

Risk for these facilities is calculated at the facility level considering that the dominant failure mode is corrosion of the tank, and that painting is required on a 15-year basis. Therefore, useful life is set to 15 years. This approach is acceptable although not ideal because the long-term planning simulation conducted in this AMP is 10-years long.

The model is set-up to calculate:

1. Initial year: value that is the installation year of the pump for the pump stations, the year built for the corrosion control facilities and the year when the tank was last painted for the tanks.
2. Age: the difference between that initial year and today's year (2017)
3. RUL: Remaining useful life, based on age and the ESL input variables
4. LoF_RUL: likelihood of failure score as defined in the risk framework (see Supplemental Documentation)
5. LoF_Cond: likelihood of failure score given the Condition of the asset as defined in the risk framework (see Supplemental Documentation)
6. CoF: Consequence of failure score as defined in the risk framework
7. R (RUL x CoF): Physical Integrity risk score. Product of LoF_RUL and CoF.
8. R (C x CoF): Performance risk score. Product of LoF_C and CoF.
9. Average R: Average of the 2 risk scores
10. Average LoF: Average LoF associated with the Maximum risk score (since there is only one CoF, it's the Average R/CoF)
11. Box: The model finds where in the risk space each facility lays.

Figures 22 shows the Facilities model. Figure 23 shows the results obtained reported in terms of a) facility count and b) replacement value.




$ 2,701,827

| Facility Nar | Type | Year Buil | Service Capacity (GPM) | Pump Installation Year | Buildg Condition Ratin | Pump Condition Ratin | Year 0 | Renewal C | Age | ESL | RUL | LoF_RUL | LoF_Con | CoF | R (RUL x Co | R (C x Co | Avg R | Avg L | Box | Quadra |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CCF-1 | CCF | 1993 | 250 | NA | 2.23 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.23 | 3 | 15 | 6.69 | 10.845 | 4 | R | Important |
| CCF-10 | CCF | 1993 | 300 | NA | 2.31 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.31 | 3 | 15 | 6.93 | 10.965 | 4 | R | Important |
| CCF-11 | CCF | 1993 | 300 | NA | 2.35 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.35 | 3 | 15 | 7.05 | 11.025 | 4 | R | Important |
| CCF-13 | CCF | 1993 | 500 | NA | 2.42 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.42 | 4 | 20 | 9.68 | 14.84 | 4 | S | High-Risk |
| CCF-14 | CCF | 1993 | 350 | NA | 2.31 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.31 | 3 | 15 | 6.93 | 10.965 | 4 | R | Important |
| CCF-15-16 | CCF | 1993 | 1000 | NA | 2.26 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.26 | 5 | 25 | 11.3 | 18.15 | 4 | T | High-Risk |
| CCF-17 | CCF | 1993 | 600 | NA | 2.27 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.27 | 4 | 20 | 9.08 | 14.54 | 4 | S | High-Risk |
| CCF-18-19 | CCF | 1993 | 900 | NA | 2.27 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.27 | 5 | 25 | 11.35 | 18.175 | 4 | T | High-Risk |
| CCF-1M | CCF | 1993 | 920 | NA | 2.35 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.35 | 5 | 25 | 11.75 | 18.375 | 4 | T | High-Risk |
| CCF-20 | CCF | 1993 | 350 | NA | 2.32 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.32 | 3 | 15 | 6.96 | 10.98 | 4 | R | Important |
| CCF-21-22 | CCF | 1993 | 1000 | NA | 2.26 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.26 | 5 | 25 | 11.3 | 18.15 | 4 | T | High-Risk |
| CCF-23 | CCF | 1993 | 500 | NA | 2.31 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.31 | 4 | 20 | 9.24 | 14.62 | 4 | S | High-Risk |
| CCF-2-3 | CCF | 1993 | 750 | NA | 2.33 | NA | 1993 | $ 5,000 | 24 | 5 | 0 | 5 | 2.33 | 5 | 25 | 11.65 | 18.325 | 4 | T | High-Risk |

**Figure 22 – Facilities Risk Model**

Thirteen facilities fall in the high-risk quadrant and represent a renewal investment of $0.45 million. Eleven facilities fall in the maintenance and monitoring quadrant, with a renewal cost of $1.05 million. Seven facilities are in the *important* quadrant and equate to $50,000 of renewal costs. Thirteen facilities are in the low-risk quadrant with a renewal cost of $1.13 million.

**a) Risk Distribution by Facility Count (risk as average of risk factors)**

| | | 7 | | | | | | 13 |
|---|---|---|---|---|---|---|---|---|
| 0 | LoF | 5 | - | - | - | - | - | |
| 20 | | 4 | - | - | 7 | 6 | 7 | |
| 20 | | 3 | - | - | 11 | 9 | - | |
| 2 | | 2 | - | - | 1 | - | 1 | |
| 2 | | 1 | - | - | 1 | 1 | - | |
| | | 13 | CoF 1 | 2 | 3 | 4 | 5 | 11 |
| | | | 0 | 0 | 20 | 16 | 8 | |

**b) Risk Distribution by Replacement Value (risk as average of risk factors)**

| | | $0.05 M | | | | | | $0.47 M |
|---|---|---|---|---|---|---|---|---|
| 0 | LoF | 5 | $ - | $ - | $ - | $ - | $ - | |
| 521,455 | | 4 | $ - | $ - | $ 50,000 | $ 436,455 | $ 35,000 | |
| 400,000 | | 3 | $ - | $ - | $ 220,000 | $ 180,000 | $ - | |
| 913,704 | | 2 | $ - | $ - | $ 893,704 | $ - | $ 20,000 | |
| 866,667 | | 1 | $ - | $ - | $ 20,000 | $ 846,667 | $ - | |
| | | $1.13 M | CoF 1 | 2 | 3 | 4 | 5 | $1.05 M |
| | | | 0 | 0 | 1,183,704 | 1,463,123 | 55,000 | |

**Figure 23 – Risk Distribution of Facilities using Risk as average of Risk Scores, for 2017**

Figure 24 shows the facilities in their corresponding risk quadrants.

| Important | | | High-Risk | | |
|---|---|---|---|---|---|
| | | | | | CCF-4-5 |
| | CCF-1 | CCF-20 | CCF-13 | CCF-1M | CCF-6-7-8 |
| | CCF-10 | CCF-24 | CCF-15-16 | CCF-21-22 | CCF-9 |
| | CCF-11 | PS-11 | CCF-17 | CCF-23 | PS-9 |
| | CCF-14 | | CCF-18-19 | CCF-2-3 | SANDY POND |
| **Low Risk** | | | **Maint/Monitoring** | | |
| PS-1 | PS-24 | PS-7 | PS-001M | PS-17 | PS-22 |
| PS-10 | PS-3 | PS-8 | PS-13 | PS-18 | PS-23 |
| PS-14 | PS-4 | PROSPECT HILL | PS-15 | PS-19 | GERMAN HILL |
| PS-2 | PS-5 | | PS-16 | PS-21 | |
| PS-20 | PS-6 | | | | |

**Figure 24 – Facilities in their Risk Quadrants (2017)**

# 7 FINANCIAL PLANNING

This section presents the methodology used for estimating future necessary investments in the water system to maintain the levels of service defined in Section 2, while meeting demands, at an acceptable level of risk. The purpose of financial planning is to identify and quantify future investment needs so that the Division can prepare accordingly by either adjusting their rates or use other financial strategies such as bonds. The time horizon used for this financial needs analysis is 10 years to match MassDEP guidance.

## 7.1 DISTRIBUTION SYSTEM

### *7.1.1 System Replacement Cost and Annual Investment*

A financial model in Excel was developed using water mains data from GIS. All the water mains segments (1903 records) were imported into the model. Each segment had material (ductile Iron), diameter, C value, year installed and length in feet. Other model variables were:

- Year of Analysis (default value is 2017)
- Estimated Service Life of ductile iron (range between 55 years and 110 years)
- Replacement unit costs
- Repair costs
- Number of breaks per year

With unit costs ranging from $100/ft for the 2-inch mains to $230/ft for the 24-inch mains the distribution system network has a replacement value of $200.8 million. The system should be replaced continually as assets deteriorate and fail. Considering the average estimated service life of the system to be 90 years, which is an acceptable value for ductile iron pipes, the Division should be expected to invest an average of $2.23 million per year in pipe replacement.

The system has 2,118 hydrants, which with an estimated replacement cost of $4,000 each, they represent a replacement cost of $8.47 million. The distribution system valves replacement cost totals $12 million (excluding valves smaller than 6 inches and curb stops), based on the inventory of assets (see section 4). Estimates are summarized in Table 15.

Using these replacement costs, one can estimate the expected average yearly investment on the system to maintain the assets over time. The estimate is calculated by dividing the total cost by the estimated service life of the asset. We calculated an optimistic estimate (considering the largest value of the ESL), a conservative estimate (using the smallest value of the ESL) and a standard or common estimate (using common or standard values of ESL for those asset types). Results are presented in Table 16. Given the size of the system, **the Yarmouth's Water Division should be expected to invest between $2.10 and $4.67 million a year in water distribution system replacement (mains, hydrants and valves) to sustain the system over time.**

**Table 15– Estimated replacement value of system valves**

| Diameter (inches) | Num. of Hydrant Valves | Num. of Gate Valves | Total Valves | Unit Cost (ea) | Total Replacement Value |
|---|---|---|---|---|---|
| 6 | 594 | 1030 | 1624 | $1,200 | $1,948,800 |
| 8 | 980 | 1546 | 2526 | $1,700 | $4,294,200 |
| 10 | 129 | 220 | 349 | $3,000 | $1,047,000 |
| 12 | 323 | 539 | 862 | $3,400 | $2,930,800 |
| 16 | 31 | 48 | 79 | $10,000 | $790,000 |
| 20 | 21 | 47 | 68 | $12,000 | $816,000 |
| **Totals** | **2078** | **3430** | **5508** | | **$11,826,800** |

**Table 16 – Estimated Annual System Investments**

| Asset | Total Replacement Cost | Estimated Service Life (years) | | Annual Investment - Optimistic | Annual Investment - Standard | Annual Investment - Conservative |
|---|---|---|---|---|---|---|
| Hydrants | $8,472,000 | Optimistic | 75 | $ 112,960 | $ 169,440 | $ 423,600 |
| | | Standard | 50 | | | |
| | | Conservative | 20 | | | |
| Valves | $11,826,800 | Optimistic | 75 | $ 157,691 | $ 236,536 | $ 591,340 |
| | | Standard | 50 | | | |
| | | Conservative | 20 | | | |
| Distribution Mains | $200,802,863 | Optimistic | 110 | $ 1,825,481 | $2,231,143 | $ 3,650,961 |
| | | Standard | 90 | | | |
| | | Conservative | 55 | | | |
| ***Total*** | $221,101,663 | | | **$ 2,096,131** | **$2,637,119** | **$ 4,665,901** |

### *7.1.2 Risk-Based Prioritization*

The financial model was developed to estimate risk scores, and risk-mitigation strategies for years 2017 (baseline), 2022 (5-year time horizon) and 2027 (10-year time horizon). The model was built from the risk model described in section 6, and used water mains data from GIS (all segments were loaded into the model).

A simple deterioration function was added to the model to estimate LoF ratings and risk scores for the three timeframes. This function required the addition of a model variable to simulate the decrease of the C value of pipes over time.

The model used a decision-making function that assigned risk mitigation strategy (*replace* or *do nothing*) to pipe segments based on their risk results. The model followed these steps:

1. Calculated replacement value based on material, diameter and length of pipe segment;

2. Calculated age, condition score, remaining useful life, likelihood of failure rating and risk (risk score, risk box and risk quadrant) for each of the water mains segments for, year 2017;
3. Assigned a risk mitigation strategy to each water main based on risk parameters and on user-input (user needs to enter which risk quadrant is a priority. The model was set up to replace assets in the *high-risk* and *important* quadrants).
4. Calculated the costs associated with those decisions;
5. Calculated total costs;
6. Calculated age, deterioration, remaining useful life, condition ratings and LoF for each segment for year 2022 (considering whether the segment was replaced on year 2017 or not).
7. Repeated steps 3 through 5 for year 2022
8. Repeating steps 6-10 for year 2027 (10-year horizon).

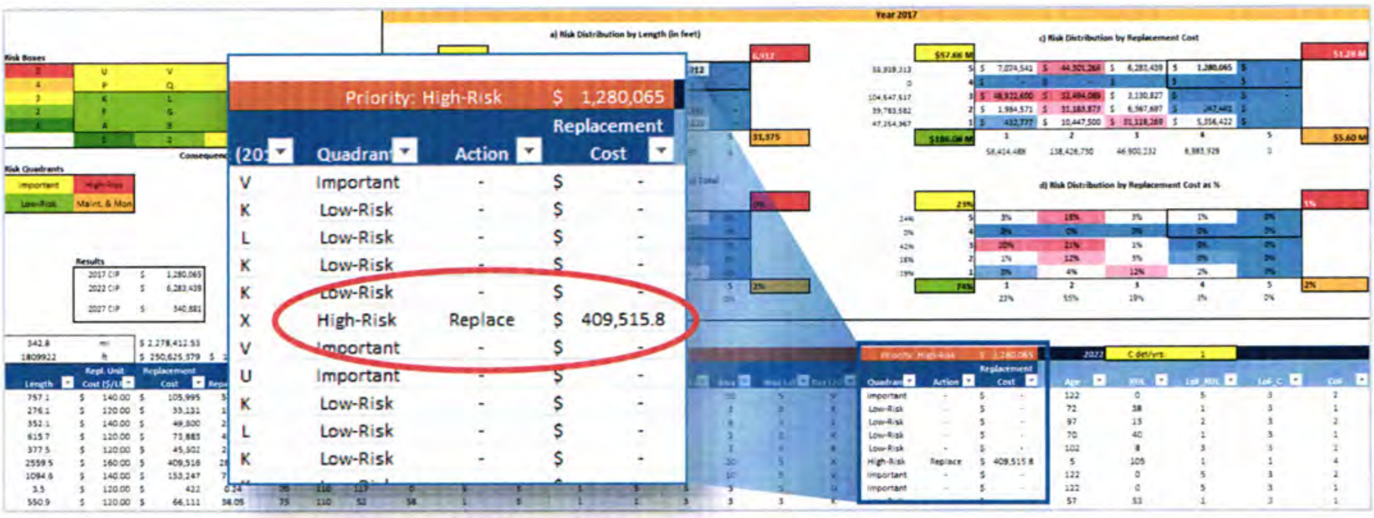



**Figure 25 – Financial Model with Decision Making Algorithm**

The decision-making function for the water mains assigned the value "Replace" to assets that met a given criteria. Only replacement costs for assets with the value "Replace" were added to calculate the total estimated replacement costs for each year.

For the purposes of these analysis, which are identifying the Priority list of assets (PLA) and the Secondary List of Assets (SLA), and their costs, the Estimated Service Life of ductile iron (model variable) was set to 90 years, and the replacement costs the same as in section 7.1.1. The model is dynamic and produces immediate results when those values are changed by the user.

Figure 16 displays the results obtained for year 2017. The system displays a healthy risk distribution. Since based on the risk framework the maximum criticality for water mains is set to 4, there are only about 3% of the system with CoF value of 4. These water mains appear in the maintenance and monitoring quadrant because of their low LoF (values of 1). Given these results (no assets were found to require immediate attention) the decision-making function, which was set to identify as "Replace" assets in the high-risk quadrant, yield "no-action" for all the water main segments.

**a) Risk distribution by length**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 23,223 | | | | | | 0 |
| 21,177 | LoF 5 | 14,402 | 6,228 | 547 | - | - | |
| 2,046 | 4 | 778 | 1,268 | - | - | - | |
| 799,496 | 3 | 484,716 | 306,615 | 8,166 | - | - | |
| 393,730 | 2 | 8,779 | 374,629 | 10,187 | 135 | - | |
| 272,073 | 1 | 5,377 | 28,599 | 199,919 | 38,179 | - | |
| | 1,426,986 | CoF 1 | 2 | 3 | 4 | 5 | 38,313 |
| | | 514,052 | 717,338 | 218,819 | 38,313 | 0 | |

**b) Risk distribution by length as %**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2% | | | | | | 0% |
| 1% | LoF 5 | 1% | 0% | 0% | 0% | 0% | |
| 0% | 4 | 0% | 0% | 0% | 0% | 0% | |
| 54% | 3 | 33% | 21% | 1% | 0% | 0% | |
| 26% | 2 | 1% | 25% | 1% | 0% | 0% | |
| 18% | 1 | 0% | 2% | 13% | 3% | 0% | |
| | 96% | CoF 1 | 2 | 3 | 4 | 5 | 3% |
| | | 35% | 48% | 15% | 3% | 0% | |

**Figure 26 - Risk Distribution of water main (by length) by 2022, with ESL=90 years**

The next step was to re-do the calculations in the model for 2022.

The deterioration model was set-up to subtract 1 point per year to the original C-value (C-values are considered to apply to 2017 and deteriorate going forward). This deterioration rate is also a model variable and can be subject of sensitivity analysis. For the purpose of this simulation we considered that a 1-point per year deterioration was a fair assumption. The results for year 2022 are displayed in figures 27 and 28.

The risk distribution for 2022 shows $2.71 million worth of replacements in the *Important* quadrant. We set-up the model to assign the decision strategy to "Replace" for those assets.

**c) Risk distribution by replacement cost**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $2.71 M | | | | | | $0.00 M |
| 2,448,216 | 5 | $ 1,486,972 | $ 879,189 | $ 82,055 | $ - | $ - | |
| 262,106 | 4 | $ 84,582 | $ 177,524 | $ - | $ - | $ - | |
| 100,722,745 | 3 | $ 56,546,096 | $ 42,951,759 | $ 1,224,890 | $ - | $ - | |
| 55,700,531 | 2 | $ 1,009,529 | $ 53,135,986 | $ 1,528,106 | $ 26,910 | $ - | |
| 41,669,264 | 1 | $ 645,197 | $ 4,175,040 | $ 29,987,788 | $ 6,861,239 | $ - | |
| | $191.20 M | 1 | 2 | 3 | 4 | 5 | $6.89 M |
| | | 59,772,377 | 101,319,498 | 32,822,840 | 6,888,148 | 0 | |

**d) Risk distribution by replacement cost as %**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1% | | | | | | 0% |
| 1% | 5 | 1% | 0% | 0% | 0% | 0% | |
| 0% | 4 | 0% | 0% | 0% | 0% | 0% | |
| 50% | 3 | 28% | 21% | 1% | 0% | 0% | |
| 28% | 2 | 1% | 26% | 1% | 0% | 0% | |
| 21% | 1 | 0% | 2% | 15% | 3% | 0% | |
| | 95% | 1 | 2 | 3 | 4 | 5 | 3% |
| | | 30% | 50% | 16% | 3% | 0% | |

**Figure 27- Risk Distribution for Year 2022 (ESL = 90)**

We used the same numerical model to calculate risk, decision and replacement costs for year 2027, considering the replacements were conducted in 2022. Results are presented in figures 29 and 30.

**a) Risk distribution by length**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 157,623 | | | | | | 0 |
| 3,143 | 5 | 2,208 | 697 | 238 | - | - | |
| 154,480 | 4 | 139,922 | 11,344 | 3,214 | - | - | |
| 936,451 | 3 | 347,143 | 584,595 | 4,714 | - | - | |
| 359,604 | 2 | 9,599 | 104,595 | 207,097 | 38,313 | - | |
| 34,844 | 1 | 15,180 | 16,107 | 3,556 | - | - | |
| | 1,292,586 | 1 | 2 | 3 | 4 | 5 | 38,313 |
| | | 514,052 | 717,338 | 218,819 | 38,313 | 0 | |

**b) Risk distribution by length as %**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 11% | | | | | | 0% |
| 0% | 5 | 0% | 0% | 0% | 0% | 0% | |
| 10% | 4 | 9% | 1% | 0% | 0% | 0% | |
| 63% | 3 | 23% | 39% | 0% | 0% | 0% | |
| 24% | 2 | 1% | 7% | 14% | 3% | 0% | |
| 2% | 1 | 1% | 1% | 0% | 0% | 0% | |
| | 87% | 1 | 2 | 3 | 4 | 5 | 3% |
| | | 35% | 48% | 15% | 3% | 0% | |

**Figure 28 -Risk Distribution for Year 2027 (ESL=90)**

**c) Risk distribution by replacement cost**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $19.17 M | | | | | | $0.00 M |
| 361,710 | 5 | $ 228,365 | $ 97,615 | $ 35,730 | $ - | $ - | |
| 18,812,686 | 4 | $ 16,742,425 | $ 1,588,143 | $ 482,118 | $ - | $ - | |
| 122,676,647 | 3 | $ 40,078,148 | $ 81,891,456 | $ 707,043 | $ - | $ - | |
| 54,584,502 | 2 | $ 1,151,884 | $ 15,479,987 | $ 31,064,483 | $ 6,888,148 | $ - | |
| 4,367,317 | 1 | $ 1,571,554 | $ 2,262,297 | $ 533,466 | $ - | $ - | |
| | $174.74 M | 1 | 2 | 3 | 4 | 5 | $6.89 M |
| | | 59,772,377 | 101,319,498 | 32,822,840 | 6,888,148 | 0 | |

**d) Risk distribution by replacement cost as %**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10% | | | | | | 0% |
| 0% | 5 | 0% | 0% | 0% | 0% | 0% | |
| 9% | 4 | 8% | 1% | 0% | 0% | 0% | |
| 61% | 3 | 20% | 41% | 0% | 0% | 0% | |
| 27% | 2 | 1% | 8% | 15% | 3% | 0% | |
| 2% | 1 | 1% | 1% | 0% | 0% | 0% | |
| | 87% | 1 | 2 | 3 | 4 | 5 | 3% |
| | | 30% | 50% | 16% | 3% | 0% | |

**Figure 29 – Risk distribution by costs by 2027 (ESL=90)**

In 2027 there are $19.17 million worth of replacements in the Important quadrant. A second round of prioritization needs to be conducted within this quadrant to address first the assets with LoF=5 and then the assets with higher criticality.

It is interesting to see how the model shifts assets vertically from the bottom up to represent the aging of the system. It would be useful to see by when the hot spot (41% of the system) that by 2027 is still in the *low-risk* area will cross over to the *Important* quadrant. The replacement value of those assets as a group is almost $82 million, and should be spread over time appropriately.

### *7.1.3 Water Main Repairs*

We added a simple calculation to the model to estimate necessary funds for water main repairs. This is calculated by distributing the total number of breakages per year, which is a variable, over the system by length, and calculating an average cost for repairs using a set of unit repair cost per diameter. Unit repair cost (as $ per break) range between $3,000 (for a 2-inch water main break repair) and $10,000 (for a 20-inch). The results are presented in table 18. The Division is just starting now to track water main breaks and the average number of breaks per year is still unknown. For planning purposes, a minimum of $108,000 should be allocated yearly to cover for about 20 water main break repairs (which correspond to 7.1 breaks/100 miles of pipe).

**Table 17- Estimated Costs for Water Main Break Repairs**

| Breaks/year | Breaks/(100 mile – year) | Water Main Break Repair Estimate |
|---|---|---|
| **20** | 7.1 | $107,760 |
| **30** | 10.6 | $161,639 |
| **40** | 14.2 | $215,519 |
| **50** | 17.7 | $269,399 |

## 7.2 FACILITIES

The financial model for the facilities was set-up similarly to the water-mains. The model expands on the risk model (presented in section 7), incorporating a simple decision-making algorithm and a cost estimate function. The three types of facilities, pump stations, corrosion control facilities, and tanks are evaluated. The model considers for the pump stations an estimated service life of 10 years for renewal of the pump, motor and other relevant equipment; those improvements have an estimated cost of $20,000 per pump station. Corrosion control facilities have an assigned ESL of 5 years (as life expectancy of the treatment equipment) and a renewal cost of $5,000 per facility. Tanks have a 15-year cycle for painting, and the painting costs considered were $846,667 for the German Hill Tank, $893,704 for the Prospect Hill Tank and $396,455 for the Sandy Pond Tank. These costs were escalated costs based on historical costs. This approach doesn't take into consideration necessary improvements for the wells (which as stated in section 6, undergo regular cleaning on a five-year basis), or needs with longer life-cycles such as roof replacements.

As in the water mains financial model, the facilities model is set up with ESL values and renewal costs as model variables. That means that the model calculates dynamically the results as these values are changed by the user. This allows to do a sensitivity analysis to figure out the range of the results. In the case of the facilities, the ESL values and renewal costs are well understood based on historical information, and therefore the results reported here don't include a conservative or an optimistic range as we did with the water mains.

As in the water-mains, the model has a simple deterioration model that depends on the estimated service life of the asset. Since condition ratings range from 1 (excellent) to 5 (failed) the assumption is that any given asset has ESL years to go from condition rating of 1 to 5. The deterioration rate is therefore calculated as 4/ESL (as condition points per year).

The decision-making function assigns "renewal" or "do-nothing" actions to assets based on the risk quadrant that each asset falls into. Then costs are calculated using the renewal costs per asset type discussed above. Renewal costs and ESL are model variables.

### *7.2.1 Annual Investment*

Using the renewal costs stated above, the renewal of the 3 tanks (painting), the 17 corrosion control facilities and the 24 pump stations would be $2.7 million, which translates, based on the ESL of 15 years for the tanks, 10 years for the pump stations and 5 years for the corrosion control facilities in $207,455 per year.

**Table 18 - Estimated Annual investment for Facility Renewal**

| Facility Type and count | ESL | Unit Renewal Cost | Annual Investment |
|---|---|---|---|
| Pump Station (24) | 10 | 20,000 | $48,000 |
| Corrosion Control (17) | 5 | 5,000 | $17,000 |
| Tank (3) | 15 | $894 K - $396 K | $142,455 |
| Total | | | **$207,455** |

The estimated necessary investment in the system in an annual basis is summarized below:

**Table 19 - Total Estimated Needed Annual Investment**

| Concept | Annual Investment |
|---|---|
| **Water Main Replacement** | $2,231,143 |
| **Hydrant and Valves Replacement** | $405,976 |
| **Facilities Renewal** | $207,455 |
| **Water Main Break Repairs (assuming 20 breaks/year)** | $107,760 |
| **Total** | **$2,952,334** |

### *7.2.2 Risk-Based Prioritization*

As explained in section 6, most facilities have a set criticality of 3.5, 4 and 5 (which means most of them will "move" as time progresses from the *maintenance and monitoring* quadrant to the *high-risk* quadrant – see Risk Framework in section 7). The model is set-up to renew all assets that fall in the *high-risk* quadrant and in the *Important* quadrants for 2022 and 2027. The results are presented in Figures 31 and 31. Because of the short time-span associated with the renewal of these assets (5, 10 and 15 years) in comparison with the time-step of this financial model (which is a 10-year model with a time-steps at years 2017, 2022 and 2027), the facilities assets tend to go quickly from the minimum LoF value (1) to the maximum (5). The corrosion control facilities appear constantly at the top of the risk space since they are due for renovation every 5 years. Therefore, this approach doesn't provide a lot of insight on the prioritization of the corrosion control facilities except for the fact that their criticality scores are different based on their treatment capacity. Future model improvements should be include increasing the model's time-horizon (40 years or more) and conducting the analysis at the asset level considering the asset portfolio of all assets within a facility and other failure modes such as structural integrity.

**Year 2022**

**a) Risk Distribution by Facility Count**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 19 | | | | | | 23 |
| 40 | 5 | - | - | 18 | 15 | 7 | |
| 2 | 4 | - | - | 1 | - | 1 | |
| 2 | 3 | - | - | 1 | 1 | - | |
| 0 | 2 | - | - | - | - | - | |
| 0 | 1 | - | - | - | - | - | |
| | 1 | 1 | 2 | 3 | 4 | 5 | 1 |
| | | 0 | 0 | 20 | 16 | 8 | |

**b) Risk Distribution by Replacement Value**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $1.16 M | | | | | | $0.67 M |
| 921,455 | 5 | $ - | $ - | $ 270,000 | $ 616,455 | $ 35,000 | |
| 913,704 | 4 | $ - | $ - | $ 893,704 | $ - | $ 20,000 | |
| 866,667 | 3 | $ - | $ - | $ 20,000 | $ 846,667 | $ - | |
| 0 | 2 | $ - | $ - | $ - | $ - | $ - | |
| 0 | 1 | $ - | $ - | $ - | $ - | $ - | |
| | $0.02 M | 1 | 2 | 3 | 4 | 5 | $0.85 M |
| | | 0 | 0 | 1,183,704 | 1,463,123 | 55,000 | |

**Figure 30- Financial Model Results (Risk) for Year 2022**

**Year 2027**

**a) Risk Distribution by Facility Count**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 7 | | | | | | 12 |
| 1 | 5 | - | - | 1 | - | - | |
| 18 | 4 | - | - | 6 | 5 | 7 | |
| 25 | 3 | - | - | 13 | 11 | 1 | |
| 0 | 2 | - | - | - | - | - | |
| 0 | 1 | - | - | - | - | - | |
| | 13 | 1 | 2 | 3 | 4 | 5 | 12 |
| | | 0 | 0 | 20 | 16 | 8 | |

**b) Risk Distribution by Replacement Value**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | $0.05 M | | | | | | $0.90 M |
| 20,000 | 5 | $ - | $ - | $ 20,000 | $ - | $ - | |
| 931,667 | 4 | $ - | $ - | $ 30,000 | $ 866,667 | $ 35,000 | |
| 1,750,160 | 3 | $ - | $ - | $ 1,133,704 | $ 596,455 | $ 20,000 | |
| 0 | 2 | $ - | $ - | $ - | $ - | $ - | |
| 0 | 1 | $ - | $ - | $ - | $ - | $ - | |
| | $1.13 M | 1 | 2 | 3 | 4 | 5 | $0.62 M |
| | | 0 | 0 | 1,183,704 | 1,463,123 | 55,000 | |

**Figure 31 – Financial Model Results (Risk) for Year 2027**

## 7.3 PRIMARY AND SECONDARY LISTS OF ASSETS

To create the primary and secondary list of assets, we used the financial models for water mains and facilities, and used the risk scores to identify which assets were to be replaced (water mains) or renew (facilities) within the 5-year and 10-year horizon. To do this, we used the default decision-making function of the model, but manually added other assets to the list based on their risk scores to meet the expected annual investment budgets.

### *7.3.1 Priority List of Assets (PLA)*

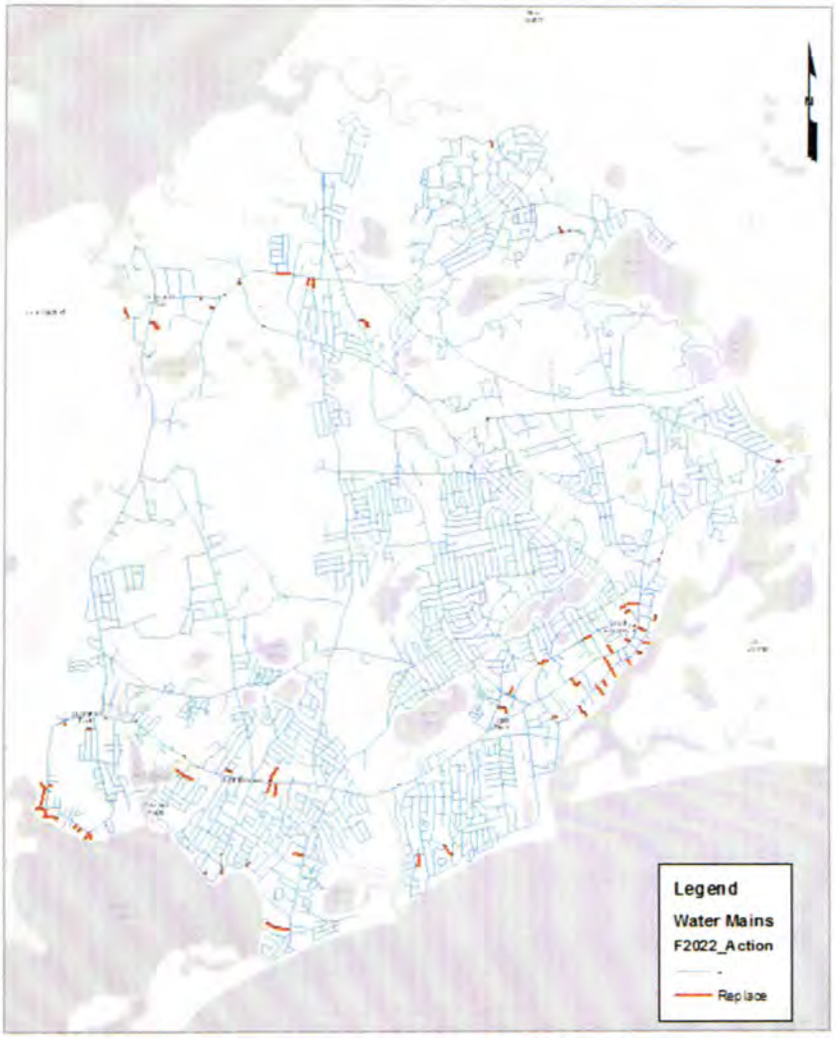



**Figure 32 - Identified Replacements by 2022 (water mains PLA)**

We created the PLA from the water mains financial model and the facilities financial model that were identified for being replaced or renewed between 2017 and 2022 (included).

The financial model for the water mains was set up with ESL of 90 years. The distribution system (water mains only) average yearly budget is $2.23 million, which is $22.31 million total (with no escalation for inflation) for the 10-year plan. As explained in the previous section, year 2017 of the simulation resulted in a 0% of the system in the *high-risk* quadrant. No replacements are needed immediately. This is because the only mains in the system with high criticality (diameters 16 and 20 inch) had good C values and were fairly new.

By 2022, there are 23,223 feet of main with LoF values of 4 and 5 (above the threshold). These segments fall in the *Important* quadrant, and represent a replacement cost of $2.71 million. These mains are represented in Figure 33. The segment list by asset Id is available in the Supplemental Documentation. Table 20 summarizes the results of the combined list for facilities and water mains. For reporting purposes, we merged all pipe segments that had same year of installation and same diameter. The PLA has the risk scores associated with each asset. The risk scores reported in table 20 correspond to the scores of the asset in 2022. Detailed risk scores for each asset at the 2017, 2022 and 2027 time horizons are presented in the supplemental documentation.

The total investment for these renewal and replacement projects results in $4.55 million, which distributed over five years represents a $909,100. This number is significantly lower than the estimated necessary investment for water main replacement ($2.23 million) plus facility renewals ($207,455).

**Table 20 – Priority List of Assets**

| | Identifier: Facility ID or for water mains: | | | | |
|---|---|---|---|---|---|
| Asset Type | Year Inst. | Diam. (in) | Total Length (ft) | Replacement Cost | Risk Score |
| Facility | | CCF-4-5 | | $ 5,000 | 21.9833 |
| Facility | | CCF-6-7-8 | | $ 5,000 | 21.8833 |
| Facility | | CCF-1M | | $ 5,000 | 21.7083 |
| Facility | | CCF-2-3 | | $ 5,000 | 21.6583 |
| Facility | | CCF-18-19 | | $ 5,000 | 21.5083 |
| Facility | | CCF-15-16 | | $ 5,000 | 21.4833 |
| Facility | | CCF-21-22 | | $ 5,000 | 21.4833 |
| Facility | | PS-16 | | $ 20,000 | 20 |
| Facility | | PS-19 | | $ 20,000 | 20 |
| Facility | | PS-22 | | $ 20,000 | 20 |
| Facility | | PS-23 | | $ 20,000 | 20 |
| Facility | | PS-9 | | $ 20,000 | 20 |
| Facility | | SANDY POND | | $ 396,455 | 18.6667 |
| Facility | | PS-13 | | $ 20,000 | 18 |
| Facility | | PS-15 | | $ 20,000 | 18 |
| Facility | | PS-17 | | $ 20,000 | 18 |
| Facility | | PS-18 | | $ 20,000 | 18 |
| Facility | | PS-21 | | $ 20,000 | 18.00 |
| Facility | | CCF-13 | | $ 5,000 | 17.51 |
| Facility | | PS-001M | | $ 20,000 | 17.50 |
| Facility | | CCF-9 | | $ 5,000 | 17.4067 |
| Facility | | CCF-23 | | $ 5,000 | 17.2867 |
| Facility | | CCF-17 | | $ 5,000 | 17.2067 |
| Facility | | PS-11 | | $ 20,000 | 15 |
| Water Main | 1900 | 12 | 272.325 | $ 40,849 | 15 |
| Water Main | 1910 | 12 | 104.348 | $ 15,652 | 15 |
| Water Main | 1930 | 12 | 170.358 | $ 25,554 | 15 |
| Facility | | PS-10 | | $ 20,000 | 13.5 |
| Facility | | PS-14 | | $ 20,000 | 13.5 |
| Facility | | PS-2 | | $ 20,000 | 13.5 |
| Facility | | PS-20 | | $ 20,000 | 13.5 |
| Facility | | PS-24 | | $ 20,000 | 13.5 |
| Facility | | PS-3 | | $ 20,000 | 13.5 |
| Facility | | PS-4 | | $ 20,000 | 13.5 |
| Facility | | PS-5 | | $ 20,000 | 13.5 |
| Facility | | PS-6 | | $ 20,000 | 13.5 |
| Facility | | PS-7 | | $ 20,000 | 13.5 |
| Facility | | PS-8 | | $ 20,000 | 13.5 |
| Facility | | CCF-11 | | $ 5,000 | 13.03 |
| Facility | | CCF-20 | | $ 5,000 | 12.98 |
| Facility | | CCF-10 | | $ 5,000 | 12.97 |
| Facility | | CCF-14 | | $ 5,000 | 12.965 |
| Facility | | CCF-24 | | $ 5,000 | 12.95 |
| Facility | | CCF-1 | | $ 5,000 | 12.845 |
| Facility | | PROSPECT HILL | | $ 893,704 | 12.8333 |
| Water Main | 1900 | 10 | 601.487 | $ 90,223 | 10 |
| Water Main | 1900 | 8 | 2960.18 | $ 414,425 | 10 |
| Water Main | 1910 | 8 | 497.247 | $ 69,615 | 10 |
| Water Main | 1920 | 8 | 1483.78 | $ 207,729 | 10 |
| Water Main | 1930 | 10 | 127.303 | $ 19,095 | 10 |
| Water Main | 1930 | 8 | 557.872 | $ 78,102 | 10 |
| Water Main | 1970 | 8 | 1007.82 | $ 141,095 | 8 |
| Water Main | 1980 | 8 | 260.209 | $ 36,429 | 8 |
| Water Main | 1900 | 2 | 6806.18 | $ 680,618 | 5 |
| Water Main | 1900 | 6 | 606.886 | $ 72,826 | 5 |
| Water Main | 1910 | 2 | 179.841 | $ 17,984 | 5 |
| Water Main | 1910 | 6 | 9.1086 | $ 1,093 | 5 |
| Water Main | 1920 | 2 | 2508.01 | $ 250,801 | 5 |
| Water Main | 1920 | 6 | 775.082 | $ 93,010 | 5 |
| Water Main | 1930 | 2 | 3008.7 | $ 300,869 | 4.00 |
| Water Main | 1930 | 6 | 1286.3 | $ 154,352 | 4.00 |

| Total | $ 4,545,482 |
|---|---|

### *7.3.2 Secondary List of Assets (SLA)*

The secondary list of assets is generated by selecting the assets from the facilities and the water mains financial model that were identified for renewal or replacement by 2027. This list assumes that the replacements identified in the PLA have been implemented. As in the PLA, this analysis doesn't apply inflation to the cost estimates.

The total estimated cost to cover for the action items (renewal or replacement) identified in the SLA is \$20.13 million. The total of PLA plus SLA costs adds up to \$24.67 million, which represents a yearly investment of \$2.46 million, right along the estimated annual investment necessary to maintain the system discussed in section 8.2.

**Table 21 – Secondary List of Assets (Complete)**

| | Identifier: Facility ID or for water mains: | | | | |
|---|---|---|---|---|---|
| Asset Type | Year Inst. | Diam. (in) | Total Length (ft) | Replacement Cost | Risk Score |
| Facility | | CCF-15-16 | | $ 5,000 | 18.3333 |
| Facility | | CCF-18-19 | | $ 5,000 | 18.3333 |
| Facility | | CCF-1M | | $ 5,000 | 18.3333 |
| Facility | | CCF-21-22 | | $ 5,000 | 18.3333 |
| Facility | | CCF-2-3 | | $ 5,000 | 18.3333 |
| Facility | | CCF-4-5 | | $ 5,000 | 18.3333 |
| Facility | | CCF-6-7-8 | | $ 5,000 | 18.3333 |
| Facility | | GERMAN HILL | | $ 846,667 | 15.3333 |
| Water Main | 1940 | 12 | 238.2 | $ 35,730 | 15 |
| Facility | | PS-1 | | $ 20,000 | 15.00 |
| Facility | | CCF-13 | | $ 5,000 | 14.6667 |
| Facility | | CCF-17 | | $ 5,000 | 14.6667 |
| Facility | | CCF-23 | | $ 5,000 | 14.6667 |
| Facility | | CCF-9 | | $ 5,000 | 14.6667 |
| Water Main | 1960 | 12 | 2060.5 | $ 309,081 | 12 |
| Water Main | 1970 | 12 | 1153.6 | $ 173,036 | 12 |
| Facility | | CCF-1 | | $ 5,000 | 11 |
| Facility | | CCF-10 | | $ 5,000 | 11 |
| Facility | | CCF-11 | | $ 5,000 | 11 |
| Facility | | CCF-14 | | $ 5,000 | 11 |

| | Identifier: Facility ID or for water mains: | | | | |
|---|---|---|---|---|---|
| Asset Type | Year Inst. | Diam. (in) | Total Length (ft) | Replacement Cost | Risk Score |
| Facility | | CCF-20 | | $ 5,000 | 11 |
| Facility | | CCF-24 | | $ 5,000 | 11 |
| Water Main | 1930 | 8 | 9.5 | $ 1,336 | 10 |
| Water Main | 1940 | 10 | 3.0 | $ 453 | 10 |
| Water Main | 1940 | 8 | 2005.4 | $ 280,755 | 8 |
| Water Main | 1950 | 8 | 91.7 | $ 12,843 | 8 |
| Water Main | 1960 | 8 | 5039.2 | $ 705,487 | 8 |
| Water Main | 1970 | 8 | 4321.2 | $ 604,969 | 8 |
| Water Main | 2000 | 8 | 570.8 | $ 79,916 | 8.00 |
| Water Main | 1930 | 2 | 646.7 | $ 64,669 | 5 |
| Water Main | 1930 | 6 | 266.3 | $ 31,962 | 5 |
| Water Main | 1940 | 2 | 3593.6 | $ 359,362 | 4 |
| Water Main | 1940 | 6 | 824.9 | $ 98,993 | 4 |
| Water Main | 1950 | 6 | 382.3 | $ 45,877 | 4 |
| Water Main | 1960 | 6 | 96066.7 | $ 11,528,010 | 4 |
| Water Main | 1970 | 6 | 21850.3 | $ 2,622,038 | 4 |
| Water Main | 1980 | 6 | 10777.9 | $ 1,293,347 | 4 |
| Water Main | 1990 | 6 | 5825.6 | $ 699,067 | 4.00 |
| Water Main | 2000 | 6 | 1895.6 | $ 227,467 | 4.00 |

| Total | $ 20,126,064 |
|---|---|

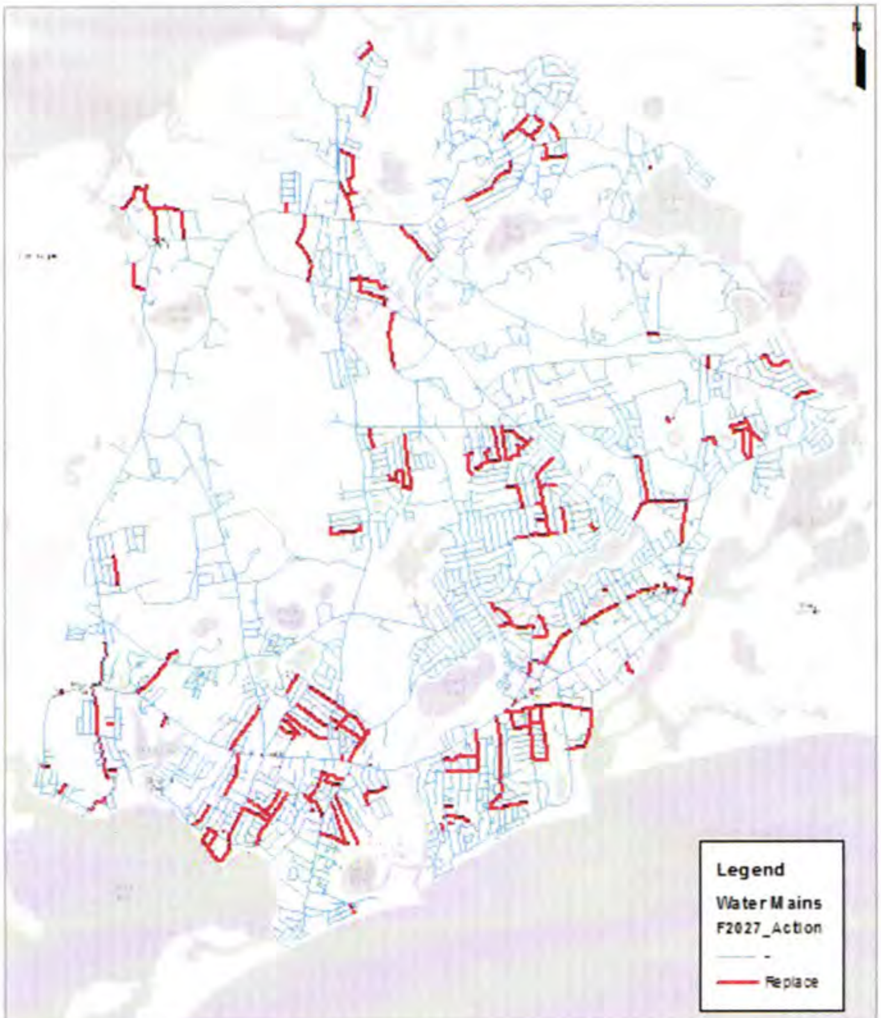



**Figure 33 - Water Main Replacement Needs (2027)**

The model identified \$19.17 million worth of pipe replacements of assets that fall in the *Important* risk quadrant. Figure 34 displays the identified assets.

A less aggressive SLA could be generated by further prioritizing the asset list in the *Important* quadrant.

If we postpone the replacement of assets with the lowest risk scores (4), the total cost of SLA improvements drops by \$16.7 million to **\$3.25 million** instead of \$20.13 million.

The SLA without the lower criticality main replacements is presented below.

## Table 22 - Secondary List of Assets

| Asset Type | Year Inst. | Identifier: Facility ID or for water mains: Diam. (in) | Total Length (ft) | Replacement Cost | Risk Score |
|---|---|---|---|---|---|
| Facility | | CCF-15-16 | | $ 5,000 | 18.3 |
| Facility | | CCF-18-19 | | $ 5,000 | 18.3 |
| Facility | | CCF-1M | | $ 5,000 | 18.3 |
| Facility | | CCF-21-22 | | $ 5,000 | 18.3 |
| Facility | | CCF-2-3 | | $ 5,000 | 18.3 |
| Facility | | CCF-4-5 | | $ 5,000 | 18.3 |
| Facility | | CCF-6-7-8 | | $ 5,000 | 18.3 |
| Facility | | GERMAN HILL | | $ 846,667 | 15.3 |
| Water Main | 1940 | 12 | 238.2 | $ 35,730 | 15.0 |
| Facility | | PS-1 | | $ 20,000 | 15.0 |
| Facility | | CCF-13 | | $ 5,000 | 14.7 |
| Facility | | CCF-17 | | $ 5,000 | 14.7 |
| Facility | | CCF-23 | | $ 5,000 | 14.7 |
| Facility | | CCF-9 | | $ 5,000 | 14.7 |
| Water Main | 1960 | 12 | 2060.5 | $ 309,081 | 12.0 |
| Water Main | 1970 | 12 | 1153.6 | $ 173,036 | 12.0 |
| Facility | | CCF-1 | | $ 5,000 | 11.0 |
| Facility | | CCF-10 | | $ 5,000 | 11.0 |
| Facility | | CCF-11 | | $ 5,000 | 11.0 |
| Facility | | CCF-14 | | $ 5,000 | 11.0 |
| Facility | | CCF-20 | | $ 5,000 | 11.0 |
| Facility | | CCF-24 | | $ 5,000 | 11.0 |
| Water Main | 1930 | 8 | 9.5 | $ 1,336 | 10.0 |
| Water Main | 1940 | 10 | 3.0 | $ 453 | 10.0 |
| Water Main | 1940 | 8 | 2005.4 | $ 280,755 | 8.0 |
| Water Main | 1950 | 8 | 91.7 | $ 12,843 | 8.0 |
| Water Main | 1960 | 8 | 5039.2 | $ 705,487 | 8.0 |
| Water Main | 1970 | 8 | 4321.2 | $ 604,969 | 8.0 |
| Water Main | 2000 | 8 | 570.8 | $ 79,916 | 8.0 |
| Water Main | 1930 | 2 | 646.7 | $ 64,669 | 5.0 |
| Water Main | 1930 | 6 | 266.3 | $ 31,962 | 5.0 |

**Total: $ 3,251,904**

# 8 IMPLEMENTATION PLAN

As Yarmouth's DPW engages in the adoption of an asset management software for all their divisions, the Water Division's was seeking to understand their status in terms of data and learn about asset management. The Division understands that any asset management software needs to be customized to meet the organization's needs and expectations, which includes enhancing daily activities, optimizing budgets, managing risk and ensuring customer satisfaction. This AMP constitutes a starting point for the Division for integrating asset management concepts, strategies and philosophy as cornerstone of their business model. This sections outlines the next steps for the Division.

## 8.1 RECOMMENDATIONS REGARDING ASSET MANAGEMENT SYSTEM IMPLEMENTATION:

### *8.1.1 Regarding Asset Register*

- Water mains in GIS need to be segmented properly as described in section 4.3.4
- System valves, currently represented in several feature classes need to be combined in two feature classes: distribution valves and service valves.
- All system's feature classes should have a schema designed for asset management purposes (data model)
- Asset register for all facilities needs to be developed and integrated in the asset management software
- Attribute data for most assets needs to be complete and updated
- QAQC materials and installation years for water mains
- Add meters to inventory
- Complete service connections and service valves inventory

### *8.1.2 Regarding Condition*

- Update Master Plan:
  - Hydraulic model update
  - Inspect facilities
- Build condition assessment forms: We recommend designing condition inspection forms for critical assets, crafting them in a manner that the information can be used to calculate likelihood of failure.

### *8.1.3 Regarding Risk*

- Refine risk framework and re-run analysis: facilities need to be developed in the risk framework considering other failure modes beyond the ones addressed in this AMP. Assets within the facilities such as roofs, electrical equipment, and Scada systems should participate in the risk model.

### *8.1.4 Regarding LOS*

- Build reporting tools for tracking LOS: The LOS defined in this project need to be tracked over time. We recommend developing LOS tracking tools within the asset management software or using other tools to track LOS.
- Implement Service Requests: Capturing customer complaints and requests is important to assess the LOS, and to gain understanding of water quality "hot spots" in the system.

### *8.1.5 Regarding Financial Planning*

- Refine long-term planning model:
  a. Develop deterioration curves based on real data,
  b. Consider activities that affect the lifespan and the life-cycle costs of assets (integrate work order data into financial planning)
  c. Add other asset types to the facilities financial model (wells)
  d. Conduct sensitivity analysis to evaluate results under different simulation scenarios
  e. Expand planning horizon
- Use billing information to accurate calculate revenue from customers
- Integrate billing data with asset management system
- Consider assessing energy efficiency and developing and Energy Efficiency Plan
- Analyze current water rates to evaluate whether the revenue generated from the customers is sufficient to sustain the water system over time.

### *8.1.6 Regarding O&M*

- Design and implement work order system and service request system including recurrent work orders or user-triggered work orders, common inspection forms, and service calls.
- Add document-management capabilities to the asset management system to improve operations, such as adding record drawings and tie-cards, so that they can be accessed from the field.
- Design and implement reporting and dashboarding tools.

### *8.1.7 Regarding Implementing PLA and SLA Projects*

List of improvements identified in the PLA and SLA of this project is subject to numerous assumptions explained in this document. The process presented here should be followed in following years as more data gets collected and the uncertainty of the simulations gets reduced.

We want to emphasize the need for creating a financial plan with a time-frame greater than 10 years. As explained in section 8.1.2 (see figure 30), 41% of the system falls into the same risk box, which means all those assets will probably start failing around the same time. Is important to stablish a sound prioritization strategy and replacement plan to stagger and to finance those replacements appropriately.

We recommend:

- Inspecting the facilities and generating a list of prioritized needs (at least all facilities in the PLA list)
- Inspecting and probably painting Sandy Pond and Prospect Hill tanks (both in the PLA)
- Update hydraulic model and compare results with the water mains identified in the PLA
- Assessing the water supply wells

## 8.2 RECOMMENDED ACTION PLAN

We bundled the recommendations listed above in projects and assigned an estimated cost and timeframe to create a recommended action plan. Note that recurrent activities such as well cleaning are not included in the list.

**Table 23 - Recommended Action Plan**

| | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Update GIS and Asset Register | $10,000 | $50,000 | | | |
| Inspect Facilities (PS, CCF, Tanks) | $100,000 | | | | |
| Update master plan (hydraulic model + Facilities needs) | $80,000 | | | | |
| Well assessment | $50,000 | | | | |
| Implement WO system | $0 | $0 | | | |
| Implement LOS tracking | | $25,000 | $25,000 | | |
| Rate study | $40,000 | | | | |
| Review AMP | $20,000 | | | | $50,000 |
| Paint Sandy Pond Tank | $400,000 | | | | |
| Paint Prospect Hill Tank | | | $900,000 | | |
| Water Main Replacements | | $900,000 | | $900,000 | $900,000 |
| **Total** | **$700,000** | **$975,000** | **$925,000** | **$900,000** | **$950,000** |

# APPENDIX A
# WORKSHOP MATERIALS

# Yarmouth Water Department – Workshop 1

## Principles of Asset Management and Levels of Service

**Cris Perez**
**05/13/2017**

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# In this presentation

- What is Asset Management
- Why is Asset Management important
- Principles of Asset Management
- Levels of Service

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# Asset Management…is not a new concept

Regulatory Compliance — Passes inspections

Preventive Maintenance — Change oil, filter, rotate tires…

LOS — Navigation System, AC…

Risk — Insurance

Capital — Decisions


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# Why Asset Management?

How badly do you need a car?

Can you buy a car today?

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# Infrastructure Asset Management: Asset?

Smallest item you own that you <u>manage</u> as a whole


- Fix
- Track purchases, maintenance and repair costs
- Report against (GASB34)
- Count, or count activities

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# Infrastructure Asset Management

- Don't know what I have
- Can't find anything
- Don't know what I need

- I know what I have I can find things quickly but...
- ...It takes me hours to do laundry!
- ...and I don't know where to put my sweat pants

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# What is Asset Management

## Coordinated activity of an organization to realize value from assets


Source: The Institute of Asset Management (IAM)

people · data · processes · analysis · rules · software

**The primary focus is the *long-term life cycle* of the asset and its sustained performance, rather than on short-term, day-to-day aspects of the asset**

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# Asset Management as an Optimization Strategy

- Has the objective of *minimizing total costs* of acquiring, operating, maintaining, and renewing assets…
- Within an environment of *limited resources* (constraints)
- While *continuously delivering the service levels* customers desire and regulators require (constraints)
- At an acceptable level of *risk* to the organization (constraints)

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# Why Asset Management?

- ***Things are getting expensive!***
  - Increasing demand for utility services
  - Diminishing resources
  - Aging infrastructure → Extend asset life
  - Need to optimize maintenance and renewal
- ***Things are getting more complex!***
  - Regulations are more stringent
  - Diminishing technical labor pool
  - Larger and more sophisticated facilities
  - Loss of knowledge with personnel retirements
  - Resistance to rate increases

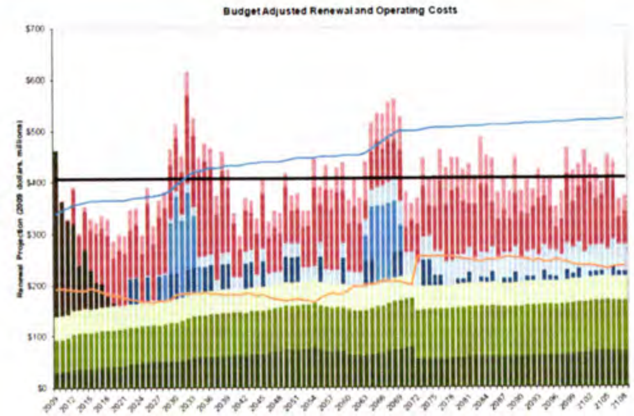
- *Need to do more with existing resources*
- *Consequences of asset failure can be severe*
- *Move from reactive to proactive work environment*
- *EPA is now requiring AM Plans for certain funding sources*



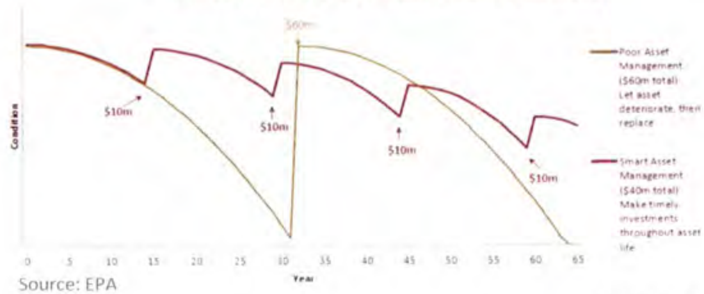
# Why is Asset Management Important

## Benefits

- Ability to plan
- Increase confidence and credibility
- Better use of capital and operating budgets
- Understand risks
- Improve performance
- Consistency
- Long-term sustainability




Source: Orange County AM Plan




Source: EPA

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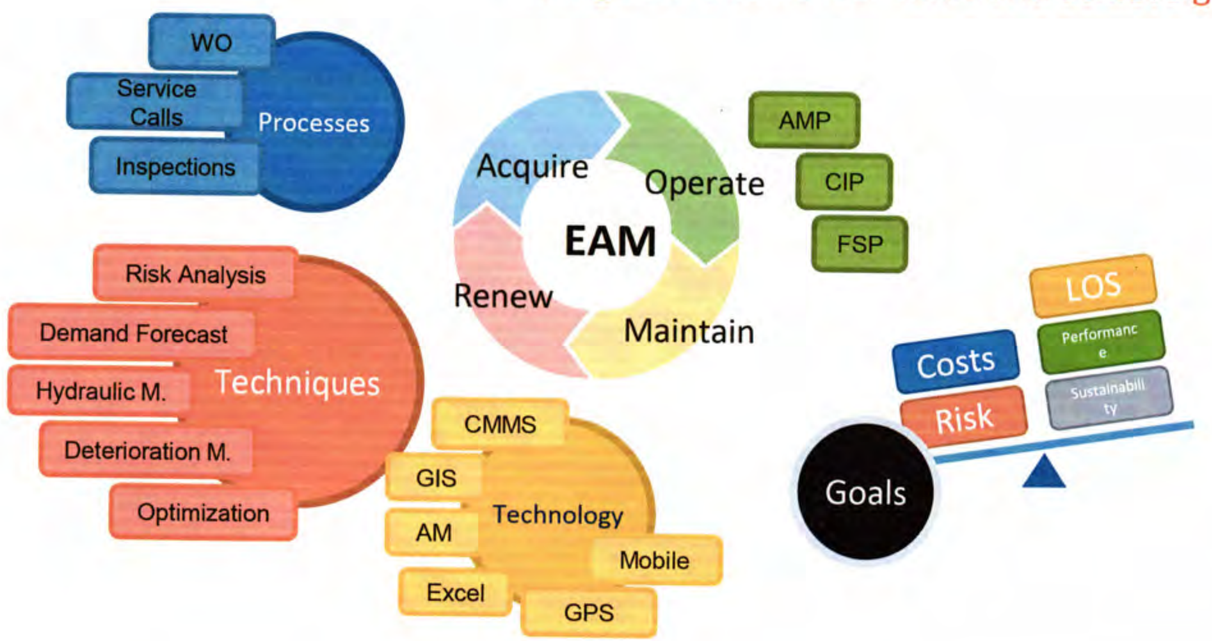
# What does that mean?

## Using assets to deliver value and achieve goals

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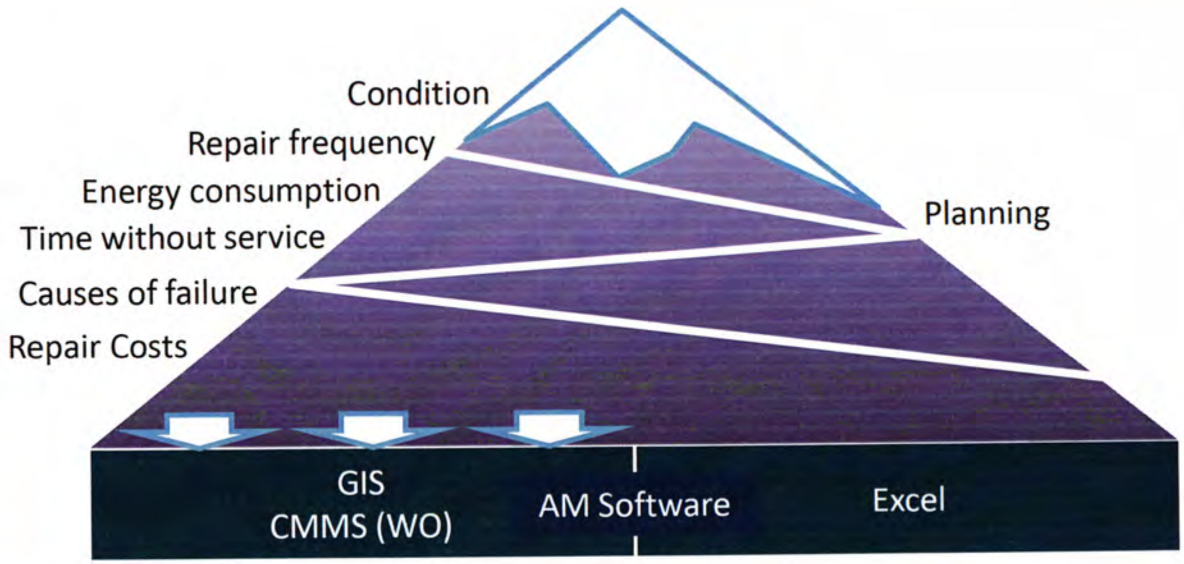
# From every day operations to long-term planning

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# Principles of Asset Management

1. **Level of Service**: assets exist to deliver services and goods that are valued by the customer-stakeholder; for each consumer-stakeholder there is a minimum level of service below which a given service is not perceived as adding value.
2. **Life Cycle**: all assets pass through a discernible life cycle, the understanding of which enhances appropriate management.
3. **Failure**: Usage and the operating environment work to break-down all assets; failure occurs when an asset can not do what is required by the user in its operating environment.
4. **Failure Modes**: not all assets fail in the same way.
5. **Probability**: not all assets of the same age fail at the same time.
6. **Consequence**: not all failures have the same consequences.
7. **Total Cost of Ownership**: there exists a minimum optimal investment over the life cycle of an asset that best balances performance and cost given a target level of service and a designated level of risk

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# Core Questions of Asset Management

1. What is the current state of my assets?
2. What is my required (and sustainable) level of service?
3. Which assets are critical to sustained performance?
4. What are my minimum life-cycle-cost CIP and O&M strategies?
5. Given those, what's my best long-term-funding strategy?

# Asset Management Terminology

- Asset Management
- Asset Management Plan
- Asset Management Software
- Asset Management Implementation Plan
- Asset Management System
- CMMS
- CIP

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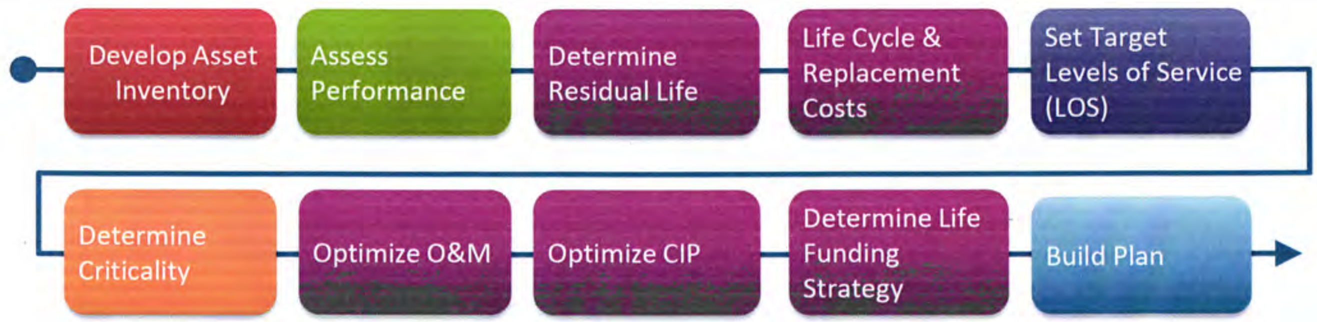
# Steps for an Asset Management Plan





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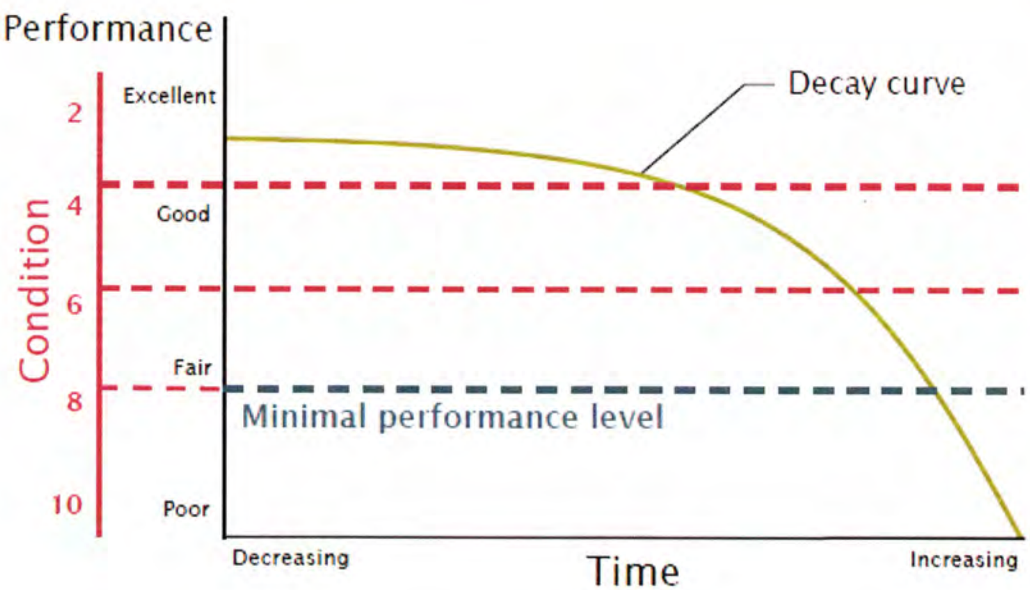
# How does it work?

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# Levels of Service

**Level of Service**: assets exist to deliver services and goods that are valued by the customer-stakeholder; for each consumer-stakeholder there is a minimum level of service below which a given service is not perceived as adding value.

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# Defining LOS

- What level of service do my stakeholders and customers demand?
- What do the regulators require?
- What is my actual performance?
- What are the physical capabilities of my assets?


- Decision making tool for allocating resources
- Track and measure your performance
- Communicate value or improvement to customers and stakeholders

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# LOS – Exercise 1

## *Workshop 1*
## *Exercise 1: Level of Service Assessment*

| ***Strengths:***<br>*What does the Water Department do well?*<br>*What do you take pride in?* | ***Challenges:***<br>*What assets are difficult to maintain?*<br>*What aspects of your role are difficult?* |
|---|---|
| | |
| ***Opportunities:***<br>*In which ways do you want the Department to improve?*<br>*What resources are needed to improve?* | ***External Factors:***<br>*What are surrounding communities doing well?*<br>*What regulatory changes impact the Department?*<br>*What are the political or financial impacts?* |
| | |

# LOS – Exercise 2

*Workshop 1*
*Exercise 2: Performance Ratings*

| | *How would the average customer rate the Department in regards to the following?* | | | | | *How do you rate the Yarmouth Water Department in regards to the following?* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Poor | | | | Excellent | Poor | | | | Excellent |
| Water Pressure | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Taste | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Water Appearance | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Responsiveness | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |

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## LOS should:

- Be determined by and owned by the Yarmouth Water Department Team!
- Be measurable
- Be attainable
- Relate to system performance and/or customer satisfaction
- Relate to the cost of the service (sustainable and relevant)
- Be driven by customers and regulations
- Tied to system, facility, or asset
- Consider Public health / safety, economics, and the environment ("triple bottom line")
- If not currently attained, specify timeframe (short term and/or long-term targets)

# LOS – Exercise 3:

| Yarmouth, MA – Water System Level of Service | | | |
|---|---|---|---|
| **Category** | **Level of Service** | **Performance Measure** | **Target** |
| | | | |
| | | | |
| | | | |

# Yarmouth Water Department – Workshop 2

## Condition, Criticality and Risk

**Cris Perez**

**05/13/2017**

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# In this workshop

- Review of AM Steps
- Risk
- Likelihood of Failure
- Consequence Factors
- Yarmouth Risk Model

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# Asset Management as an Optimization Strategy

- Has the objective of *minimizing total costs* of acquiring, operating, maintaining, and renewing assets...
- Within an environment of *limited resources* (constraints)
- While *continuously delivering the service levels* customers desire and regulators require (constraints)
- At an acceptable level of *risk* to the organization (constraints)

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# Principles of Asset Management

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# Core Questions of Asset Management

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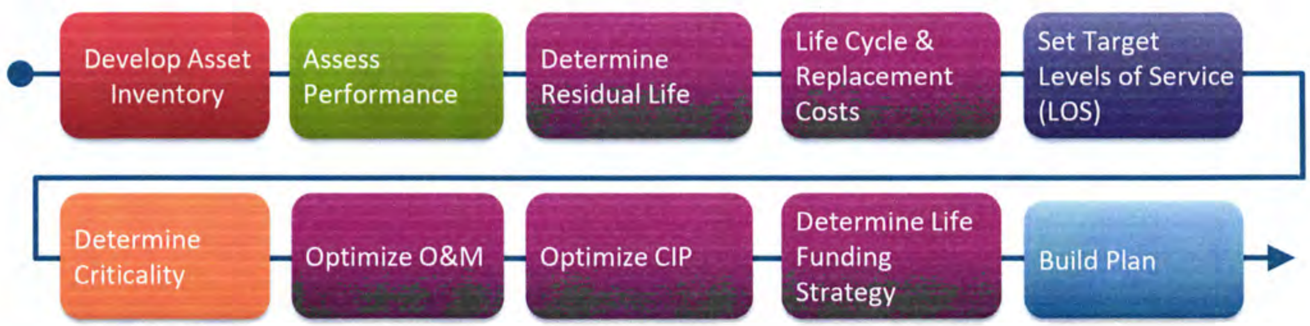
5. Given those, what's my best long-term-funding strategy?

# Steps for an Asset Management Plan





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# Terminology

- Risk
- Criticality
- Condition
- Performance
- Likelihood of failure
- Consequence of failure
- Probability of failure
- Failure
- Failure Modes
- Score
- Rating
- Prioritize

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# Risk

## RISK

- *scale* that is common to all assets
- There are ≠ types of assets→ Compare?
- Comparison ➔ Relative importance
- Prioritize = Rank, sort

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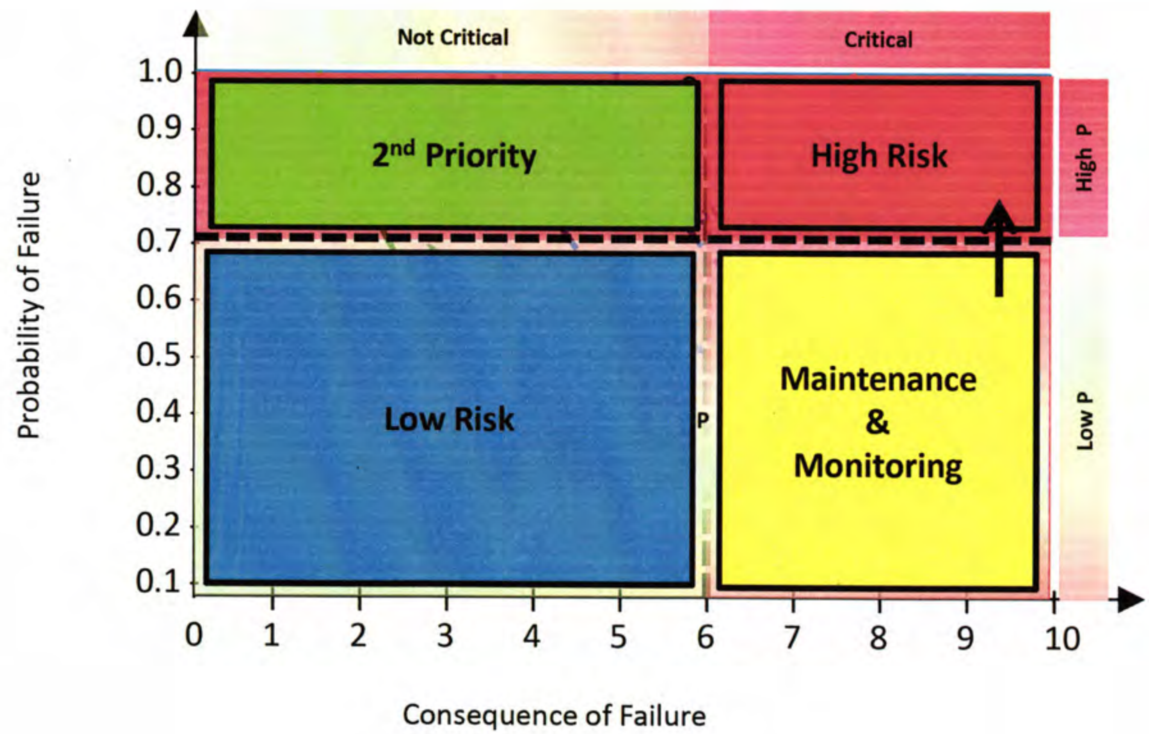
# Definition of Risk

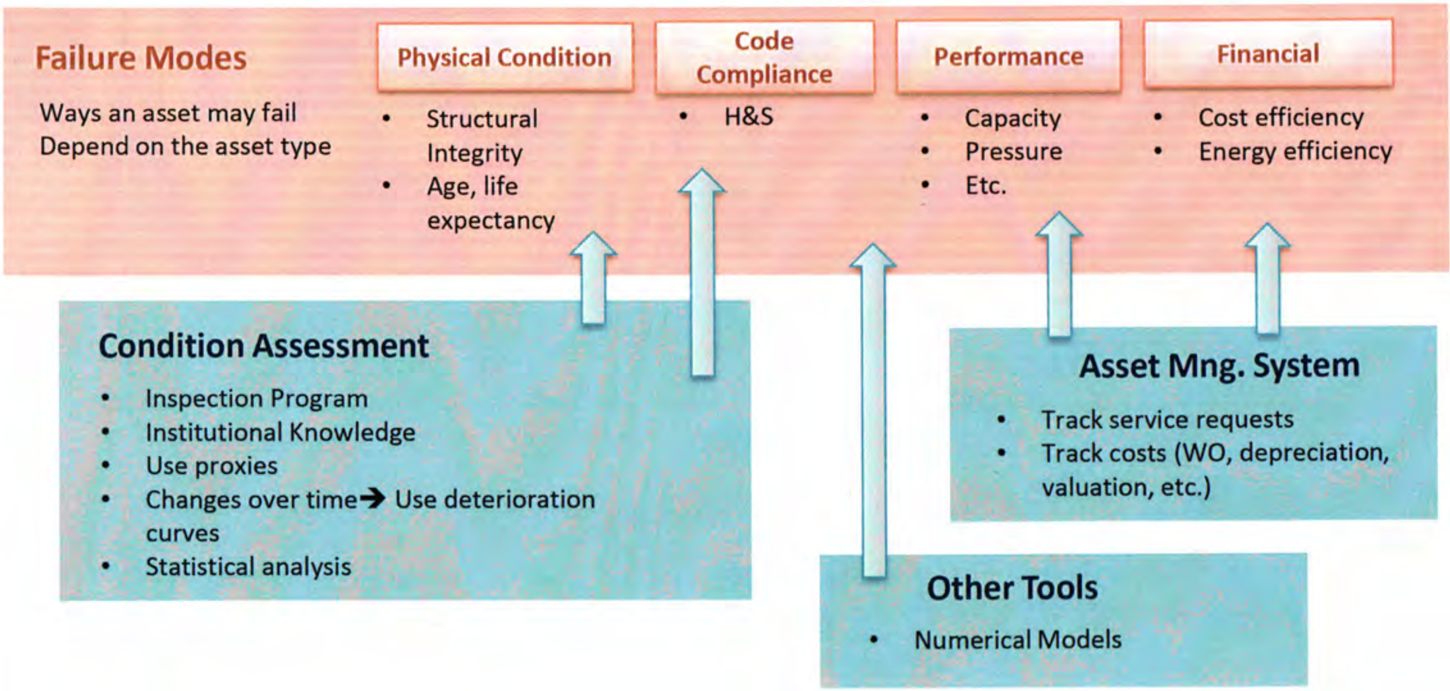
1. Risk is the potential that a chosen action or activity will lead to a loss. *Wikipedia*
2. Risk is the possibility that something unpleasant or unwelcome will happen; the possibility of financial loss. *Oxford Dictionary*
3. Risk is the product of the probability of a hazard resulting in an adverse event, times the severity of the event. *OSHAS (Occupational Health & Safety Advisory Services)*

Risk = Probability of Failure x Consequence

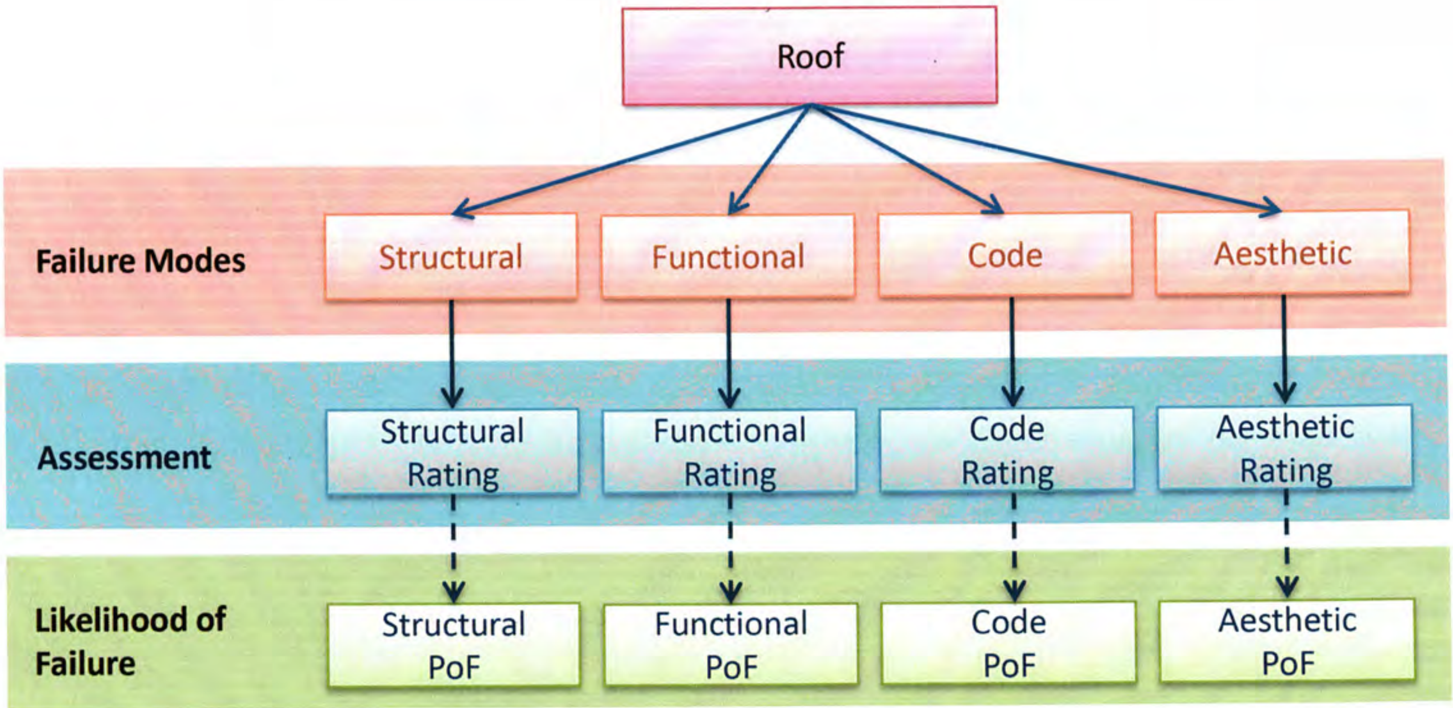
# Risk-Based Prioritization



# Likelihood of Failure



# Likelihood of Failure (LoF)



# Scorecards

1. Rating system
2. Rating scale applies throughout the asset portfolio

*Exercise – Water Mains LoF*

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# Likelihood of Failure Scorecards

## Likelihood of Failure Score Card

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Likelihood of Failure | Extrem. Unlikely | Unlikely | Likely | Very Likely | Sure | |
| | | Condition | Excellent | Good | Fair | Poor | Very Poor/Failed | |
| | | Remaining life left | >25 years | 10-25 years | 5-10 years | 2-4 years | 0-months | |
| | | Rating | 1 | 2 | 3 | 4 | 5 | Rating |
| **Failure Modes** | **Criteria** | **Measure or Proxy** | 2% | 7% | 10% | 20% | 95% | PoF (%) |
| **Water Mains** | **Water Mains** | **Water Mains** | | **Water Mains** | | **Water Mains** | | |
| Physical Integrity | Remaining Useful Life (opt 1) | Life Left (yrs) | 25 years or more | 24-11 years | 10 -5 years | 2-4 years | 1 year or less | |
| | % Life Left (opt. 2) | % Life left equivalent for DI pipes (ESL=100) | >=25% | 10-25% | 10-5 % | 2-5% | <2% | |
| | Condition | C-Value from Calibrated Hydraulic Model | >100 | 100-81 | 80-61 | 31-60 | 30 or less | |
| | | | Excellent | Good | Fair | Poor | Very Poor/Failed | |
| | | Condition Assessment (Field Data Inst. Knowledge) | New or in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. | |
| | Breakage History | #Breakages/ 100 mi pipe (pipes grouped by cohorts) | 0-5 | 5-10 | 15 | 15-20 | >20 | |
| | Physical Integrity Score = Max (Remaining useful life, Condition, Breakage Hist.) | | | | | | | |

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# Consequence Factors

1. What matters to you and to your costumers
2. Negative impacts of asset failures
3. Fall into 3 categories:
   - Impacts to people
   - Impacts to the environment
   - Economic impacts

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# Consequence Factors: What if….

| | What could happen if a … should fail? | | |
|---|---|---|---|
| | **People** | **Environment** | **Costs** |
| **Well** | | | |
| **Water Main** | | | |
| **Corrosion Control** | | | |
| **Pump Station** | | | |
| **Tank** | | | |

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# Calculating Risk: The Risk Space

| Condition | RUL | LoF | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Very Poor/Failed | 0-months | Sure | 5 | 5 | 10 | 15 | 20 | 25 |
| Poor | 2-4 years | Very Likely | 4 | 4 | 8 | 12 | 16 | 20 |
| Fair | 5-10 years | Likely | 3 | 3 | 6 | 9 | 12 | 15 |
| Good | 10-25 years | Unlikely | 2 | 2 | 4 | 6 | 8 | 10 |
| Excellent | >25 years | Extrem. Unlikely | 1 | 1 | 2 | 3 | 4 | 5 |
| | | | | 1 | 2 | 3 | 4 | 5 |
| | | | | Minor | Low | Moderate | High | Very High |
| | | | | 0 - $2K | $2K - $100K | $100K - $200K | $200K - $1M | >$1,000,000 |
| | | | | | | Consequence | | |

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# Calculating Risk: Risk Factors

Water Mains

| | | Consequence Factors | | |
|---|---|---|---|---|
| | | Social | Economic | Environmental |
| Failure Modes | LoF | 5 | 2 | 3 |
| Physical Integrity | 4 | 20 | 8 | 12 |
| Performance (Capacity) | 2 | 10 | (4) | (6) |

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# Yarmouth Risk Model

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# APPENDIX B
# LEVELS OF SERVICE

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# Yarmouth Water Division – Water System Levels of Service

## Social

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **Water Quality** | Compliance with Safe Drinking Water Act (SDWA) primary and secondary standards | Number of violations per year | 0 |
| | Compliance with Revised Total Coliform Rule (RTCR) | Number of violations per year | 0 |
| **Fire Protection** | There will be fire flow available for 100% of customers within the system | Meet Insurance Service Office's (ISO) requirements | |
| | | • Frequency of hydrant inspections | Yearly |
| | | • Frequency of hydrant flushing | Biyearly |
| | | • Distance between hydrants | 500-750 feet |
| **Water Availability** | No adverse event will cause the customer to be without water | Time without water (location based) | No more than 8 hours at a time |
| **Water Pressure** | A minimum pressure will be maintained in the distribution system | Monthly average of daily minimum values | More than 20 psi |
| **Response Time** | Respond to customer complaints/requests in a timely manner | • Emergency (water main breaks) | Within 1 hour |
| | | • Leaks | Within 1 hour |
| | | • New connection | 15 calendar days |
| | | • Meter repairs or replacement | 1 to 5 days |
| | | • Customer complaints (color, odor, bad taste) | 4 hours |
| **Complaints** | Customer complaints will be tracked and monitored on a regular basis (weekly) | Number of complaints due to unplanned or unanticipated issues such as water outages, poor pressure, colored water, or water with bad taste, odor. | Tracked weekly |
| **Communication** | Customers will be notified of planned shutdowns. | Number of days before shutdown | 3 days |

## Economic

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **System Performance** | Main break frequency per year | Number of breaks per 100 miles per year | ≤ 20 /100 miles |
| **Financial Capability** | Revenues are reviewed on an annual basis to determine adequacy for operational needs | Financial analysis | Yearly |

## Environmental

| Category | Level of Service | Performance Measure | Target |
|---|---|---|---|
| **Aquifer Protection** | Compliance with Water Management Act (WMA) Permit Conditions | Number of violations per year | 0 |
| **Water Conservation** | Minimize water loss through leaks | Frequency of system-wide leak detection survey | Every 3 years |

# APPENDIX C
# RISK FRAMEWORK

## Assigned Criticality

| | Reasoning/criteria | Measure or Proxy | Minor | Low | Moderate | High | Very High |
|---|---|---|---|---|---|---|---|
| | | Rating | 1 | 2 | 3 | 4 | 5 |
| **Criticality** | | | | | | | |
| Water Mains | Larger diameters convey more flow--> serve more customers or could impact more people. Also, larger diameters are more expensive. A break in a larger main could result in more water loss. | Diameter | Less or equal to 6 inch | 8 and 10 inch | 12 inch | 16 and 20 inch | N/A |
| Pump Stations and Corrosion Control Facilities | Impact to Customers | Pumping/Serving Capacity | NA | NA | <=350 GPM | 400 -600 GPM | >600 GPM |
| Wells | | | NA | NA | <=350 GPM | 400 -600 GPM | >600 GPM |
| Tanks | Impact to Customers | | | | Prospect Hill (3.5) | German Hill<br>Sandy Pond | |

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## Likelihood of Failure Score Card

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Likelihood of Failure | Extrem. Unlikely | Unlikely | Likely | Very Likely | Sure |
| | | Condition | Excellent | Good | Fair | Poor | Very Poor/Failed |
| | | Remaining life left | >25 years | 10-25 years | 5-10 years | 2-4 years | 0-months |
| | | Rating | 1 | 2 | 3 | 4 | 5 | Rating |
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| **Water Mains** | **Water Mains** | **Water Mains** | **Water Mains** | | **Water Mains** | | |
| Physical Integrity | Remaining Useful Life (opt 1) | Life Left (yrs) | 25 years or more | 24-11 years | 10 -5 years | 2-4 years | 1 year or less |
| | % Life Left (opt. 2) | % Life left equivalent for DI pipes (ESL=100) | >=25% | 10-25% | 10-5 % | 2-5% | <2% |
| | | | Excellent | Good | Fair | Poor | Very Poor/Failed |
| | | Condition Assessment (Field Data Inst. Knowledge) | New or in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. |
| | Breakage History | #Breakages/ 100 mi./year (pipes grouped by cohorts) | [illegible] | 5-10 | 15 | 15-20 | >20 |
| | **Physical Integrity Score = Max (Remaining useful life, Condition, Breakage Hist.)** | | | | | | |
| Performance (= Capacity) | Capacity | C-Value from Calibrated Hydraulic Model | >100 | 100-81 | 80-61 | 31-60 | 30 or less |
| | Fire Flow | Fire Flow Adequacy from hydraulic model AND | >3500 gpm | (1500-3500) gpm | (750-1500) gpm | (750-500) gpm | <500 gpm |
| | | Available Fire Flow (hydraulic Model) and Needed Fire Flow (NFF) | Avg AFF>Avg NFF and min AFF > max NFF | Avg AFF>Avg NFF and min AFF > Avg NFF | Avg AFF>Avg NFF and min AFF > min NFF | Max AFF < min NFF and Avg AFF < Avg NFF | max AFF < min NFF |
| | **Performance Score = Maximum (Pressure, FireFlow)** | | | | | | |
| **Pumps + Motors** | **Pumps + Motors** | **Pumps + Motors** | **Pumps + Motors** | | **Pumps + Motors** | | **Pumps + Motors** |
| Physical Integrity | Remaining Useful Life | Life Left (yrs) - Based on ESL of 40 years, for pumps | 29-25 yrs | 24-15 yrs | 14-8 yrs | 7-4 yrs | 3-2 yrs |
| | | | Excellent | Good | Fair | Poor | Very Poor/Failed |
| | Condition | Condition Assessment (Field Data Inst. Knowledge) | New or in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. |
| | **Physical Integrity Score = Max (RUL, Condition)** | | | | | | |
| Performance | Obsolescence | Availability of components | N/A | N/A | N/A | N/A | Very old. Replacement parts are hard to find. It may take + 30 days to get a part |
| | High Repair/Maintenance Need | Frequency of repairs | 1/year | 1/6 months | 1/3 months | monthly | weekly |
| | **Performance Score = (Maximum Obsolescence, Repairs, Capacity)** | | | | | | |
| Energy Efficiency | Energy Use/Evaluation | Energy Efficiency in % from assessment | 92-88 | 87-84 | 83-80 | 79-75 | 74-70 |
| | **EE Score = Energy Use** | | | | | | |
| **Water Supply Wells** | **Water Supply Wells** | **Water Supply Wells** | | **Water Supply Wells** | | **Water Supply Wells** | **Wate** |
| Physical Integrity | Remaining Useful Life | Life Left (yrs) | 75-60 yrs | 60-30 yrs | 30-15 yrs | 15-5 yrs | 5-1 yrs |
| | Condition | Derived from condition assessment | | | | | |
| | **Physical Integrity Rating= Max (RUL, Screen Cond, Casing Cond)** | | | | | | |
| Performance | Water Quality | Need to define | ? | ? | ? | ? | ? |
| | Specific Capacity | Current SC/Original SC (as %) | 100% | 90% | 80% | 65% | <40% |
| | **Performance Score = (Maximum WQ, Drawdown)** | | | | | | |
| Efficiency | Wire to Water Efficiency | Wire to water efficiency | 65% to 70% | 55% to 65% | 50% to 55% | 40% to 50% | <40% |
| | **EE Score = Energy Use** | | | | | | |

## Likelihood of Failure Score Card

| Failure Modes | Criteria | Measure or Proxy | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|
| | | Likelihood of Failure | Extrem. Unlikely | Unlikely | Likely | Very Likely | Sure | |
| | | Condition | Excellent | Good | Fair | Poor | Very Poor/Failed | |
| | | Remaining life left | >25 years | 10-25 years | 5-10 years | 2-4 years | 0-months | |
| | | Rating | 1 | 2 | 3 | 4 | 5 | Rating |
| **Failure Modes** | **Criteria** | **Measure or Proxy** | 2% | 7% | 10% | 20% | 95% | PoF (%) |
| **Storage Tanks** | **Storage Tanks** | **Storage Tanks** | **Storage Tanks** | | **Storage Tanks** | **Storage Tanks** | | |
| Physical Integrity | Remaining Useful Life | Life Left (yrs) | To be developed | | | | | |
| | Num of Years since Painted | Number of years since last painted | 0-5 | 6-9 | 10-12 | 13-14 | 15 | |
| | Condition (opt. 1) | | Excellent | Good | Fair | Poor | Very Poor/Failed | |
| | | Condition Assessment (Field Data Inst. Knowledge) | Not new, but in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. | |
| | Condition (opt. 2) | | Excellent | Good | Fair | Poor | Very Poor/Failed | |
| | | Exterior Coatings / Interior Coatings | Extent of corrosion requires to be re inspected in the next 10 years | Extent of corrosion requires to be re inspected in the next 5 years | Extent of corrosion requires issues to be addressed within 3-4 years or re-inspected within 2 years | Extent of corrosion requires issues to be addressed within 1 year | Extent of corrosion requires issues to be addressed immediately | |
| | | Structural Elements | No structural issues | Tank has some (<5%) minor structural issues that need to be addressed in the next 1-2 years | Tank has structural issues (5-25%) that need to be addressed in the next 1-2 years | 25-50% of the structure has issues that require immediate attention | More than 50% of the structure have issues that need to be addressed immediately | |
| | Condition (opt. 3) | Itemized Condition from Cond. Assessment | To be developed | | | | | |
| | | | Physical Integrity Score = Max (RUL, Condition) | | | | | |
| Performance | Capacity | Fire Flow capacity with Emergency Storage | To be developed | | | | | |
| | | Pressure Regulating Capacity | To be developed | | | | | |
| | | | Performance Score = (Maximum FF Capacity, PR Capacity) | | | | | |
| Code Compliance | Code compliance | Code Compliance Issues | Meets code | | | | Doesn't meet code | |
| | | | Code = Code compliance Rating | | | | | |
| **Corrosion Control Facilities** | | | | | | | | |
| Physical Integrity | Remaining Useful Life (opt 1) | Life Left (yrs) | 25 years or more | 24-11 years | 10 -5 years | 2-4 years | 1 year or less | |
| | Conditon | | To be developed | 0 | 0 | 0 | 0 | |
| | | Condition Assessment (Field Data Inst. Knowledge) | New or in very good condition with no indicators of obsolescence and providing a high level of remaining service potential | Aged, but in good condition providing an adequate remaining service potential. No signs of immediate or short term obsolescence | Providing an adequate level of remaining service potential but some concerns over the ability of the asset to continue to provide an adequate level of service in the short to medium term. May be signs of obsolescence in short or mid-term. | Indicators that will need to renew, upgrade or scrap in near future. Should be reflected by inclusion in CIP to renew or replace in the short-term. | At intervention point. No longer providing an acceptable level of service. Requires immediate renewal, replacement or closure. | |
| | | | Physical Integrity Score = Max (Remaining useful life, Condition, Breakage Hist.) | | | | | |