infraPLAN

Asset Management Services

AWC

KANEW Study

MA Systems

Hingham-Hull, Millbury, Oxford

November 6, 2016

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1 Executive Summary

Introduction

Aquarion Water Company of Connecticut (AWC) has retained infraPLAN to conduct a KANEW study that determines the optimal long-term strategy of Renewal and Replacement (R&R) of the water mains from 2017 to 2050 for its MA water Systems, Hingham-Hull (HH), Oxford (OX) and Millbury (MILL). The overall goal is to balance costs (of investment in R&R) and benefits (mainly reduction in Break Rate). A "KANEW study" is named after the software (KANEW) used for this study.

The KANEW software allows the user to simulate various Scenarios of R&R, and, ultimately, generate the optimal R&R plan, based on the length of mains that reach the end of their Effective Useful Life (EUL) each year, and various constraints on desired service levels (cost, length of work per year, and acceptable Break Rate).

While this is the first KANEW study conducted for the MA Systems, several such studies were previously completed by infraPLAN for the AWC CT Systems between 2009 and 2015. The type of analytical approach adopted for the CT Systems in order to generate the necessary input values (EUL, aging curves, current Break Rate) was not an option for the MA Systems because of inadequate data. We therefore organized the MA mains into cohorts similar to the ones created for the CT Systems, and, when necessary, used some of the 2015 input values we had generated for CT, adjusting them for the MA cohorts.

Data

The MA Systems are made of close to 286 mi of active mains (after data clean up) with an average age of 61 years old, as follows:

- Hingham-Hull: 188 mi; 64.4 yrs. old
- Millbury: 52 mi; 59.5 yrs. old
- Oxford: 45.8 mi; 48.7 yrs. old

The most prevalent MATs are AC, DI, PCI, SCI; other MATs are regrouped in an "ELSE" category. The mains have been organized based on the System, their material (MAT) and diameter (DIAM). A cohort of mains is defined by the System, MAT and DIAM. For example, the HH_DI_L cohort includes DI large mains (DIAM>12") located in Hingham-Hull. Main statistical results (after clean up) and KANEW input values appear in Table 1.

Name	Medium 50% EUL Value *0.15/0.25	2016 Break Rate	Aging Factor	Length-Weighted Average Age	Length (mi)
HH_AC	66/82	0.13	3.35	62.2	27.4
HH_DI_L	75/89	0.025	3.5	23.1	2.0
HH_DI_S	57/71	0.04	4	25.5	43.1
HH_ELSE	71/86	0.096	3.4	72.5	6.3
HH_PCI_L	200/200	0.038	1.3	100.9	5.9
HH_PCI_S	107/129	0.15	2.5	106.5	42.9
HH_SCI_L	200/200	0.025	0.7	56.9	0.9
HH_SCI_S	94/132	0.08	1.35	58.3	49.6
MILL_AC	66/82	0.17	3.35	70.3	0.8
MILL_DI_S	57/71	0.035	4	23.0	15.8
MILL_ELSE	71/86	0.096	3.4	77.0	0.7
MILL_PCI_L	200/200	0.045	1.3	116.0	1.3
MILL_PCI_S	107/129	0.14	2.5	105.0	4.0
MILL_SCI_S	94/132	0.11	1.35	70.0	26.8
OX_AC	66/82	0.13	3.35	62.2	8.9
OX_DI_L	75/89	0.01	3.5	1.6	0.7
OX_DI_S	57/71	0.035	4	23.1	19.0
OX_ELSE	71/89	0.096	3.4	66.0	0.0
OX_PCI_S	107/129	0.16	2.5	109.0	4.9
OX_SCI_S	94/132	0.07	1.35	56.0	10.2

Table 1 Main Statistical Results

*The EUL values that appear in the Table 1 correspond to the age read on the aging curve (Break Rate based on age) of the cohort when the threshold Maximum Break Rate (MBR) values of 0.15 and then 0.25 Breaks/mi./yr., respectively, are reached.

EULs and aging values in red are borrowed from the CT 2015 study.

Summary of the Main Results - Selected Scenario

We first created Scenarios with EULs defined with a MBR of 0.15 Breaks/mi./yr. and an Efficiency Factor (EF) of 1 and then 2 (the notion of EF is explained in 5.1.2.) They resulted in R&R lengths and investment costs, as well as, in some cases, Break Rates that were too high. To limit the size of the report, those results are not shown here. We then solely explored Scenarios with MBR of 0.25 and an EF of 2. These results are shown in the report.

Scenario 1 (also called the "Needs" Scenario; Section 6.4.1) follows the EULs provided as input values (Table 5); it results in an investment cost that is too high. Scenario 4 (Section 6.4.3) is created by imposing the current R&R budget of $1.75 M every year until 2100 for the 3 MA Systems (2060 for MA as a whole.) The backlog after the planning horizon and the Break Rate are higher than is acceptable. The poor performance of Scenario 1 and Scenario 4 justifies the optimization conducted in Scenario 2.

Scenario 2, the Scenario selected, was generated using the amount of R&R obtained with Scenario 1 (“Needs”) optimized at the cohort level (the methodology is described in Section 5.2. The results for Scenario 2 appear in Figure 1 and Figure 2. They show, for medium, short (pessimistic) and long (optimistic) EULs (“service lives”):

- the resulting Break Rate (“Future network Break Rate”)
- the investment cost (“Investment cost for rehabilitation”)
- the Length of R&R (“Future rehabilitation needs per asset type”)

While AWC requested a plan up to 2050, we always looked at predictions past the end of the planning horizon to ensure that the plan we propose does not result in a backlog after that date.

The minimum investment (with Medium EULs, black curve) that is projected is $2.6 M as of 2017, higher than the current yearly budget of $1.5 M - $2 M (we will use $1.75 M) for the 3 Systems. It would need to be ramped up to $3.7 M by 2100 (including the replacement of the new mains by that time). The Break Rate with that Scenario remains around 0.12 Breaks/mi./yr. and it ensures that there be no unmanageable backlog after 2100.

The same series of results is also provided for each System (Scenario 1 “Needs”, Scenario 2, and Scenario 4).

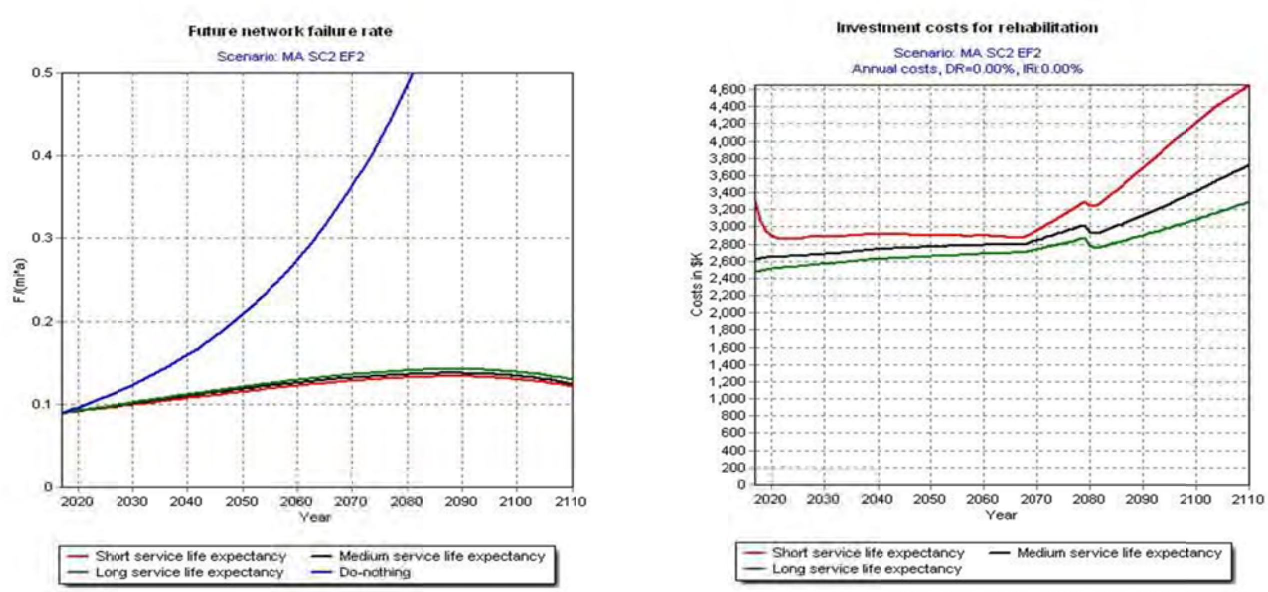


Figure 1 MA Scenario 2 - Break Rate and Investment Cost

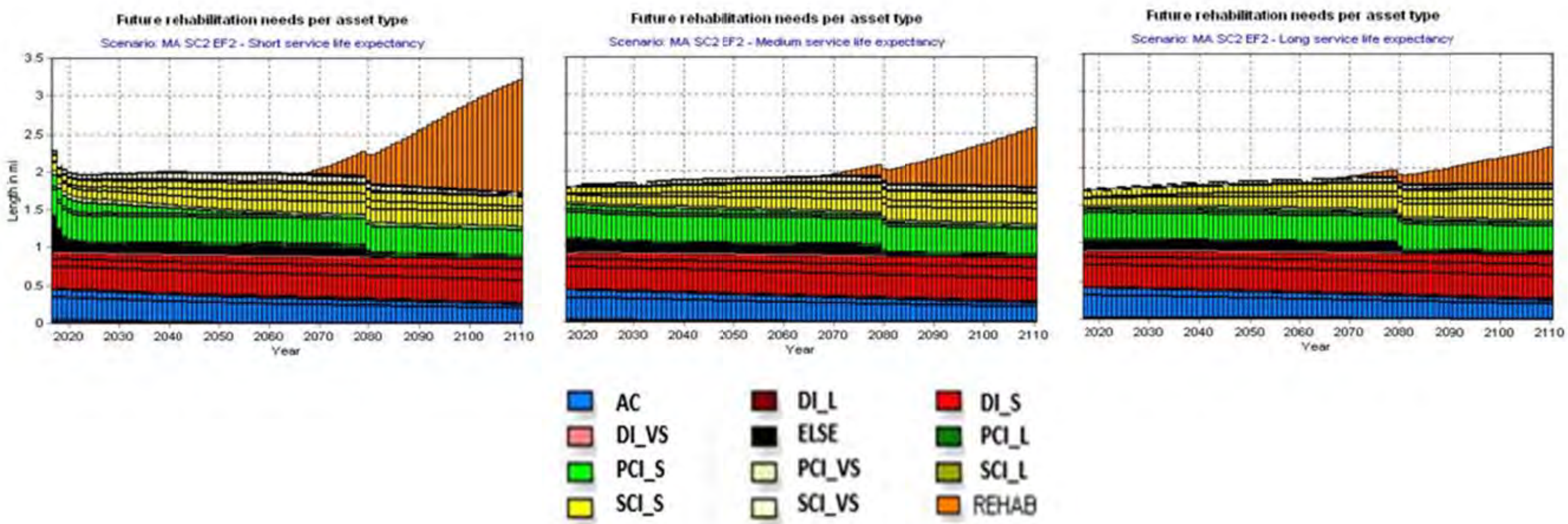


Figure 2 MA Scenario 2 - Future Rehabilitation Needs per Asset Type

The left Figure above reads as follows: In 2030, there is a need for (approximately) 0.4 mile of R&R for AC mains, 0.5 mile of DI_S, and 0.4 mile for PCI_S, etc.

Recommendations – Data Quality

This first KANEW study gave us the opportunity to review the data. We subsequently provide recommendations in order to improve EULs and aging curves when running future similar studies, and ultimately R&R projections.

Mains (GIS layer)

- Each GIS main should be given a unique FeatureID.
- The nature of each GIS main should be reported ("true" main, service, fire line, hydrant lines.) That attribute could also indicate whether a main is proposed "proposed main".
- Only one attribute pertaining to the YOI should be kept. Which may require to combine the 3 YOIs that are currently in the GIS.
- Missing YOI and MAT should be investigated.
- The YOI peaks should be investigated as they may be default values.
- Discrepancies between the CEP and the GIS Mains layer should be reconciled. The CEP should match the GIS as is at the date the CEP was produced.
- An abandoned (ABN) Mains layer should be initiated in the GIS (similar to the CT GIS ABN Mains layer).
- A new main that replaces an ABN main should be given a new ID.
- The Date of Abandonment (DOA) should be reported.
- The report includes recommendations pertaining to the treatment of the ABN mains.

Breaks

- The breaks should be reported in one document, preferably the Breaks layer of the GIS.
- Reporting breaks in the GIS Mains layer does not allow to properly report the Year of the Break (YOB.)
- Each break should be assigned to its main. This is to be done after each main has been given a unique FeatureID.
- The type of break should also be properly identified. Leaks should not be included in the computation of the Break Rate.
- Breaks that occurred on ABN mains should be kept in the GIS Breaks layer even after the main has been physically removed.

Acronyms

Acronyms	Definition
ABN	Abandoned
AC	Asbestos Cement
ACT	Active
AWC	Aquarion Water Company
DI	Ductile Iron
DIAM	Diameter
DOB	Date Of Break
DOI	Date Of Installation
EUL	Effective Useful Life
MAT	Material
MBR	Maximum Break Rate
PCI	Pit Cast Iron
PVC	Plastic
R&R	Rehabilitation & Replacement
SCI	Spun Cast Iron
YOB	Year Of Break
YOI	Year Of Installation

Aquarion Water Company of Connecticut (AWC) has retained infraPLAN to conduct a KANEW study that evaluates long-term strategies of Renewal and Replacement (R&R) of the water mains from 2017 to 2050 for the 3 MA water Systems, Hingham-Hull, Millbury, and Oxford. "KANEW study" is named after the software (KANEW) used for that study. While this is the first KANEW study done for the MA System, such studies were previously conducted by infraPLAN for the AWC CT Systems in 2009, 2011, 2013, and 2015.

2 Methodology

The KANEW software allows the user to simulate Scenarios of R&R, and ultimately generate an optimal plan, based on the length of mains that reach the end of their Effective Useful Life (EUL) each year, and various constraints on desired service levels (cost, amount of work per year, and acceptable Break Rate). The overall goal is to balance costs (of investment in R&R) and benefits (mainly reduction in Break Rate). When data allows, the preferred and more advanced approach, as done for the CT System, consists in determining the EUL of each cohort of mains (group of mains degrading in a similar fashion defined here by System_MAT_DIAM) specific to a System (as opposed to using a generic value). This is done by plotting the aging curve (Break Rate based on age if no R&R is undertaken) of each cohort based on a statistical analysis of the System's mains' attributes and their historic breaks.

For the advanced approach, the failure forecasting model LEYP (Linear Extended Yule Process) is used to generate the Predicted Break Number (PBN) for each year and for each main. That advanced approach was not possible for the MA Systems because the break data was not adequate. We therefore organized the data in cohorts similar to the ones we formed for the CT Systems and used their aging curves and EULs.

It is also possible that even if the break data was improved, some cohorts and the number of breaks would be too small for the advanced approach.

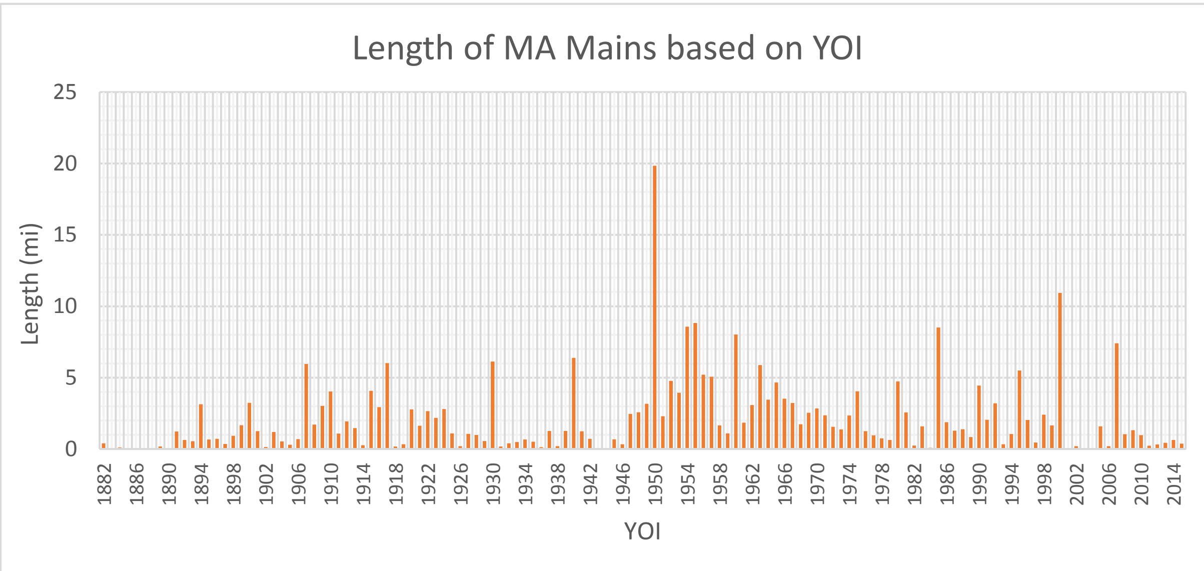
The main data allowed us to determine the average age of each cohort, but the break data did not allow us to compute the current Break Rate of each cohort. It was therefore assumed using the corresponding CT aging curves.

3 Data

3.1 Mains

3.1.1 Original Data

The MA System is made of close to 285.8 mi of mainly AC, CI and DI mains. Installation started as early as in the 1880s (Hingham-Hull). The distribution of the Year of Installation (YOI) varies based on the System. And so do the ages.



Main data received by infraPLAN consists in:

Hingham-Hull

- a GIS layer dated May 3 that includes active (ACT) and abandoned mains (ABN).
- a CEP inventory in the form of an excel spreadsheet provided Aug 23 (“Pipe Input Data”) that lists mains and, for each main, its number of breaks.

Millbury

- a GIS layer dated Aug 11 that includes active (ACT) and abandoned mains (ABN).
- a CEP inventory in the form of an excel spreadsheet provided Aug 31 (“Millbury CEP Pipe Input Data”) that lists a Break Rate per 1,000 feet for each main.

Oxford

- a GIS layer dated Aug 11 that includes active mains (ACT). No information about Life Status.
- a CEP inventory in the form of an excel spreadsheet provided Aug 31 (“Oxford CEP Pipe Input Data”). It just mentions whether a main broke or not.

While the GIS Mains layer and the CEP both list mains, there are discrepancies between those two documents. For example:

Hingham-Hull

Both the CEP and the GIS Mains layer have 1959 entries. There is no Feature ID in GIS but each pipe has a unique ID and Label which also appear in the CEP, which seems to pertain to the same main. It looks as if the CEP and the GIS Mains layer are synchronized. P-1319 appeared twice and was removed. All mains are ACT.

Millbury

The CEP lists 522 mains while the GIS Mains layer has 570. There is no Feature ID in GIS but each pipe has a unique ID, OBJECTID and OBJECTID_1., and a non-unique Label (10 duplicates). The CEP identifies each pipe with a unique Label.
An attribute in the GIS indicates whether the main is active (0=ABN; 1=ACT). There are 31 ABN mains in the GIS. There were removed for this study. 539 are left.

Oxford

The CEP lists 369 mains while the GIS Mains layer has 387. There is no Feature ID in GIS but each pipe has a unique OBJECTID and OBJECTID_1. The CEP identifies each pipe with a unique Label. No information about the Life Status of the mains. All will be considered to be ACT.

The data that appear in the GIS layers (and not the CEP) is kept for this study.

3.1.2 Data Clean up

We look at MAT, DIAM, and YOI.

MAT:

Figure 3 and Table 2 show the distribution of the original MAT based the System.

MAT	Hingham-Hull	Millbury	Oxford	TOTAL
AC	27.4	0.8	8.9	37.2
CI	76.4		0.0	76.5
CU	0.0	0.2	0.0	0.3
DI	43.1	16.5	19.9	79.5
Lined CI (LCL)	34.7	0.1		34.8
GAL	2.9	0.4		3.3
PCI		5.0	4.9	10.0
PL	0.1	0.1		0.1
Prestressed CONC	2.4			2.4
PVC	1.0			1.0
SCI		28.8	11.9	40.8
TOTAL	188.0	52.0	45.8	285.8

Table 2 MA - Length and Number of Mains based on MAT and System – Original Data

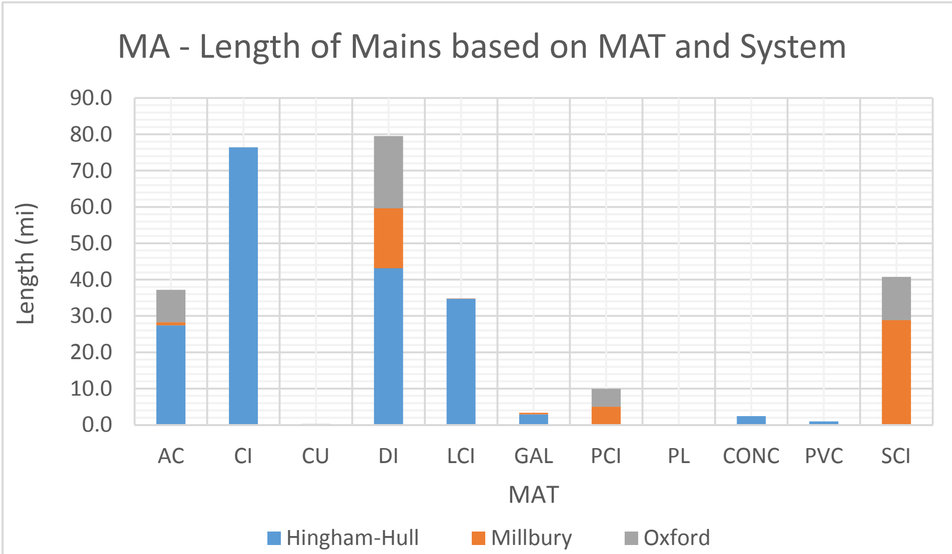


Figure 3 MA - Number and Length of Mains based on MAT - Original Data

PL, PVC, GAL, CU, CONC, and PL are minor MAT. They are regrouped under the “ELSE” category. There is no UNK MAT.

In order to align the cohorts with the work done at AWC we make the following changes of MAT:

- if a CI or DI main was installed before 1927, we make it a PCI main.
- if a CI main was installed in 1927 or after, but before 1975, we make it a SCI main.
- If a CI main was installed after 1975 we make it a DI main.
- if a DI main was installed in 1927 or after, but before 1965, we make it a SCI.

We are left with the following distribution:

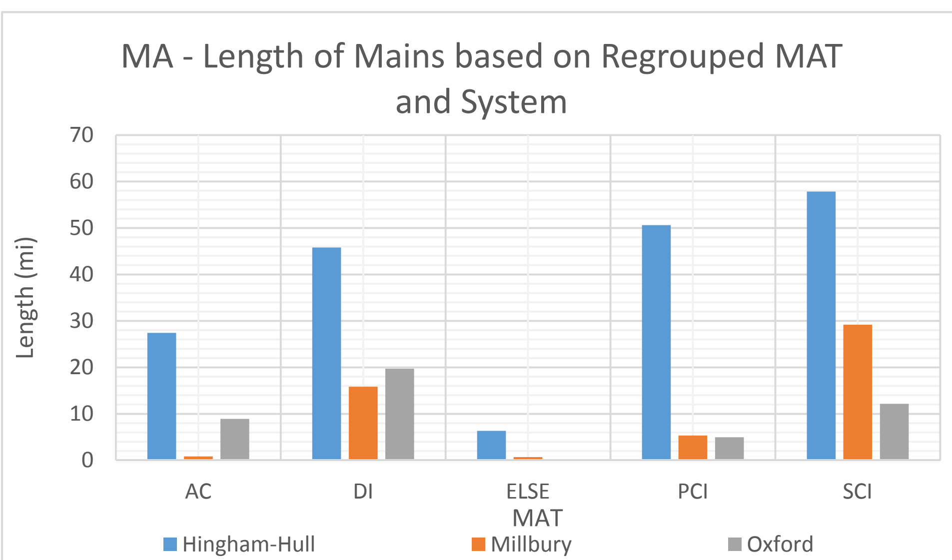


Figure 4 MA - Length of Mains based on Regrouped MAT and System - Original Data

DIAM:

As seen in Table 3 and Figure 5, the DIAMs vary between 1 and 24”.
There is no missing diameter (DIAM).
17.4 mi have a DIAM that is smaller than 3”. It was not clear whether they are service mains. They have been kept in the study. The type of main should be identified in the GIS.
In the definition of the KANEW cohorts we break down the 3 main MAT (DI, PCI and SCI) based on the DIAM (Large = larger than 12”, and Small = 12” and smaller). The (post clean-up) distribution of Length based on System, MAT and DIAM is shown in Figure 8.

DIAM	1	1.25	1.5	2	2.25	3	4	6	8	10	12	14	16	20	24	TOTAL
length	0.6	0	0.2	9.2	7.3	0.4	6.9	84.2	112.3	5.3	46.4	0.6	3.1	7.3	2	285.9

Table 3 MA - Length of Mains based on DIAM and System - Original Data

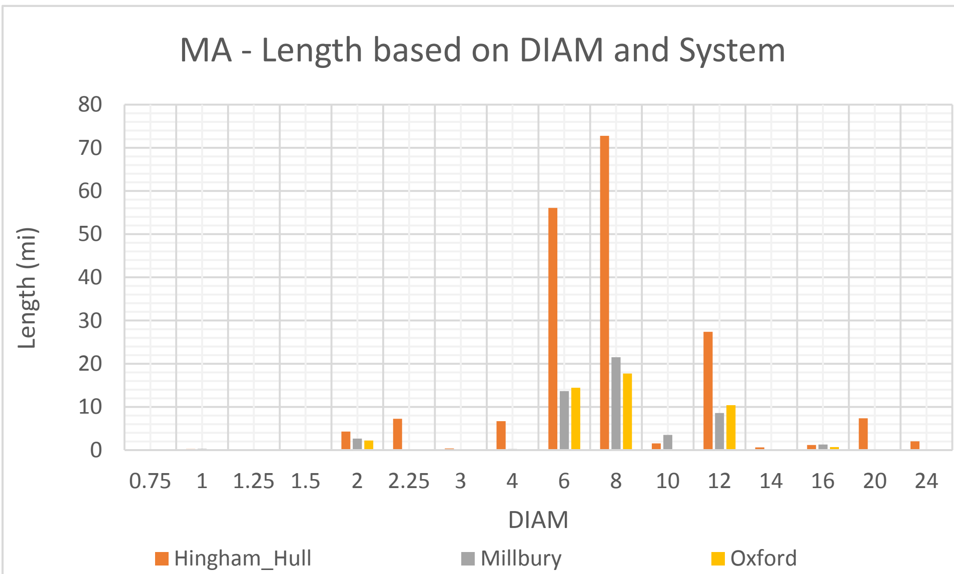


Figure 5 MA - Length of Mains based on DIAM - Original Data

The KANEW cohorts are defined using the System and the MAT. The main MAT (DI, PCI and SCI) are further broken down based on the DIAM (Large = larger than 12”, and Small = 12” and smaller). The (post clean-up) distribution of Length based on System, MAT and DIAM is shown in Figure 8.

YOI:

The YOI is identified as follows in each GIS file:

- Hingham-Hull: Installati. There is no missing data.
- Millbury: Date_Inst (empty) and Installati (populated). 11 mains do not have any data. 8 are ABN. 3 ACT. 2 mains have a YOI of 2030 indicating that they are proposed. They were also removed.
- Oxford: InstallYea. 20 mains do not have any data.

The (post clean-up) distribution of Length based on System, MAT, and YOI is seen in Figure 9, Figure 10, Figure 11, and Figure 12.

3.1.3 Final Data after Clean up

After clean up we are left with a total of 2,282 mains for 285.7 mi.

In this Section we look at the length and length-weighted average age based on DIAM, MAT, System and YOI.

System:

The length of mains based on the System is shown in Figure 6 below.

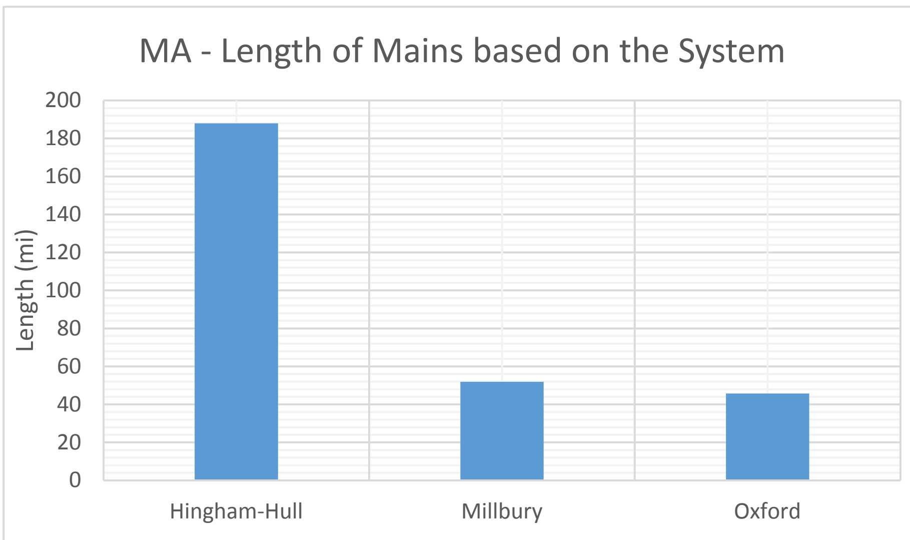


Figure 6 MA - Length of Mains based on the System - Post Clean up

The Hingham-Hull System is the largest with 188 mi; then come Millbury (51.9 mi.) and Oxford (45.8 mi.)

Length and Length-Weighted Average Age based on MAT and DIAM:

Figure 7, Figure 8, and Table 4 show the length of mains and the length-weighted average age based on System, MAT and DIAM.

The average age in MA is 61 years old, with Oxford being the youngest System (48.7; then comes Millbury (59.5), and the oldest is Hingham (64.4) as seen in Figure 7 below.

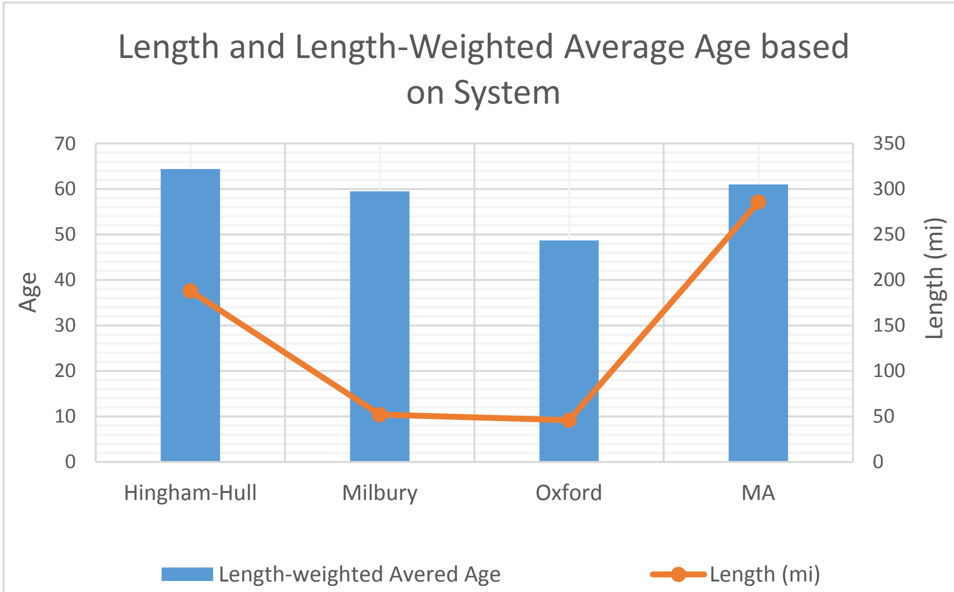


Figure 7 MA - Length and Length-Weighted Average Age based on System - Post Clean up

We now break down those results based on the MAT and DIAM.

	Hingham-Hull		Millbury		Oxford		MA	
	Length-weighted Averaged Age	Length (mi)	Length-weighted Averaged Age	Length (mi)	Length-weighted Averaged Age	Length (mi)	Length-weighted Averaged Age	Length (mi)
AC	62.2	27.4	70.3	0.8	62.2	8.9	62.4	37.2
DI_L	23.1	2.0	NA	NA	1.6	0.7	17.6	2.7
DI_S	25.6	43.8	23.0	15.8	23.1	19.0	24.5	78.6
ELSE	72.5	6.3	76.9	0.7	66.0	0.0	72.9	7.1
PCI_L	100.9	5.9	116.0	1.3	NA	NA	103.5	7.2
PCI_S	106.2	44.7	104.9	4.1	109.0	4.9	106.4	53.7
SCI_L	56.9	0.9	NA	NA	NA	NA	56.9	0.9
SCI_S	59.4	56.9	69.7	29.2	57.0	12.2	62.2	98.3
TOTAL	**64.4**	**188.0**	**59.5**	**51.9**	**48.7**	**45.8**	**61.0**	**285.7**

Table 4 MA - Length-Weighted Avg. Age and Length based on MAT, System, and DIAM - Post Clean up

There is no PCI Large main in Oxford; no SCI Large in Millbury and Oxford; no DI Large in Hingham-Hull

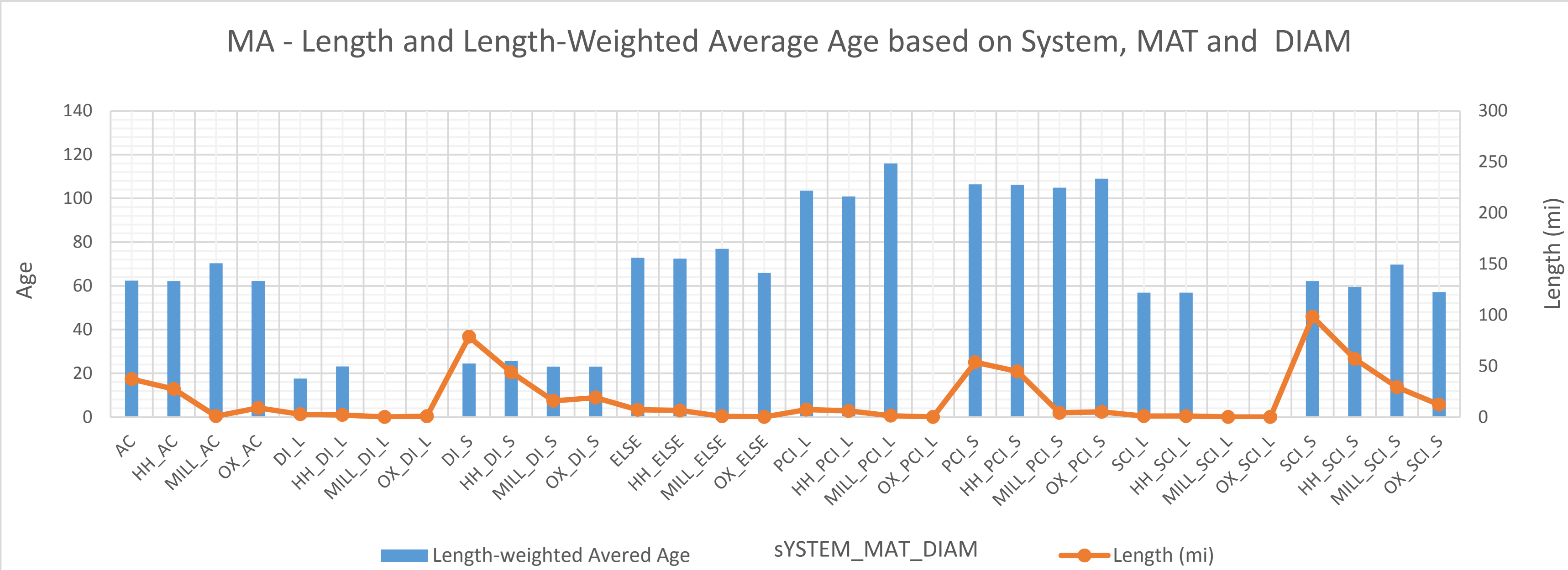


Figure 8 MA - Length and Length-Weighted Average Age of Mains based on System, MAT and DIAM - Post Clean up

Length of Mains based on System, MAT and YOI

The mains were installed starting in 1882 steadily until now (with a drop between 1930 and 1945). The peak in 1950 (mostly SCI mains in Millbury) should be investigated as it may be a default value.

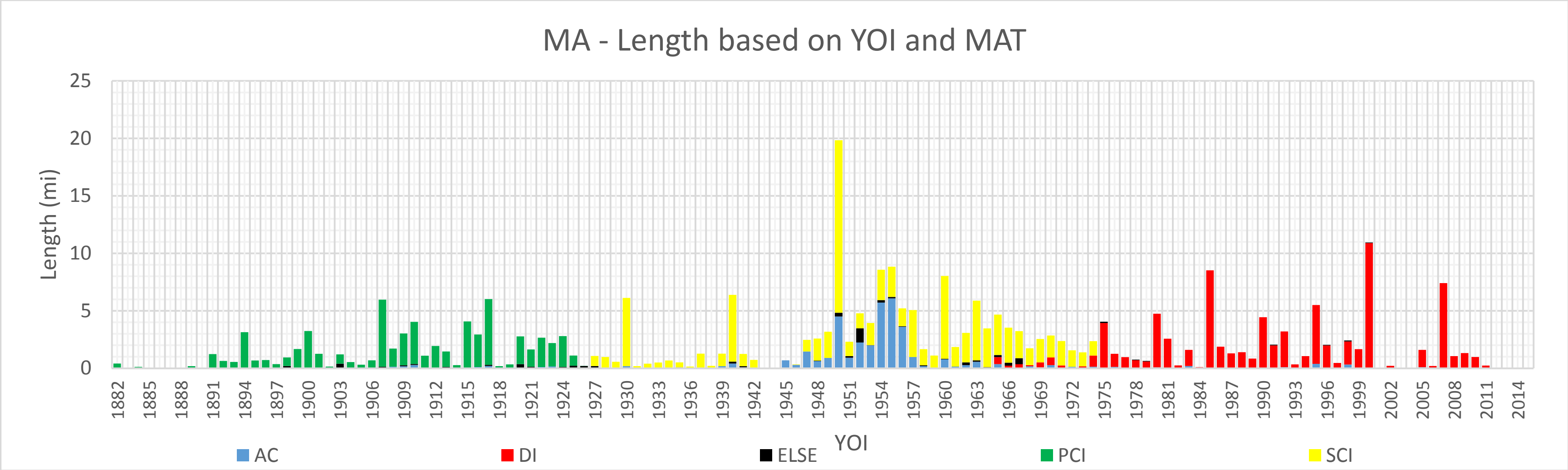


Figure 9 MA - Length of Mains based on YOI and MAT - Post Clean up

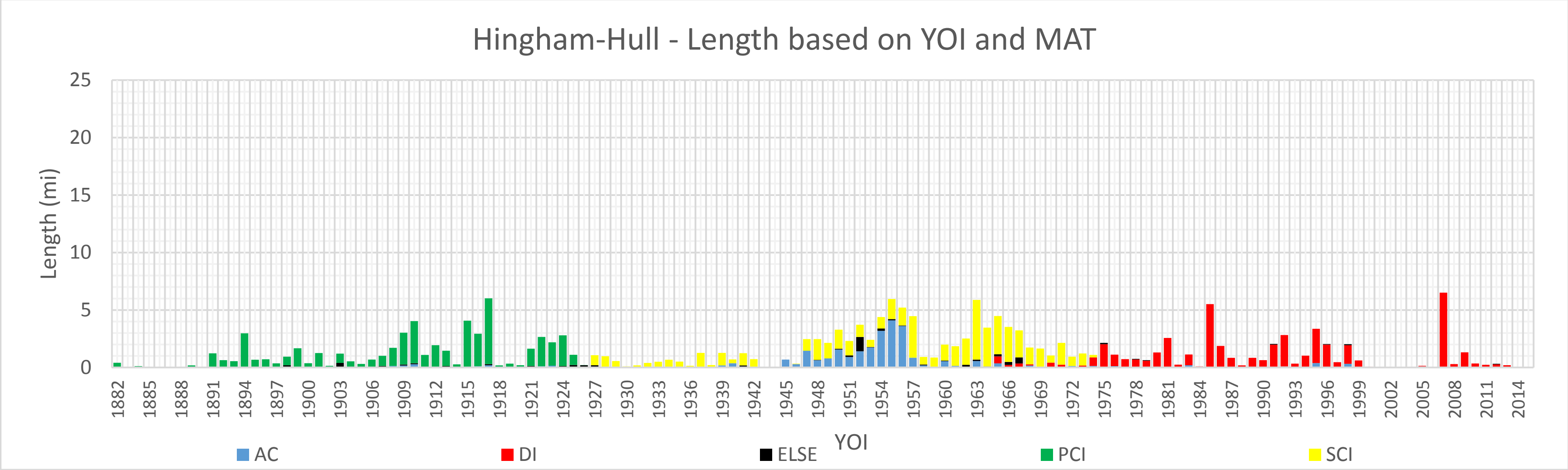


Figure 10 Hingham-Hull - Length of Mains based on MAT and MAT - Post Clean up

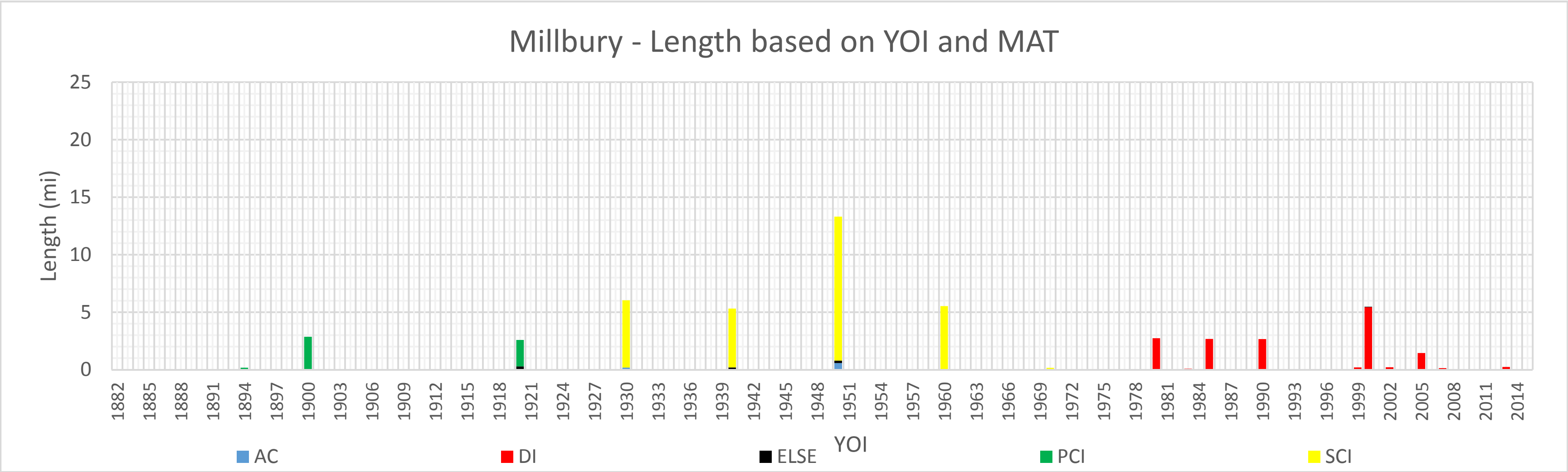


Figure 11 Millbury - Length of Mains based on MAT and YOI - Post Cleanup

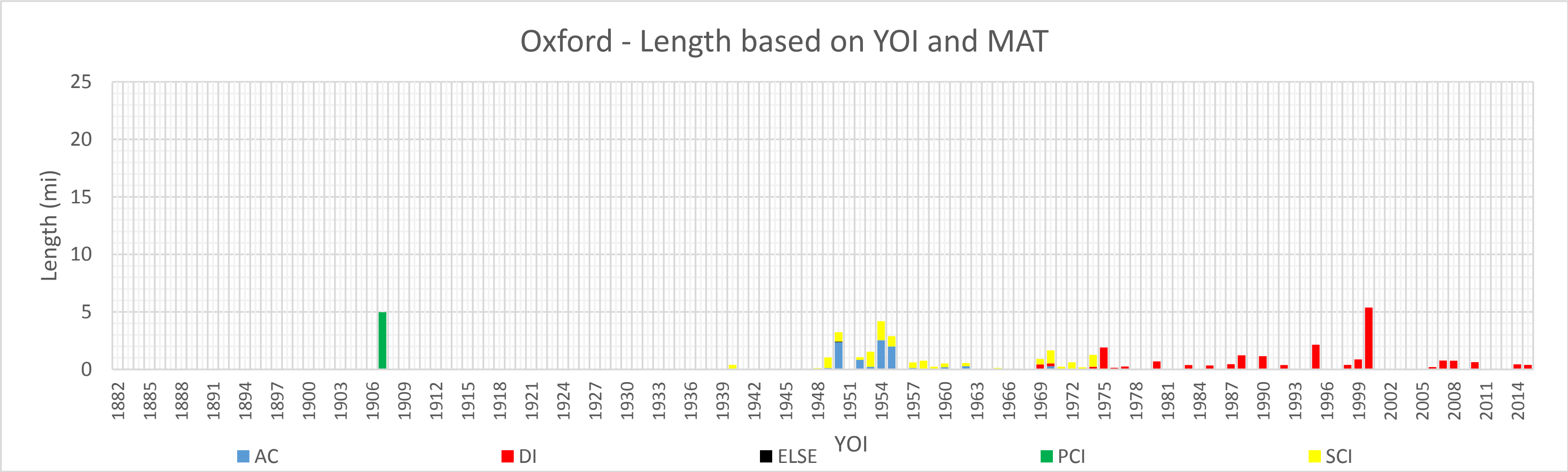


Figure 12 Oxford - Length of Mains based on YOI and MAT - Post Clean up

3.1.4 Recommendations - Mains

- Each main should be given a unique FeatureID.
- The nature of each main should be reported ("true" main, service, fire line, hydrant lines.) That attribute could also indicate whether a main is proposed "proposed main".
- Only one attribute pertaining to the YOI should be kept.
- Missing YOI should be investigated.
- The YOI peaks investigated as they may be a default value.
- Discrepancies between the CEP and the GIS Mains layer should be reconciled. The CEP should match the GIS as is at the date the CEP was produced.
- An ABN Mains layer should be initiated in the GIS (similar to the CT ABN Mains layer).
- A new main that replaces an ABN main should be given a new ID.
- The Date of Abandonment (DOA) should be reported.
- If an original main is split and one portion only is replaced, treatment of the main in GIS should be as shown in the example below:

GIS ACT mains prior to 2000

Feature ID	MAT	YOI	YOA	Length	Life Status
101	PCI	1910		500	ACT

200" are replaced in 2000.

After 2000 the ABN layer becomes:

Feature ID	MAT	YOI	YOA	Length	Life Status
101	PCI	1910	2000	200	ABN

And the ACT layer 2 new FeatureIDs are created:

Feature ID	MAT	YOI	YOA	Length	Life Status
102	PCI	1910		300	ACT
103	DI	2000		200	ACT

If a break occurred after 2000 it is to be assigned to the right section (PCI or DI). If a Break occurred prior to 2000 it was on PCI but it is difficult to know which part (the one that remains or the one that has been replaced). Since it was assigned to 101 (the only main that existed prior to 2000) we will keep it on the portion that keeps that FeatureID. Furthermore, the Break is most likely to have occurred on the piece that was removed. From the statistical standpoint, it will make little difference.

3.2 Breaks

3.2.1 Original Data

The source of information depends on the System as follows:

Hingham-Hull

- There was no break information in the GIS Mains layer (as is the case for the 2 other Systems)
- The CIP contains information about breaks in the form of an attribute called "No. of Breaks". 501 (out of 1,959) mains have experienced between 1 and 11 breaks for a total of 1,102 breaks. However, since there is no information regarding the timeframe for those breaks occurrences, we cannot calculate the Break Rate. Furthermore, as will be seen in the other source of break data, it is important to understand the nature of the event that has been reported as a break. A lot of those so-called breaks may actually be leaks.

Number of Breaks	Number of Mains having experienced that number of Breaks	Total Number of Breaks
0	1,458	0
1	286 (mains have broken once)	286
2	105 (mains have broken twice)	210
3	30	90
4	41	164
5	4	20
6	1	6
7	2	14
8	10	80
9	5	45
11	17	187
Grand Total	1,959	1,102

- 3 "Leak" spreadsheets ("AWC Master Leak Spreadsheet 2016 V3"; "AWC Master Leak Spreadsheet V3 (1)"; and "AWC Master Leak Spreadsheet V3"). Those 3 Leak spreadsheets contain information regarding 303 leaks that have occurred between January 1, 2013, and April 16, 2016, as well as some analysis about those leaks. Some attributes need to be better defined and populated so that we can decide which entry is relevant for this analysis (we want real event that show signs of physical degradation on the mains for which R&R is being budgeted; leaks are not to be included):
  - Leak Location: All the options are shown in the Table below. Main is assumed to be the only entry suitable for this analysis.

Leak Location	Total		Leak Location	Total
Abn service	1		Pulled Service	1
Corp	3		RW Main	2
Curb Box	1		Service	123
Hydrant	51		Stop leak	2
Main	111		Tee	1
Main/Hydrant	1		UNK	1
New Tap	1		Valve	4
Grand Total				303

- Type/Cause of Break. All the options are listed in the Table below. The options that are assumed to be suitable for this analysis have been highlighted in yellow.

Type/Cause of Break	Total		Type/Cause of Break	Total		Type/Cause of Break	Total
*	1		Dresser Break	1		Packing Leak	3
ABN SERVICE	1		Flare	1		Pin holes in copper	1
Blow out	4		Hit	1		Relay	5
Cir Crack	2		Hit by Contractor	1		Repair	9
Circumfrential	7		HOLE	59		Repaired leak	1
Contractor	1		Hole- contractor hit	1		Replaced curb stop	1
Contractor Hit	2		Hydrant	1		Replaced Service	2
Corp	1		Hydrant on 3 turns	1		RW LINE	2
Corrosion	3		Hydrant Valve	1		Service	1
Corrosion Holes	1		Joint	1		Split	1
CRACK	79		Leak At corp	2		Stop Leak	1
Crack @ Tap	1		Longitudinal	1		TBD	13
Curb Box Replacement	1		No Leak	1		TEE	1
Curb Stop	4		No leak Found	1		UNK	72
						Valve	9
Grand Total							303

- Additional Comments. The options appear in the Table below. Those highlighted in grew do not appear to be suitable for this analysis.

Additional Comments	Total
345001518	1
345001519	1
345003304	1
Based on Tank Drop	3
Contractor Hit Main	1
Contractor made three attempts to locate leak before found.	1
Curb Stop	2
Hit by Gas Co.	1
Hit By Light Co	2
Leak Detectiion	1
Leak Detection	90
Shut off at controling valve. Chief Russo notified. Hydrant replaced 2/2/16	1
Shut off at curb on hose.	1
UNK	196
Water loss based on customer comments of collapsed basin on 3/18/2015	1
Grand Total	303

Once the above considerations have been taken into account (what to keep or not) only 100 leaks (out of the original 303) were found to be acceptable. The distribution based on YOB and MAT is as follows.

YOB	AC	CI	GALV	PLASTIC	UNK	TOTAL
2013	3	20	4	3		30
2014	3	11	10		2	26
2015	2	16	18	3		39
2016		4	1			5
TOTAL	8	51	33	6	2	100

While we do not know over how many years the 1,102 breaks recorded in the CEP occurred (it is most likely more than 2013-2016), it looks like the CEP and the "leaks spreadsheets" are not reporting the same thing.

There is a need to report the breaks in a reliable way (see Recommendations.)

Millbury

The only document that contains information about the breaks is the CEP. It is reported by Break per 1,000 feet. However, the length of a main is not provided in that document and there is no information either about the timeframe (is the rate reported per year?). Furthermore, even though we reported in 3.1.1 the fact that the CEP and the GIS mains (where the length is reported) do not completely match, we attempted to partially join the CEP (and the Break Rate) and the GIS Mains layer (length) based on the Label. We obtained a number of Breaks for each main between 0 and 5. Again, the timeframe is not known making that number of breaks of limited interest. Furthermore, similarly to what we saw for Hingham-Hull, it is also necessary to know what constitutes a Break.

Oxford

Information about breaks appears solely in the CEP in the form of an attribute called "Break History?" with Yes/No modalities. 324 out of the 369 mains in the CEP are "No" (not broken). There is no information about the timeframe.

3.2.2 Recommendations - Breaks

- The breaks should be reported in one source, preferably the Breaks layer of the GIS. Reporting Breaks in the Mains layer does not allow to properly report the YOB.
- Each break should be assigned to its main. This is to be done after each main has been given a unique FeatureID.
- The type of break should be properly identified. Leaks should not be included in the computation of the Break Rate.
- Breaks that occurred on ABN mains should be kept in the GIS Breaks layer.

Because the break data is not adequate we cannot generate aging curves specific to each cohort of the MA Systems, nor can we, subsequently generate utility-specific EULs. We will use the aging curves and EULs of the CT System. For each cohort, we will compute the 2016 Break

Rate by reading the Break Rate on the aging curve at the current average age. See the example described in details for the AC mains in Section 4.1.

We now show the CT aging curve of each cohort.

4 Aging Curves

4.1 AC

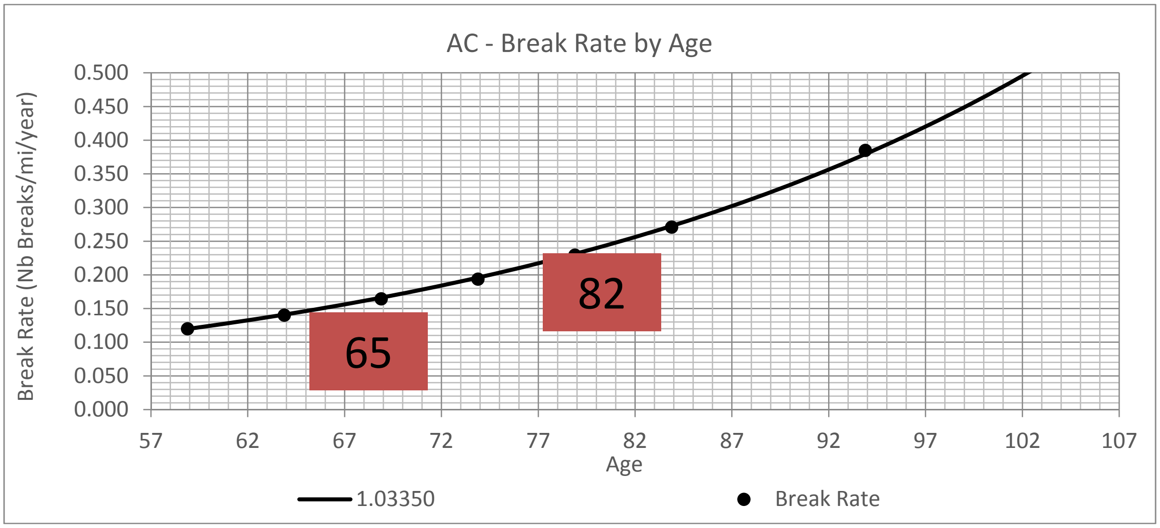


Figure 13 AC - Break Rate by Age

We call f the aging factor that defines the aging curve. It corresponds to the value that allows plotting the Break Rate based on the following geometric series:

BR at year i+1 = Break Rate at year i x f (f is the compounding factor)

For the AC aging curve we have f = 1.034 or 3.4%.

The EUL is based on the Maximum Break Rate. It is 65 for a MBR of 0.15 Breaks/mi./yr., and 82 for a MBR of 0.25 Breaks/mi./yr.

The starting Break Rate (Breaks/mi./yr.) is also read on the curve based on the average age of each cohort. It is 0.13 for AC mains in Hingham-Hull and Oxford, that have an average age close to the average age and Break Rate of the AWC System (59 years old; 0.12 Breaks/mi./yr.). It is 0,17 for Millbury that has an average age of 70.3.

AC	Hingham-Hull	Millbury	Oxford	AWC
Age	62.2	70.3	62.2	59
Break Rate (2016)	0.13	0.17	0.13	0.12

A similar approach is adopted for the other cohorts.

4.2 DI

4.2.1 DI Large

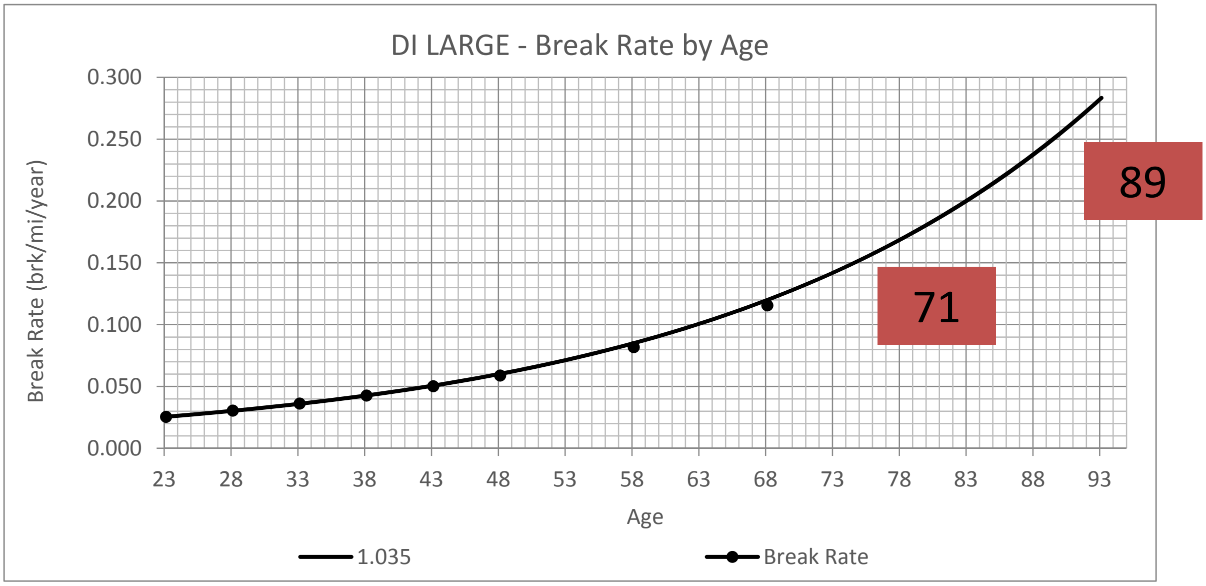


Figure 14 DI Large - Break Rate by Age

EUL (0.15) = 71; EUL (0.25) = 89; f = 3.4%

DI_L	Hingham-Hull	Millbury	Oxford	AWC
Age	23.1	NA	1.6	21.9
Break Rate (2016)	0.025	NA	0.01	0.02

4.2.2 DI Small

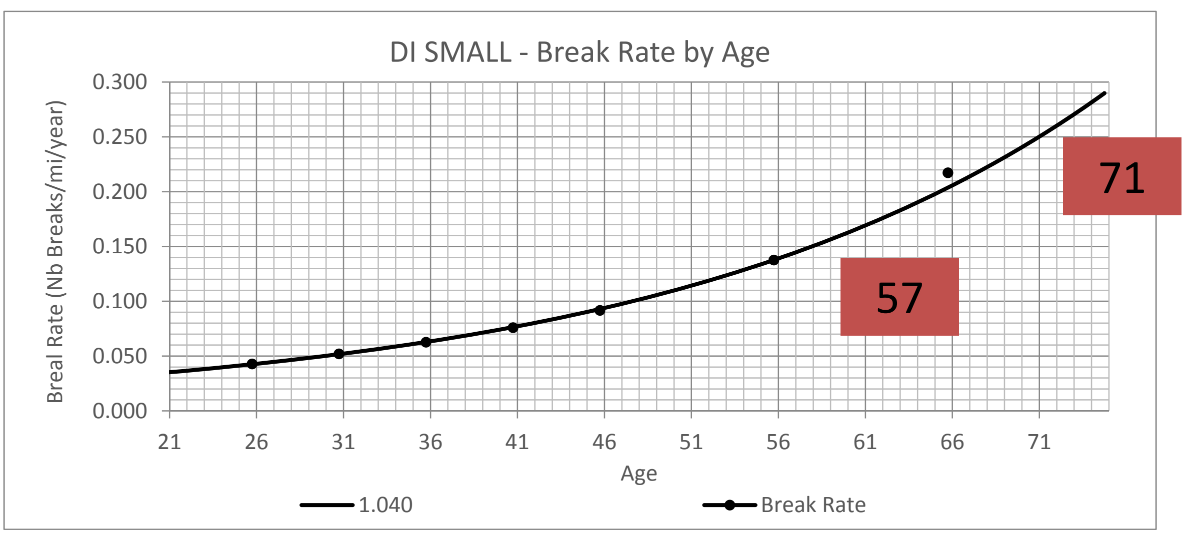


Figure 15 DI Small - Break Rate by Age

EUL (0.15) = 57; EUL (0.25) = 71; f = 4%

DI_S	Hingham-Hull	Millbury	Oxford	AWC
Age	25.5	23	23.1	21
Break Rate (2016)	0.04	0.035	0.035	0.03

4.3 PCI

4.3.1 PCI Large

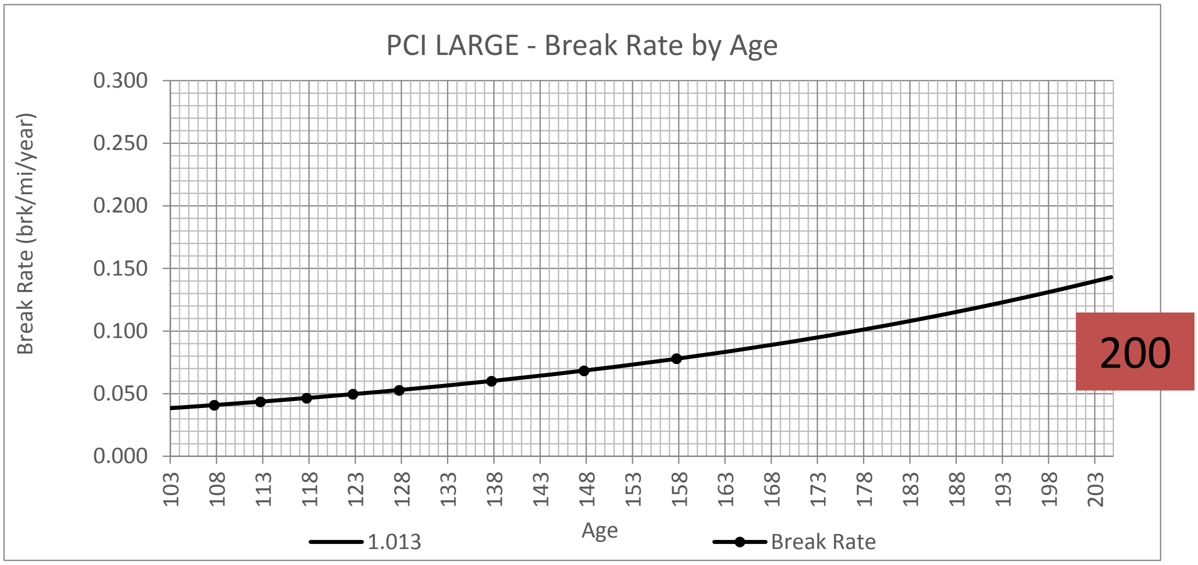
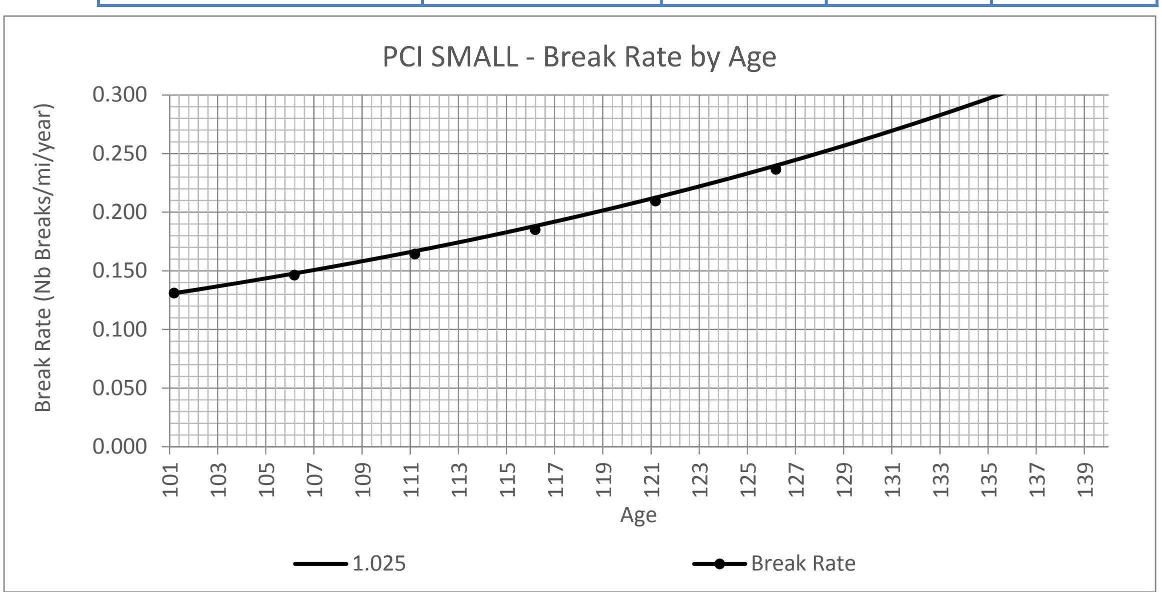


Figure 16 PCI Large - Break Rate by Age

EUL (0.15 and 0.25) = 200; f = 1.3%

PCI_L	Hingham-Hull	Millbury	Oxford	AWC
Age	100.9	116	NA	103
Break Rate (2016)	0.038	0.045	NA	0.04

4.3.2 PCI Small



107

Figure 17 PCI Small - Break Rate by Age

EUL (0.15) = 107; EUL (0.25) = 129; f = 2.5%

PCI_S	Hingham-Hull	Millbury	Oxford	AWC
Age	106.5	105	109	101
Break Rate (2016)	0.15	0.14	0.16	0.13

4.4 SCI

4.4.1 SCI Large

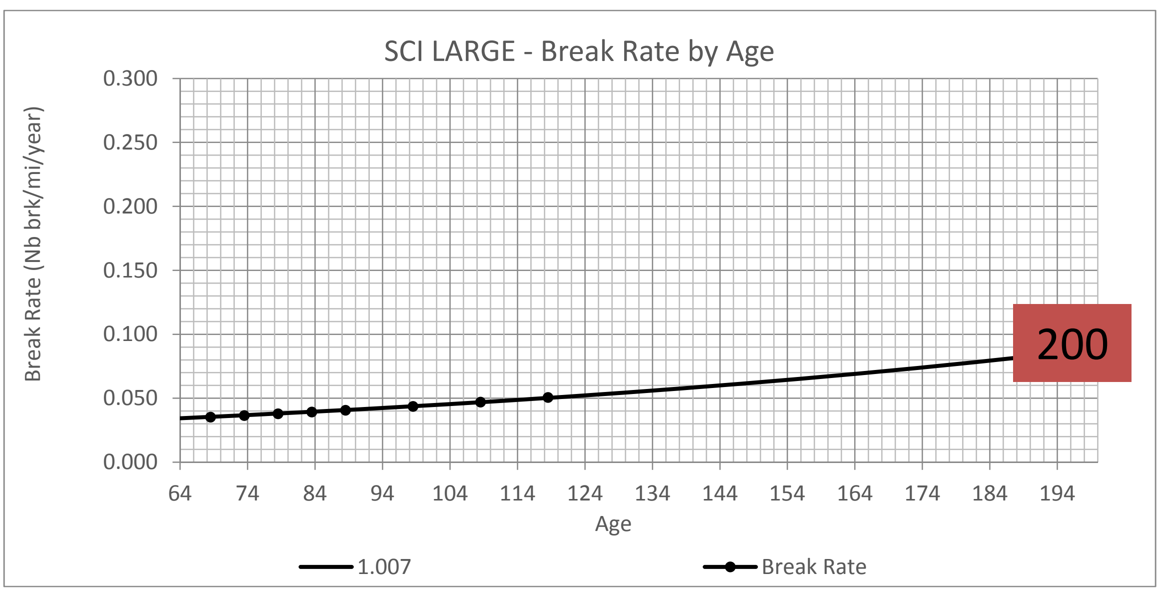


Figure 18 SCI Large - Break Rate by Age

EUL (0.15 and 0.25) = 200; f = 0.7%

SCI_L	Hingham-Hull	Millbury	Oxford	AWC
Age	56.9	NA	NA	64
Break Rate (2016)	0.025	NA	NA	0.035

4.4.2 SCI Small

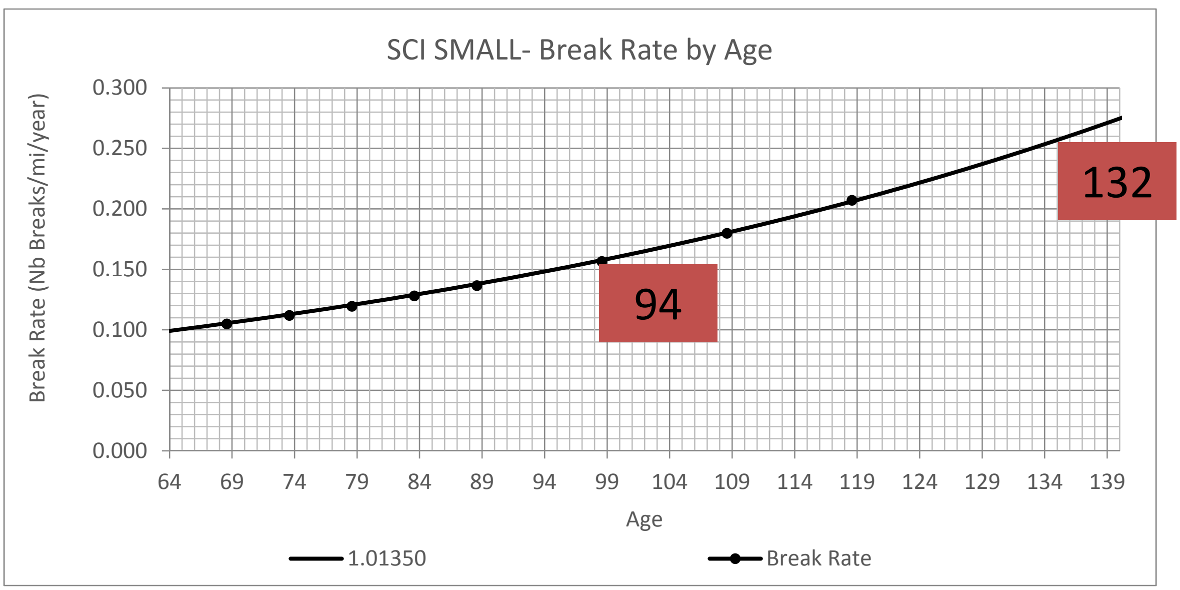


Figure 19 SCI Small - Break Rate by Age

EUL (0.15) = 94; EUL (0.25) = 132; f = 1.35%

SCI_S	Hingham-Hull	Millbury	Oxford	AWC
Age	58.3	70	56	64
Break Rate (2016)	0.08	0.11	0.07	0.1

5 KANEW Input Values and Methodology

5.1 KANEW Input Values

5.1.1 Aging

The KANEW input values for each cohort are shown in Table 5.

The 9 first values pertain to the EULs. The 50% Medium value (in red) corresponds to the 0.25 MBR threshold read on the aging curve in the previous Section. We only show the values that correspond to that MBR threshold because they are the ones used in the Scenarios that are shown in this report.

The other values (100% and 10%) illustrate the fact that not all mains will reach their EUL at the 50% value; for some it will be sooner; for others, later. By the 10% EUL value (for example 114 years old for the AC cohort medium EUL values), 10% of the mains will still be in service; no main is to be replaced before the 100% EUL age (50 years old for AC) which, when possible (there are exceptions) is chosen as the current average age as there has been little replacement so far.

The pessimistic and optimistic series of values allow for additional sensitivity analysis. While the 100% values are the same, the 50% values are typically the medium values + or – 5, 10 or 20 years depending how big the 50% value is.

The other values include, for each cohort, the 2016 Break Rate, the aging factor, and as a reference, the length of mains (not an input value). The Very Small (VS) cohorts have the same values as the Small ones. They are not shown in the Table.

	Pessimistic EUL Values (Short Lives)			Medium EUL Values			Pessimistic EUL Values (Long Lives)			2016 Break Rate	Aging Factor	Length
	100%-	50%-	10%-	100%	50%	10%	100%+	50%+	10%+			(mi)
HH_AC	50	72	94	50	82	114	50	92	134	0.13	3.35	27.4
HH_DI_L	22	79	136	22	89	156	22	99	176	0.025	3.5	2.0
HH_DI_S	20	61	102	20	71	122	20	81	142	0.04	4	43.1
HH_ELSE	57	61	65	57	71	85	57	81	105	0.096	3.4	6.3
HH_PCI_L	102	180	258	102	200	298	102	220	338	0.038	1.3	5.9
HH_PCI_S	80	109	138	80	129	178	80	149	218	0.15	2.5	42.9
HH_SCI_L	63	180	297	63	200	337	63	220	377	0.025	0.7	0.9
HH_SCI_S	63	112	161	63	132	201	63	152	241	0.08	1.35	49.6
MILL_AC	50	72	94	50	82	114	50	92	134	0.17	3.35	0.8
MILL_DI_S	20	61	102	20	71	122	20	81	142	0.035	4	15.8
MILL_ELSE	57	61	65	57	71	85	57	81	105	0.096	3.4	0.7
MILL_PCI_L	102	180	258	102	200	298	102	220	338	0.045	1.3	1.3
MILL_PCI_S	80	109	138	80	129	178	80	149	218	0.14	2.5	4.0
MILL_SCI_S	63	112	161	63	132	201	63	152	241	0.11	1.35	26.8
OX_AC	50	72	94	50	82	114	50	92	134	1	3.35	8.9
OX_DI_L	22	79	136	22	89	156	22	99	176	0.01	3.5	0.7
OX_DI_S	20	61	102	20	71	122	20	81	142	0.035	4	19.0
OX_ELSE	57	61	65	57	71	85	57	81	105	0.096	3.4	0.0
OX_PCI_S	80	109	138	80	129	178	80	149	218	0.16	2.5	4.9
OX_SCI_S	63	112	161	63	132	201	63	152	241	0.07	1.35	10.2
REHAB	50	70	90	50	80	110	50	90	130	0.01	4.2	NA

Table 5 MA - KANEW Input Values

5.1.2 EF factor

There are various reasons why a main is replaced; not all of them are due to its physical condition. The KANEW model takes into account the efficiency of targeting certain mains for R&R by using an Efficiency Factor (EF). An Efficiency Factor of 1 means that replaced mains, if not replaced, would have a Break Rate in the same range as the average Break Rate of the whole cohort or network. An Efficiency Factor of EF=x and greater than 1 means that replaced mains would have a Break Rate which is x times higher than the average Break Rate of the cohort. As a starting point the EF is kept at 1. In subsequent Scenarios, the EF can be increased to 2.

5.1.3 Cost

AWC provided the following unit costs for the R&R MAT based on the DIAM:

- DIAM 1-12”: $275/ft.
- DIAM >=16”: $300/ft.

We computed a length-weighted average cost of $277.

Currently the budget is projected at between $1.5 M and $2.0 M per year (we use $1.75 M for this study). That budget was distributed over all three MA Systems proportionally to their respective length, as follows, Hingham-Hull: $1.15 M; Millbury: $0.32 M; and Oxford: $0.28 M.

5.2 KANEW Methodology

A KANEW Scenario consists in (except for Scenario 1: R&R Needs; see Section 6) choosing an analysis period of time (for example 2016-2100) and imposing a certain length of R&R (for example, planning horizon) during that whole period or part of it (for example, 2016-2050 selected by AWC). Typical output results are:

- R&R length for each year during the overall analysis period
- R&R length right after the planning horizon if different from the period of analysis
- Future Break Rate
- Future Investment Cost

Comment about terminology: the KANEW software calls the Figure that shows the first output results mentioned above, R&R length, “Future rehabilitation *needs* per asset type” regardless of whether we are in the “Needs” Scenario or in a constrained Scenario (Scenario 2 or 4).

We had 2 sets of EULs at our disposal: one that represents the age at which the mains of various cohorts reach the MBR of 0.15 Breaks/mi./yr. (aiming for a System-wide Break Rate of approximately 0.1) and 0.25 Breaks/mi./yr. (allowing for a System-wide Break Rate around 0.12). We also have the choice between an EF of 1 or 2.

We first looked at the Needs with the EULs corresponding to a MBR of 0.15 and an EF of 1, and then 2. The resulting backlog after 2050 and the Break Rates were too high. We then created Scenarios (1, 2 and 4) solely with the EULs corresponding to a MBR of 0.25 (which are shown in Table 5) and an EF of 2.

Scenario 1 Needs merely translates the inventory and the EULs. We also show the resulting average Break Rate for the overall System.

In order to create an “optimal” Scenario (Scenario 2) we conducted a study at the cohort level. The methodology consists in first examining the Break Rate for each cohort as if we were to follow the Needs (those results can be regarded as Scenario 1 at the cohort level) and, then, optimizing the necessary length of R&R accordingly. The guiding principle is to try to do less R&R if the Break Rate remains low in the Scenario Needs; more if the Break Rate is too high.

Scenario 2 is created by adding all the optimal levels identified previously at the cohort level. As an example, we show the work done with cohort DI_S.

Scenario 4 CIP consists in simulating the budgeted levels of R&R are simulated until 2100. We looked at what happens after 2100 including backlog and Break Rate.

Results are shown solely for Scenarios 1, 2 and 4.

For Scenarios 1 Needs and Scenario 4 we show R&R lengths (Future rehabilitation needs) solely for the medium EULs. One graph is produced for the other results (Break Rate and Cost); for those, the pessimistic, medium and optimistic results are shown in the same Figure with a different color.

For Scenario 4 we show results with the medium EULs as well as with pessimistic (short), and optimistic (long) EULS.

During the period of time when the length is constrained by the analyst, only medium values are at play. After that period results are produced for medium, pessimistic and optimistic EULs.

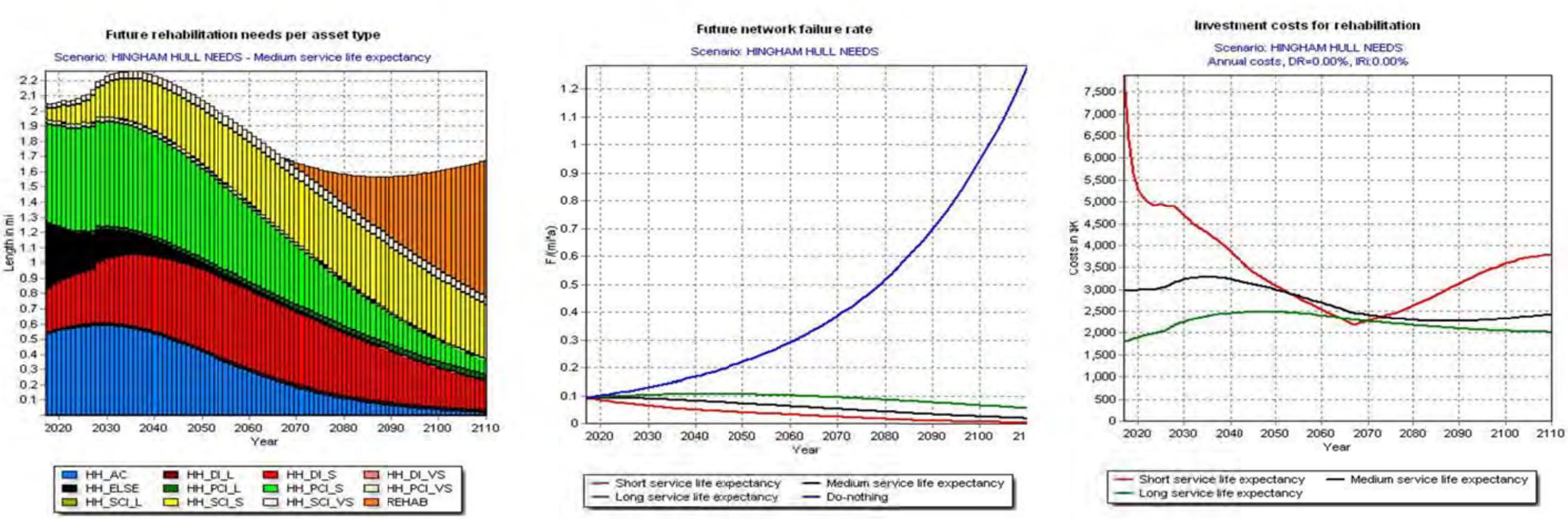
Analyses and Results are produced at the System level (including optimization at the cohort level), and then for the whole MA System.

6 KANEW Results

6.1 Hingham-Hull

6.1.1 Hingham-Hull Needs

Scenario 1 Needs merely translates the inventory and the EULs. We also show the resulting average Break Rate for the overall System. Scenario 1 is obtained with an MBR of 0.25 Breaks/mi./yr., and an EF of 2. We show the Length of R&R, Break Rate and



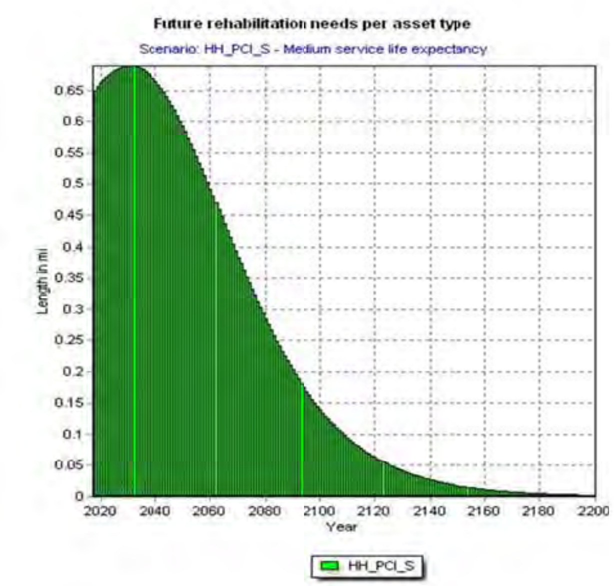
Cost.

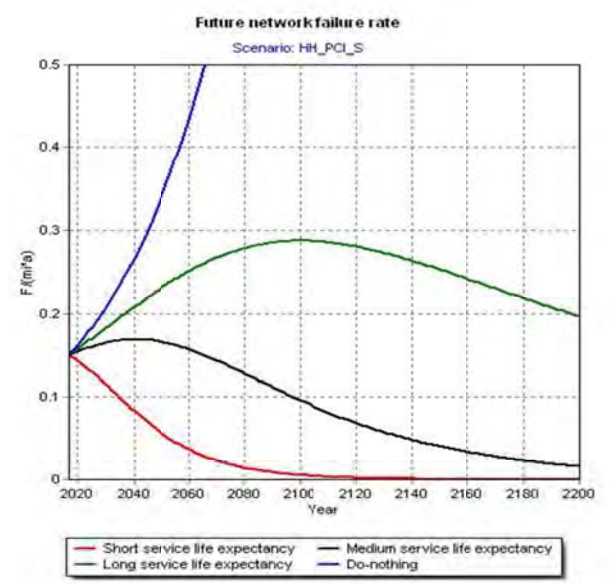
Figure 20 Hingham-Hull Needs Scenario 1 - R&R Length, Break Rate and Investment Cost

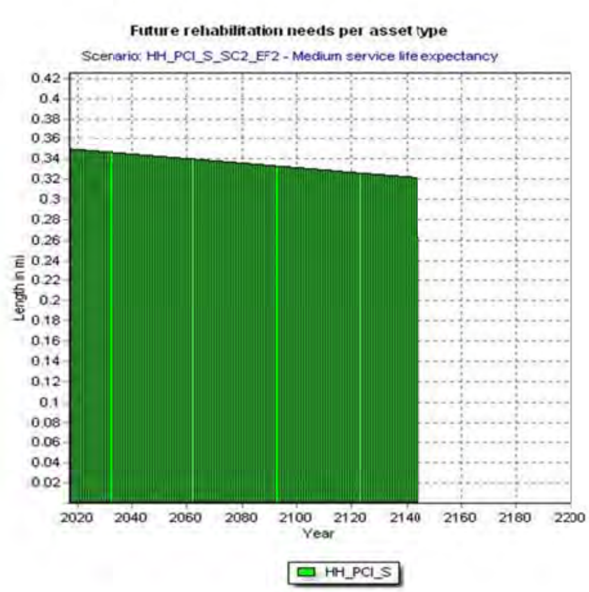
The cost is higher than what has been budgeted ($1.15 M/yr.) while the Break Rate is lower than needs to be. We therefore look at building a new Scenario, Scenario 2, where lengths are reduced at the cohort level.

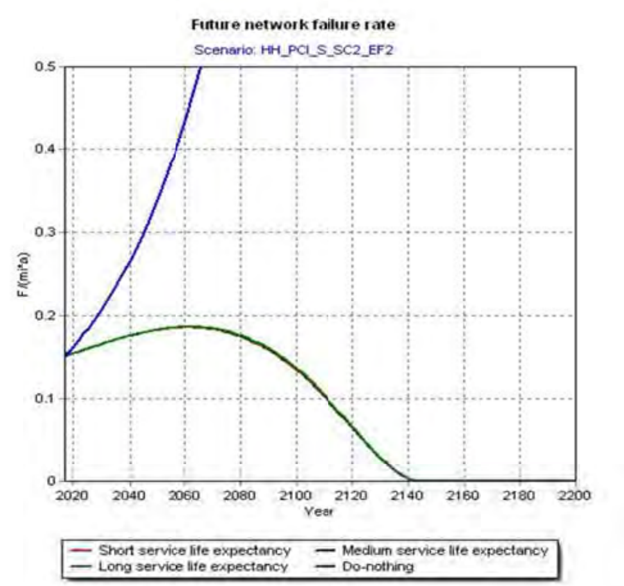
6.1.2 Hingham-Hull Scenario 2

To illustrate the work done at the cohort level, we show HH_PCI_S which is the largest cohort, therefore where the most gain can be achieved. The Needs showed a peak of R&R in the immediate future around 0.65 mi/year going down steadily after that. We are able to stretch the HH_PCI_S R&R level from 0.35 mi in 2017 to 0.3 by 2140 while keeping a Break Rate below 0.2 Breaks/mi./yr. We show results up to 2200 to demonstrate that reducing the levels of RR&R does not create a backlog after 2100. Scenario 2 results in all PCI_S mains having been replaced by 2144 while controlling the Break Rate at an acceptable level.









Scenario 2 consists in adding the optimized length obtained at the cohort level for AC, DI_S, ELSE, PCI_S and SCI_S and the Needs for the other cohorts. The lengths are seen in Figure 22. The Break Rate and Cost are seen in Figure 21.

We are not able to lower the cost to $1.15 M while keeping a Break Rate and a backlog that are acceptable.
The minimum investment that is projected is $1.8 M that could be maintained up to 2070 but, then, would need to be ramped up to $2 M by 2100 (including the new mains).

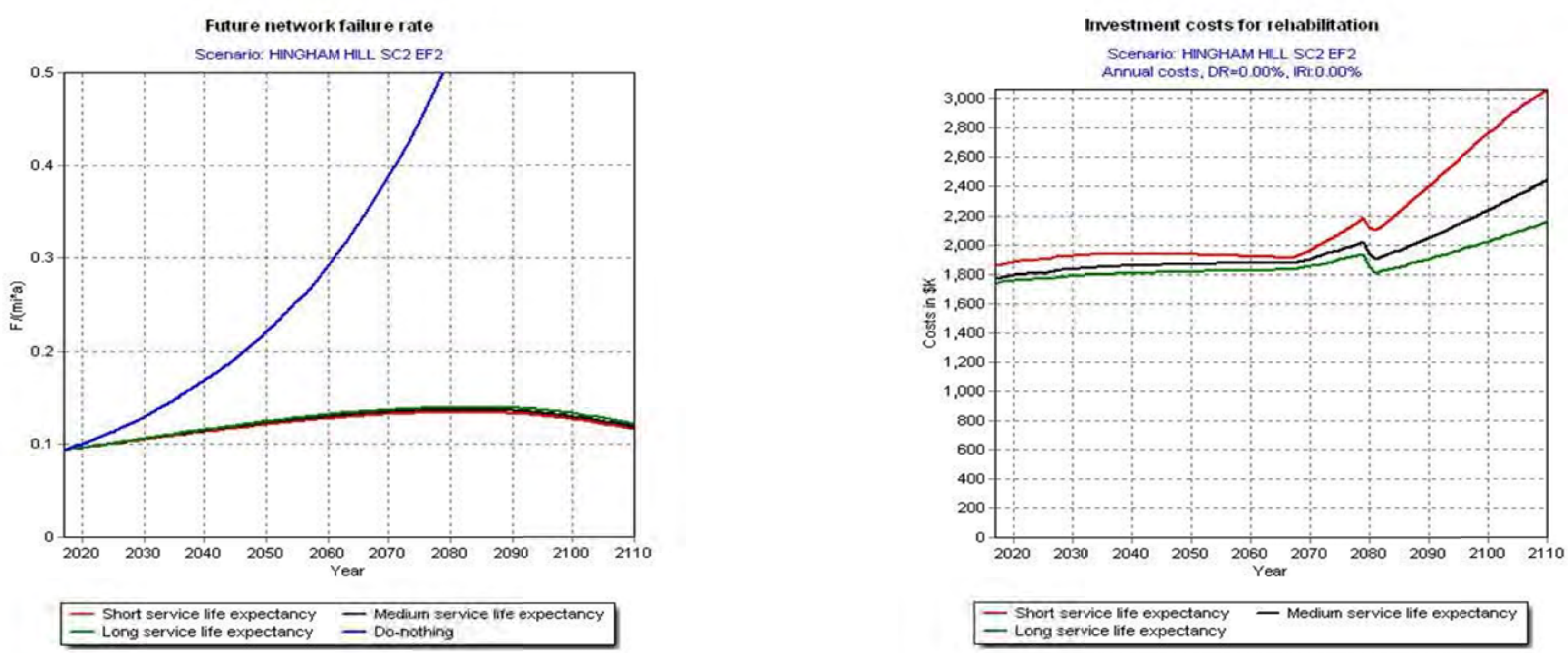


Figure 21 Hingham-Hull Scenario 2 - Break Rate and Investment Cost

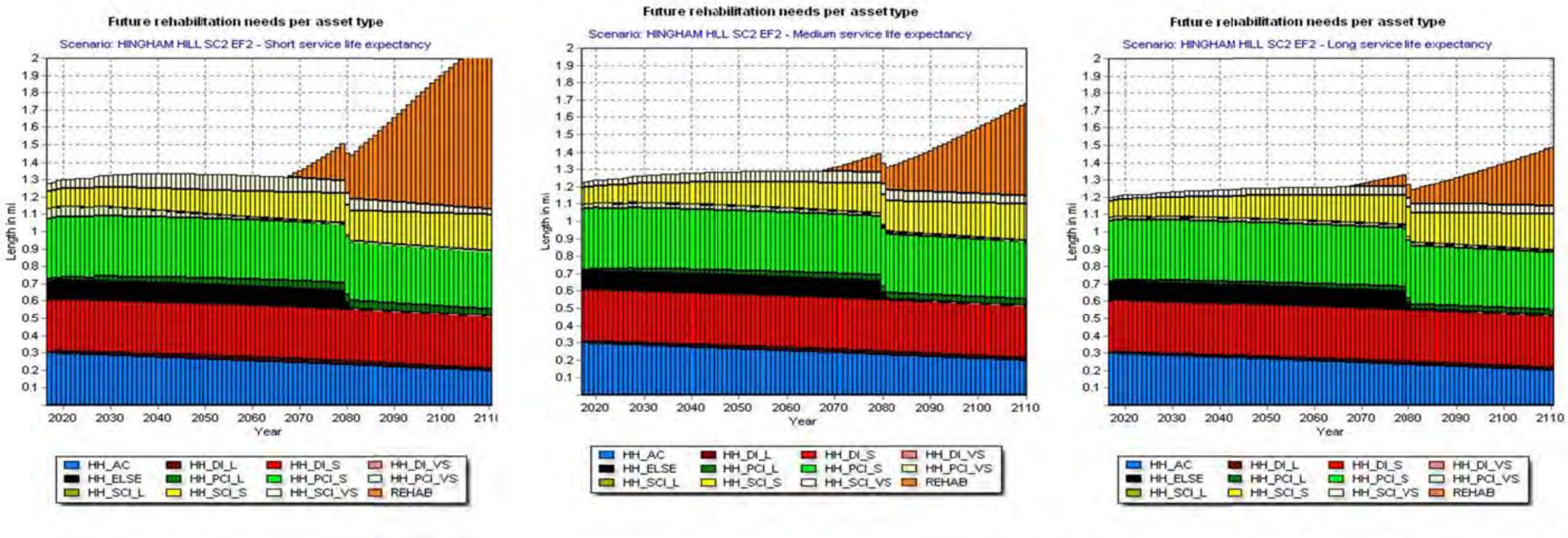


Figure 22 Hingham-Hull Scenario 2 - R&R Length

6.1.3 Hingham-Hull Scenario 4

Scenario 4 was created to see what would happen if we were to maintain the currently projected budget ($1.15 M per year) until 2100, (and to justify the need for a larger budget.) As done previously, we used the EULs that correspond to the MBR of 0.25 Breaks/mi./yr. threshold and an EF of 2.

$1.15 M/yr. @ $275/ft. or $1.452M/mi. ➔ 0.8 mi./yr. We distribute that amount to each cohort proportionally to the relative length of R&R in the Needs Scenario. Figure 23 and Figure 24 show that Scenario 4 would result in a steep backlog (close to 4 miles in 2101) and a cost of $13 M in 2101. Figure 24 also shows that the Break Rate would climb to 0.4 Breaks/mi./yr.

2100 2110

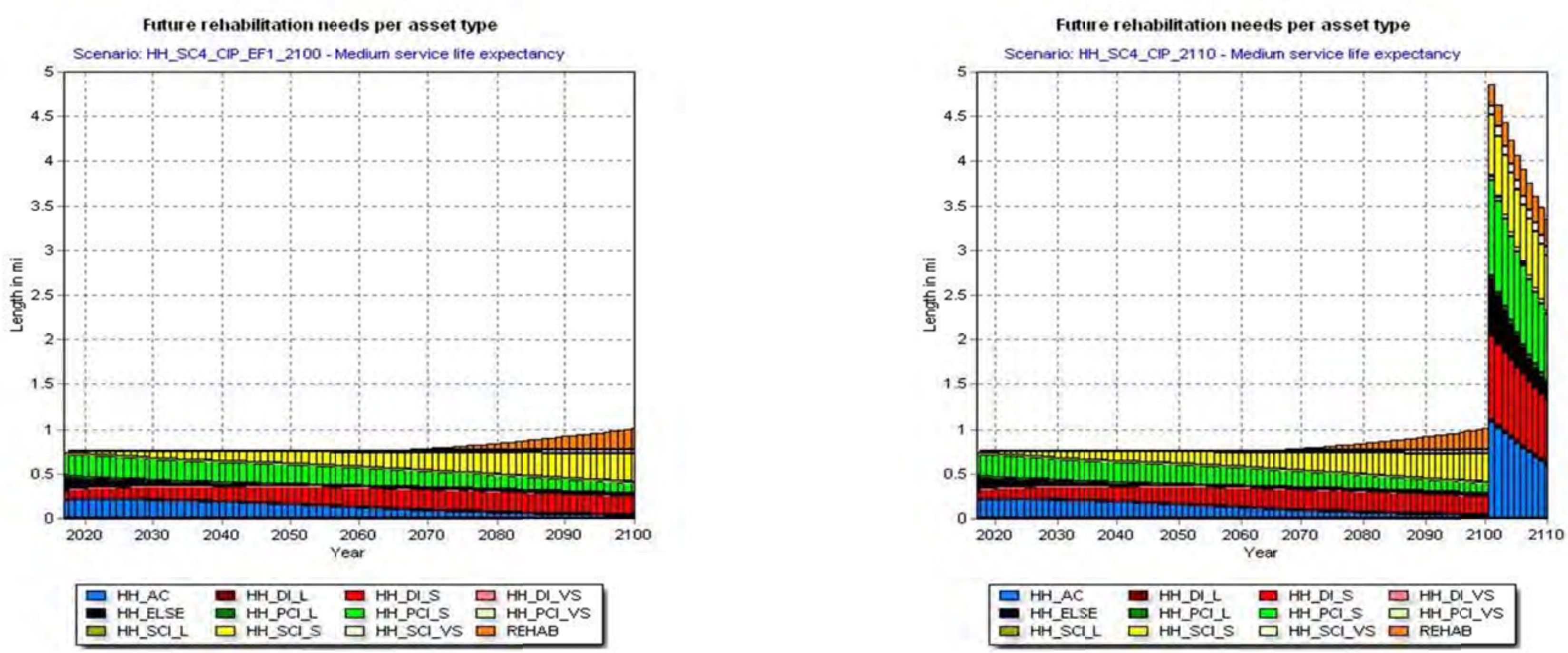
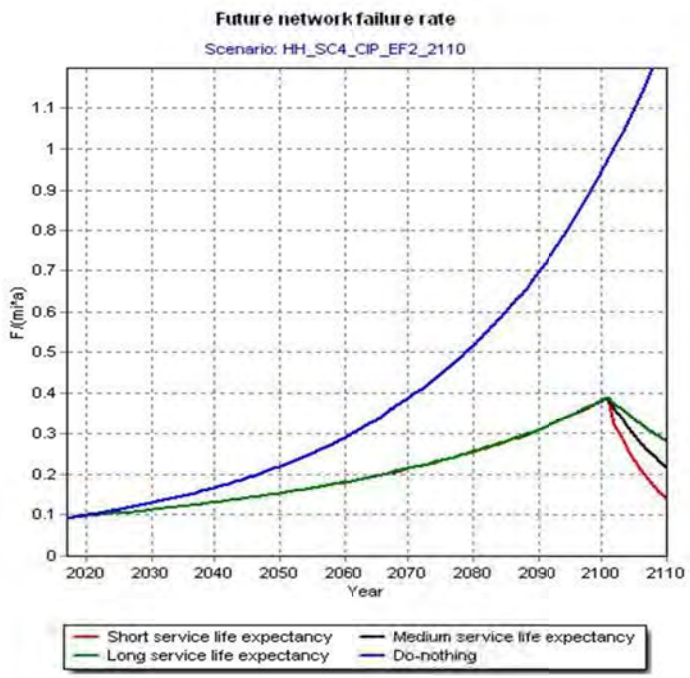


Figure 23 Hingham-Hull Scenario 4 - R&R Length



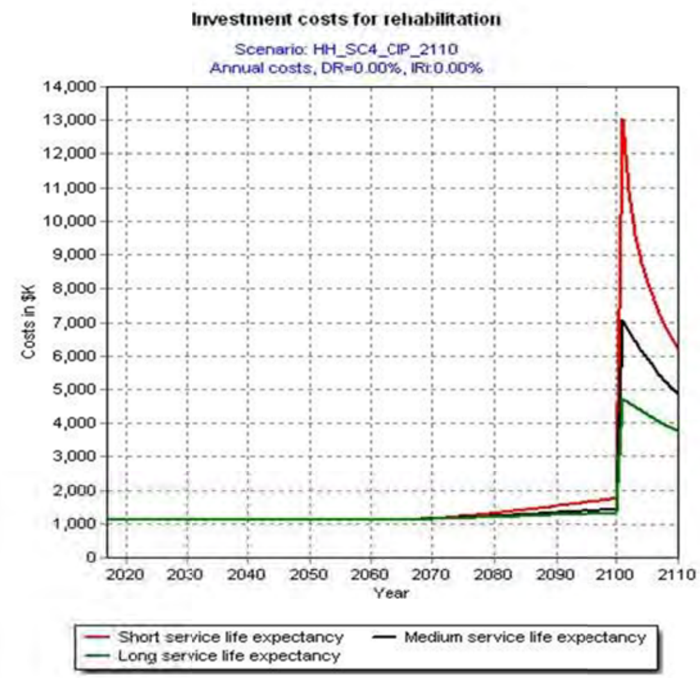


Figure 24 Hingham-Hull Scenario 4 - Break Rate and Investment Cost

6.2 Millbury

6.2.1 Millbury Needs

Scenario 1 Needs merely translates the inventory and the EULs. We also show the resulting average Break Rate for the overall System. Scenario 1 is obtained with an MBR of 0.25 Breaks/mi./yr., and an EF of 2. We show the Length of R&R, Break Rate and Cost in Figure 25.

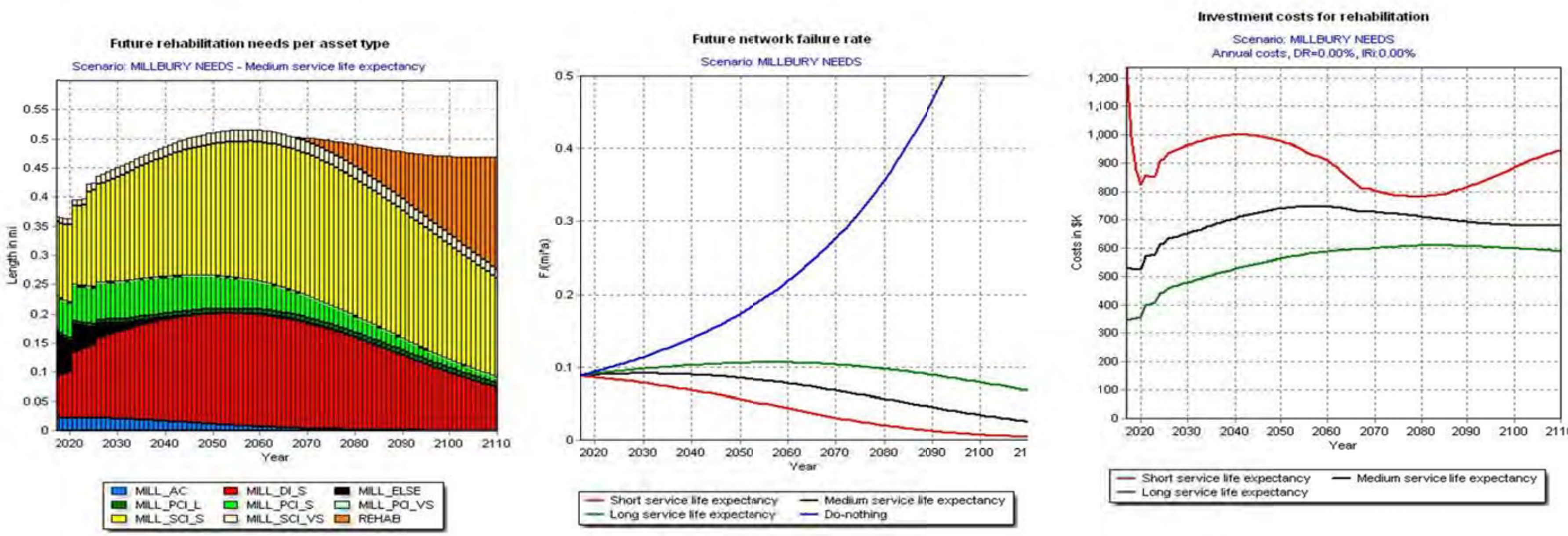


Figure 25 Millbury Needs Scenario 1 - R&R Length, Break Rate and Investment Cost

The cost starts at $0.53 M, and then goes up, peaking at $0.75 M by 2055. This is higher than what has been budgeted ($0.32 M/yr.) while the Break Rate is lower than needs to be. We therefore look at building a new Scenario, Scenario 2, where, when possible, lengths are reduced at the cohort level. An example was shown for Hingham-Hull in Section 6.1.2.

6.2.2 Millbury Scenario 2

For Millbury, we were able to optimize the R&R lengths for the DI_S and SCI_S cohorts. The resulting Scenario 2 consists in adding the optimized lengths and, for the other cohorts, the Needs. The resulting R&R lengths are seen in Figure 27.

While the lengths of R&R and cost went down, we were not able to bring the cost to $0.32 M while keeping a backlog that is acceptable.

Figure 27 shows that the minimum investment projected is $0.55 M. It then goes down to $0.4 M by 2070, then goes up again (including the new mains). The Break Rate is acceptable.

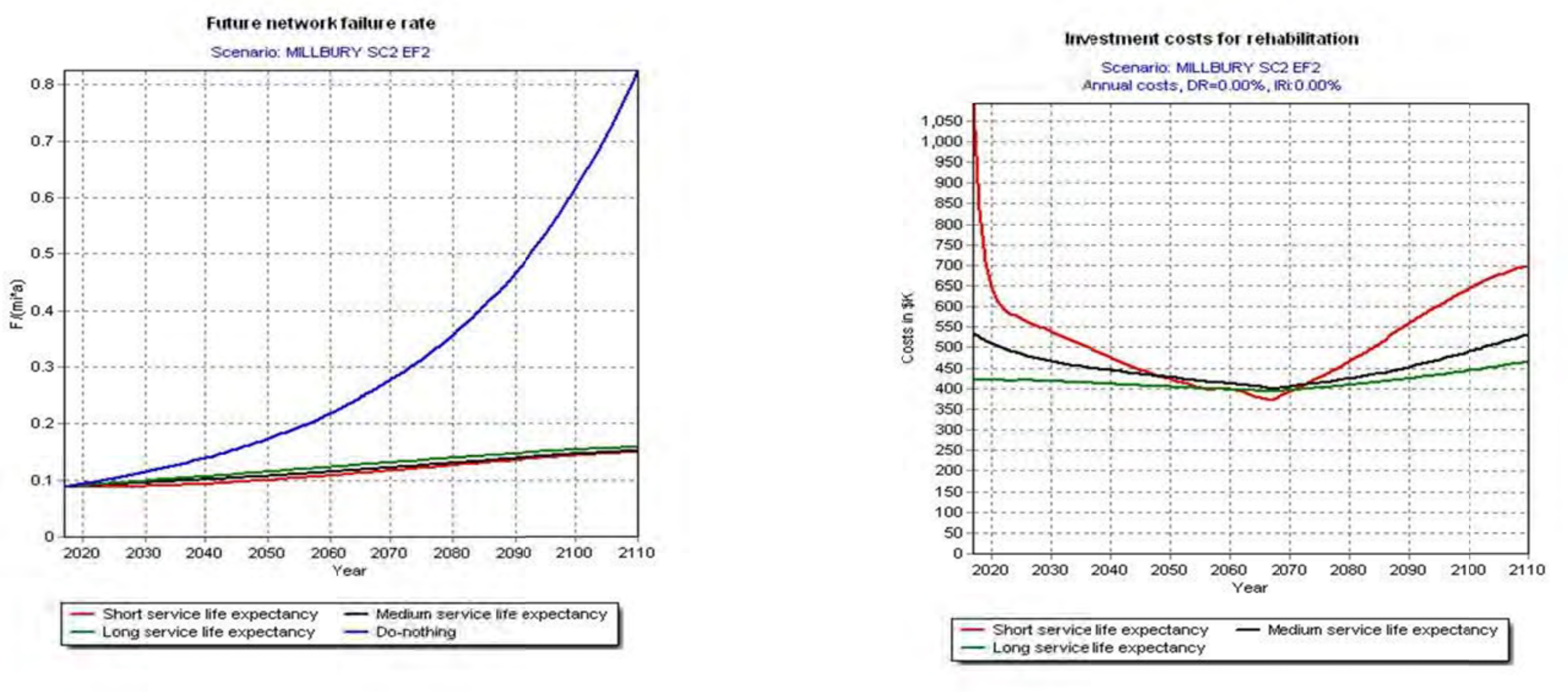


Figure 26 Millbury Scenario 2 - Break Rate and Investment Cost

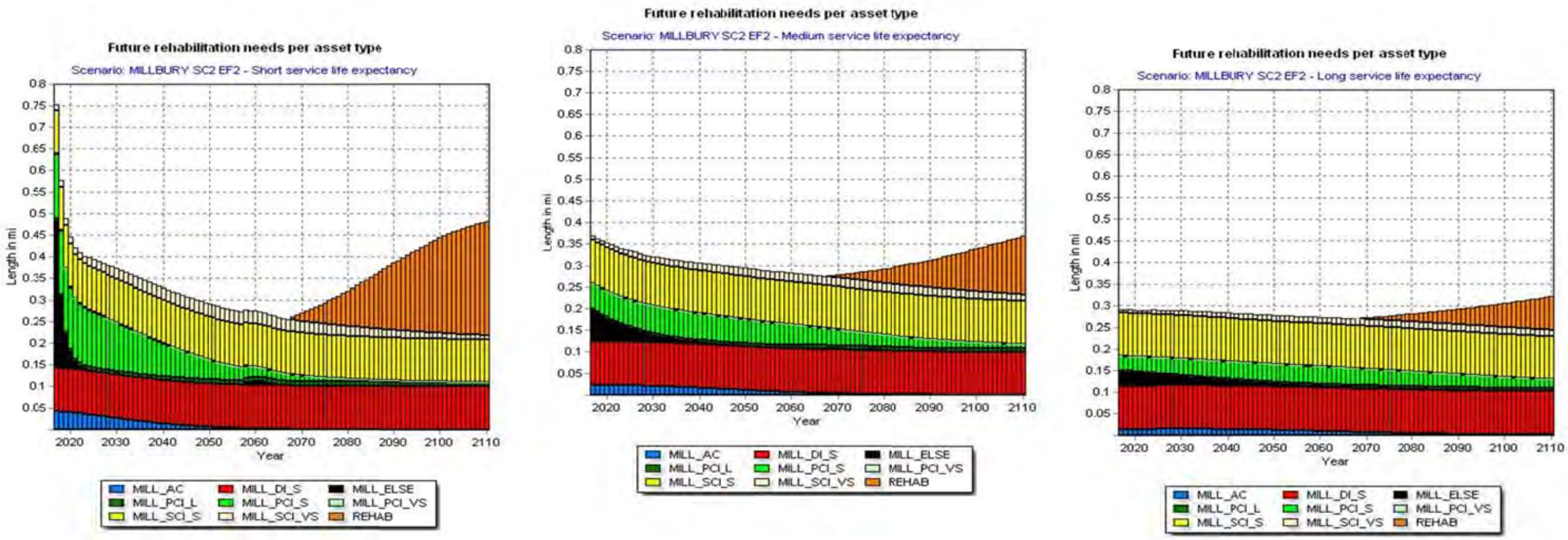


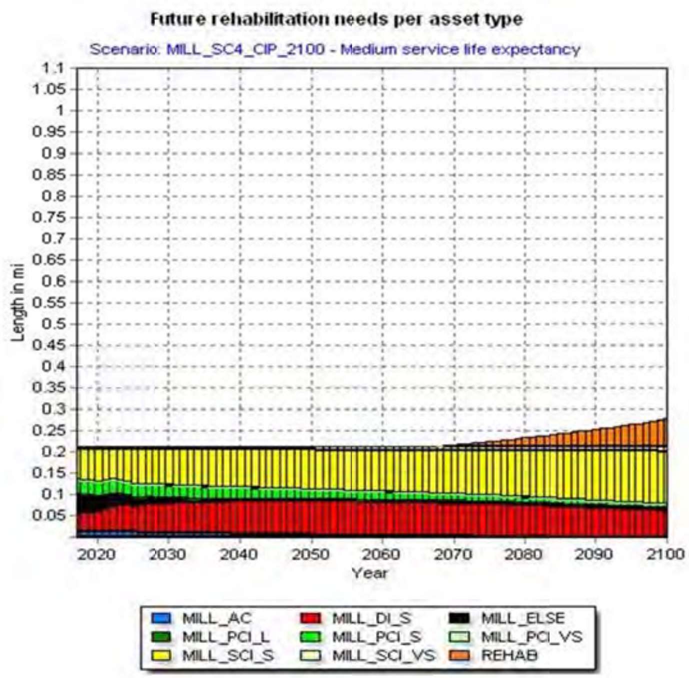
Figure 27 Millbury Scenario 2 - R&R Length

6.2.3 Millbury Scenario 4

Scenario 4 was created to see what would happen if we were to maintain the currently projected budget ($0.32 M per year) until 2100, and to justify the need for a larger budget. As previously we used the EULs that correspond to the MBR of 0.25 Breaks/mi./yr. threshold and an EF of 2.

$0.32 M/yr. @ $275/ft. or $1.452M/mi. ➔ 0.22 mi./yr. We distribute that amount to each cohort proportionally to the relative length of R&R in the Needs Scenario. The right-hand Figure 28 shows the steep backlog (close to 1 mile in 2101) that would result for that Scenario. This results in a cost of $1.4 M in 2101 (see next page). The Break Rate would also climb to 0.3 Breaks/mi./yr. (see Figure 29).

2100



2110

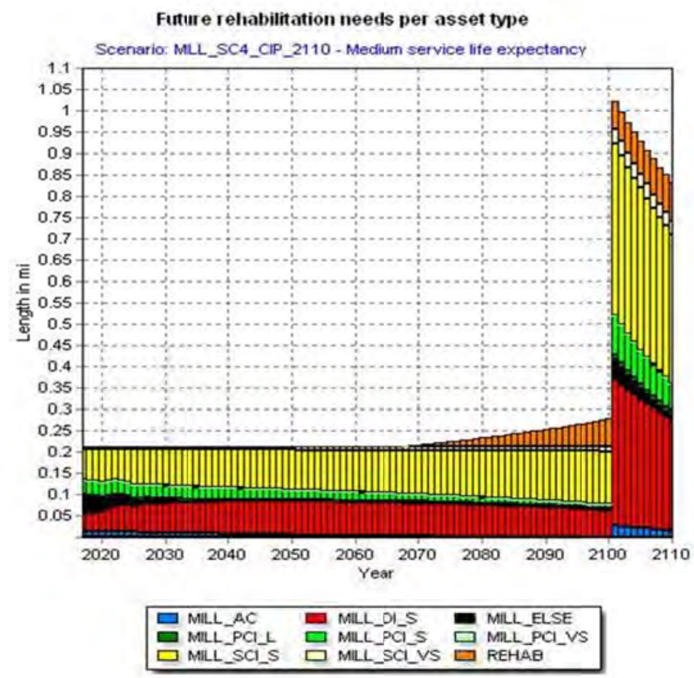


Figure 28 Millbury Scenario 4 - R&R Length

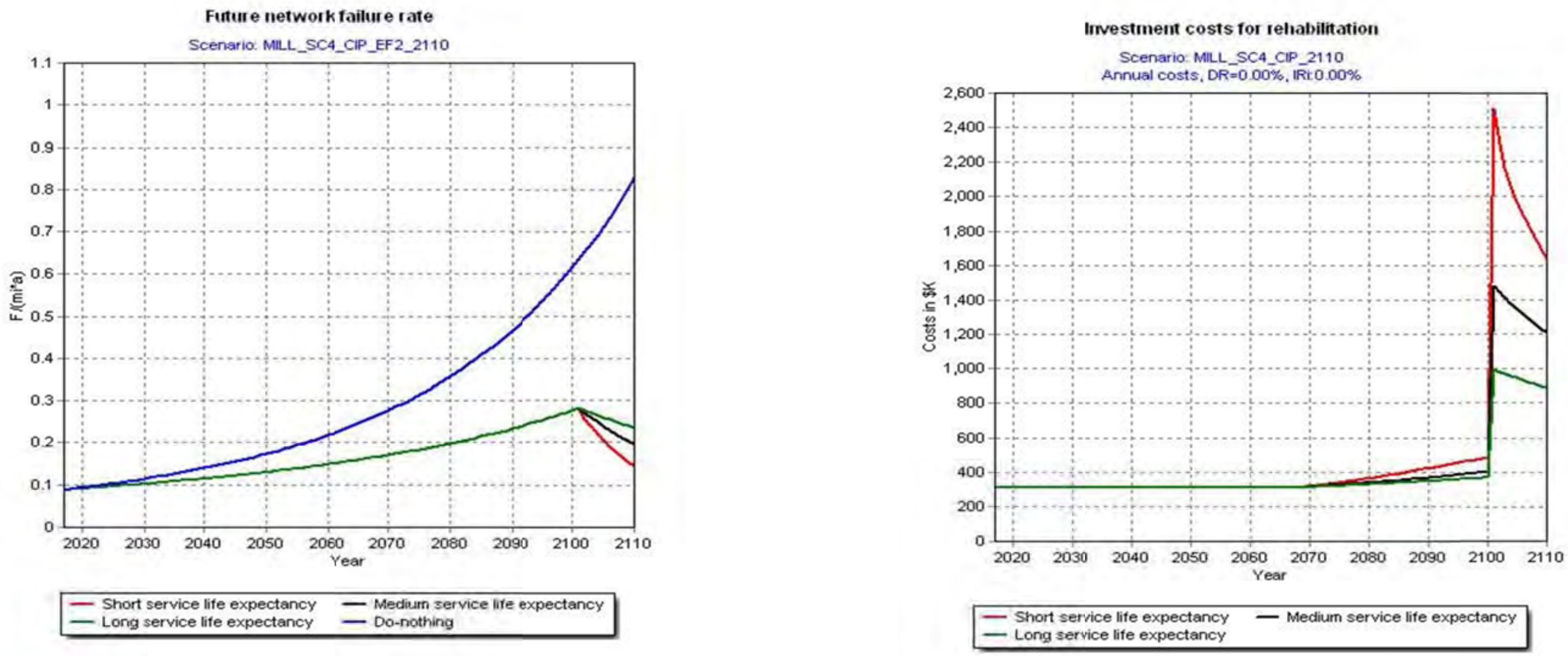
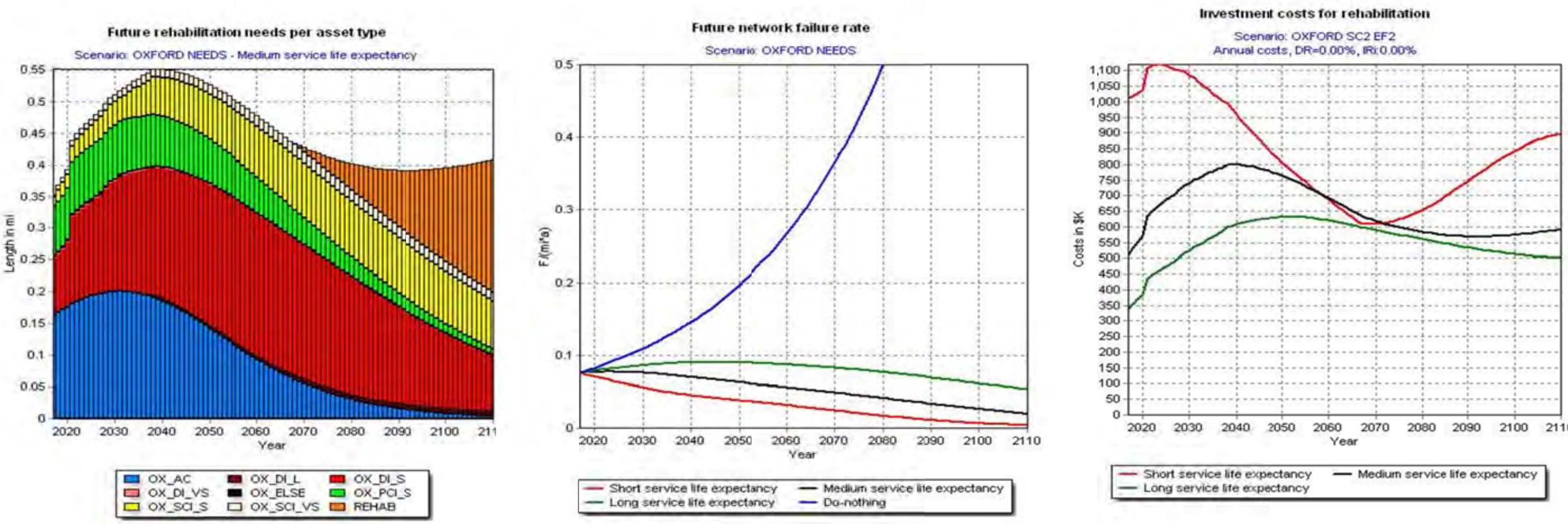


Figure 29 Millbury Scenario 4 - Break Rate and Investment Cost

6.3 Oxford

6.3.1 Oxford Needs

Scenario 1 Needs merely translates the inventory and the EULs. We also show the resulting average Break Rate for the overall System. Scenario 1 is obtained with an MBR of 0.25 Breaks/mi./yr., and an EF of 2. We show the Length of R&R, Break Rate and



Cost in Figure 30.

Figure 30 Oxford Needs Scenario 1 - R&R Length, Break Rate and Investment Cost

The cost is higher than what has been budgeted ($0.28 M/yr.) while the Break Rate is lower than needs to be. We therefore look at building a new Scenario, Scenario 2, where lengths are reduced at the cohort level. An example was shown in The Hingham-Hull Section.

6.3.2 Oxford Scenario 2

We were able to optimize the AC, DI_S, and PCI_S cohorts.
Scenario 2 consists in adding the optimized length obtained at the cohort level for AC, DI_S, and PCI_S, as well as the Needs for the other cohorts. The resulting R&R lengths are seen in Figure 32.
As seen in Figure 31 we are not able to lower the cost to $0.28 M while keeping a Break Rate and a backlog that are acceptable.

The minimum investment that is projected is $0.37 M going steadily up to reach $0.67 M (including the new mains). The Break Rate remains at an acceptable level.

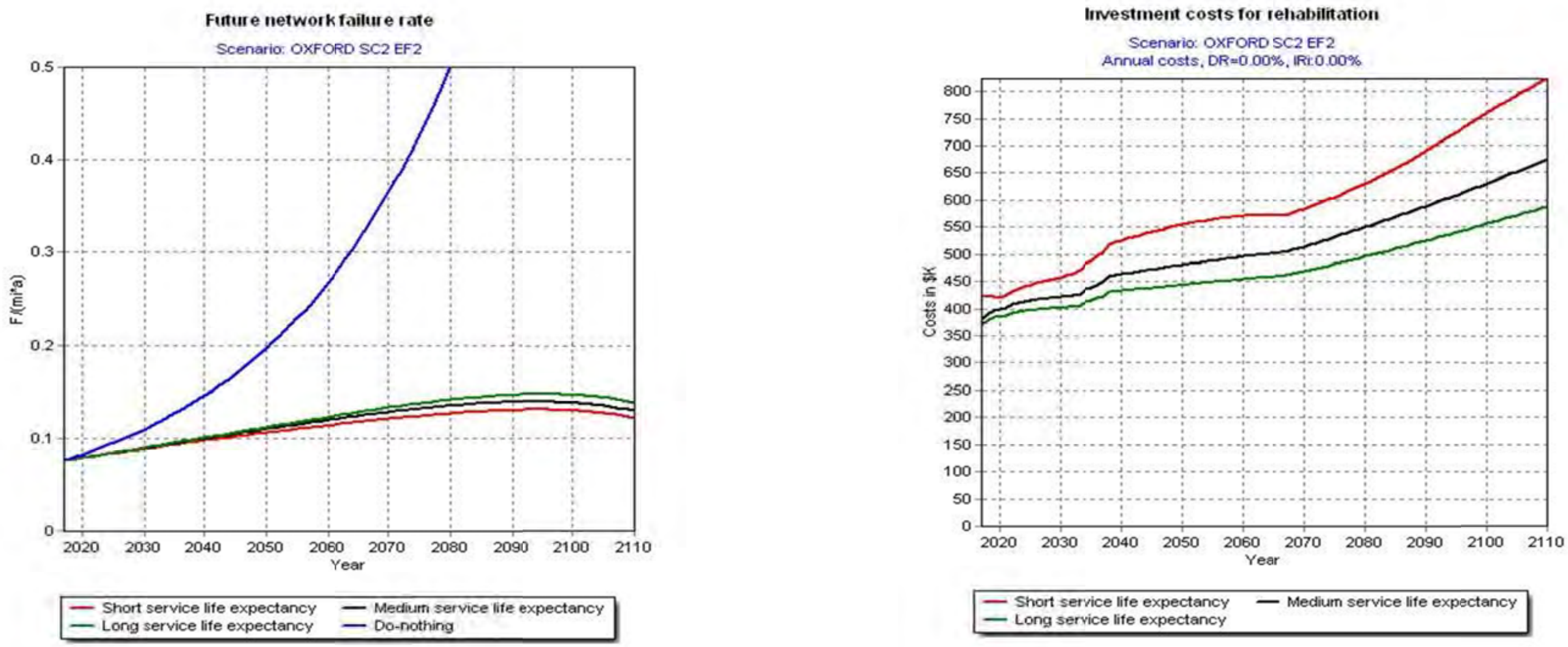
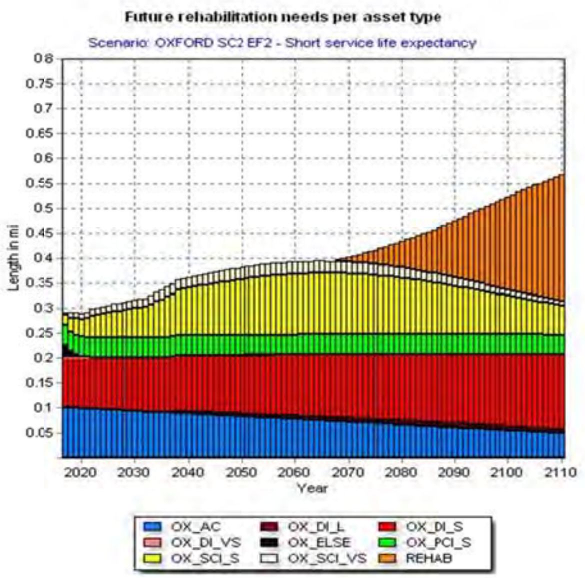
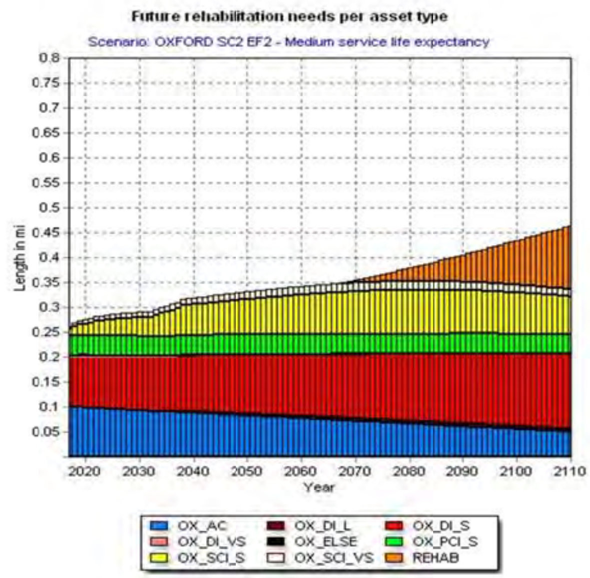


Figure 31 Oxford Scenario 2 - Break Rate and Investment Cost

Figure 32 Oxford Scenario 2 - R&R Length





6.3.3 Oxford Scenario 4

Scenario 4 was created to see what would happen if we were to maintain the currently projected budget ($0.28 M per year) until 2100, and to justify the need for a larger budget. As previously we used the EULs that correspond to the MBR of 0.25 Breaks/mi./yr. threshold and an EF of 2.

$0.28 M/yr. @ $275/ft. or $1.452M/mi. → 0.19 mi./yr. We distribute that amount to each cohort proportionally to the relative length of R&R in the Needs Scenario. The right-hand Figure 33 shows the steep backlog (close to 1.1 miles in 2101) that would result for that Scenario. It corresponds to a cost of $1.6 M in 2101 (see Figure 34). The Break Rate would also climb to 0.6 Breaks/mi./yr. (see Figure 34 as well).

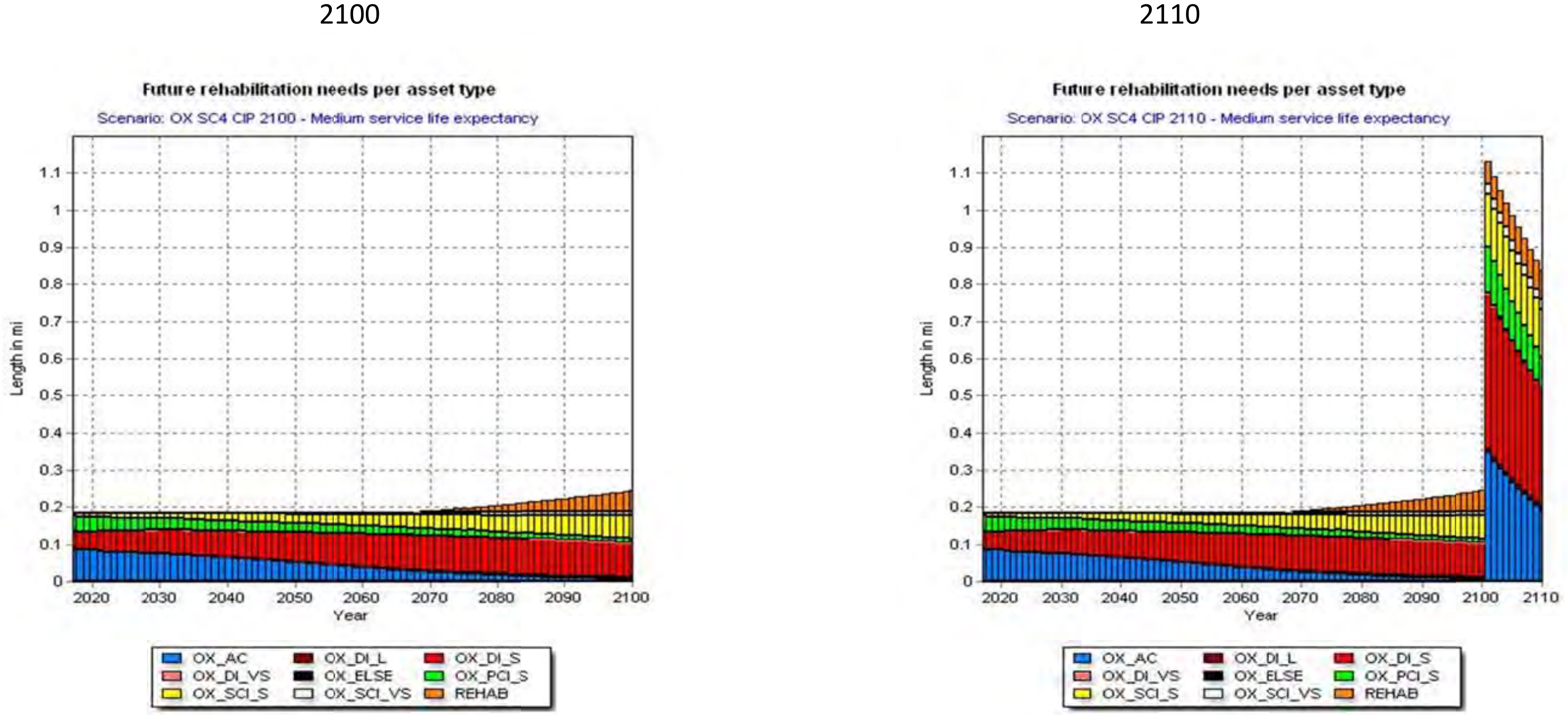
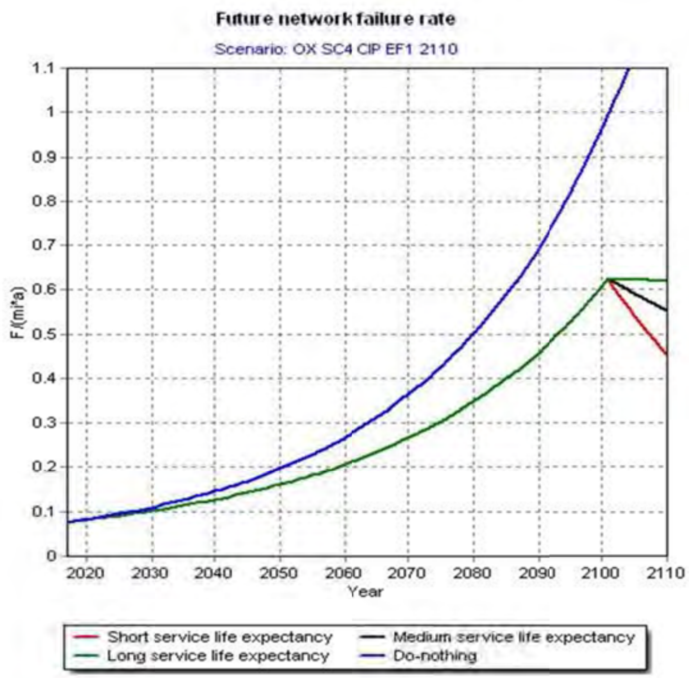


Figure 33 Oxford Scenario 4 - R&R Length



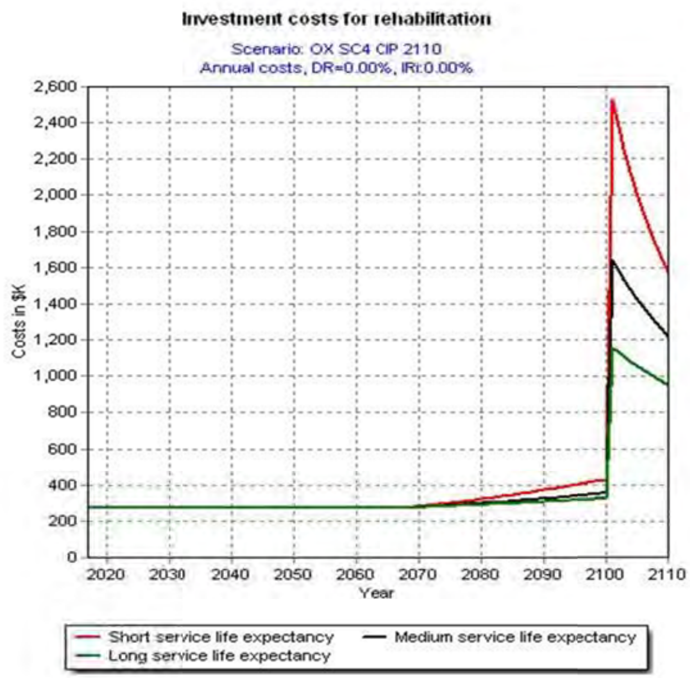


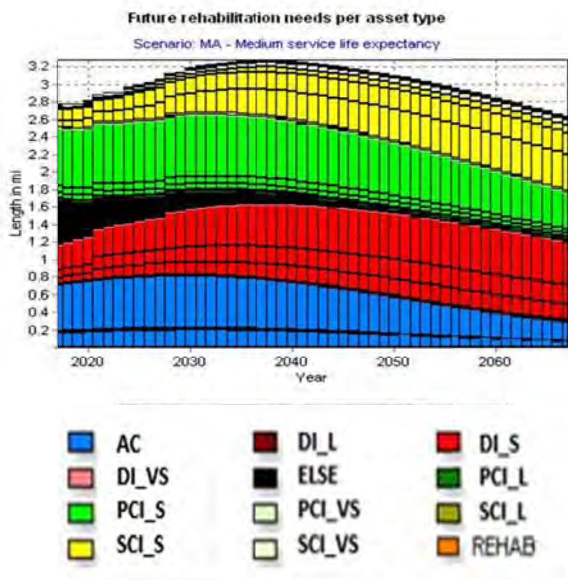
Figure 34 Oxford Scenario 4 - Break Rate and Investment Cost

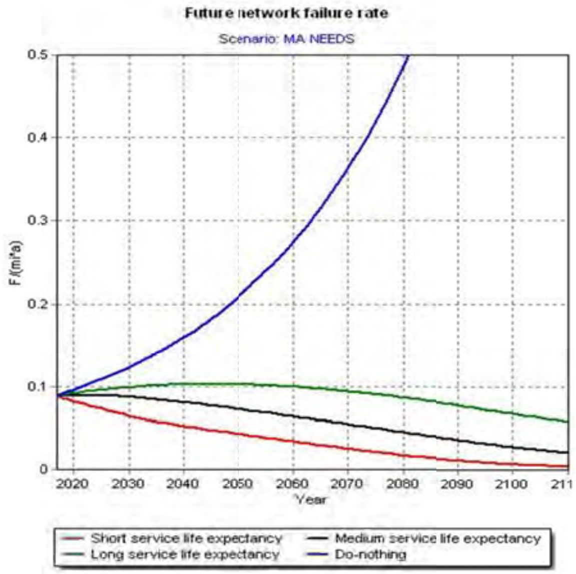
6.4 MA - 3 Systems

6.4.1 MA Needs

Scenario 1 Needs merely translates the inventory and the EULs. We also show the resulting average Break Rate for the overall

System. Scenario 1 is obtained with an MBR of 0.25 Breaks/mi./yr., and an EF of 2. We show the Length of R&R, Break Rate and Cost in Figure 35.


Future rehabilitation needs per asset type
Scenario: MA - Medium service life expectancy
Length in mi
Year
AC
DI_L
DI_S
DI_VS
ELSE
PCI_L
PCI_S
PCI_VS
SCI_L
SCI_S
SCI_VS
REHAB


Future network failure rate
Scenario: MA NEEDS
F (mi*a)
Year
Short service life expectancy
Medium service life expectancy
Long service life expectancy
Do-nothing

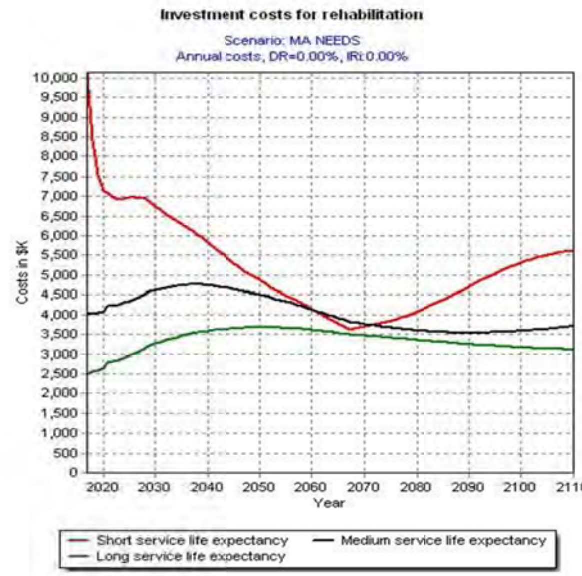
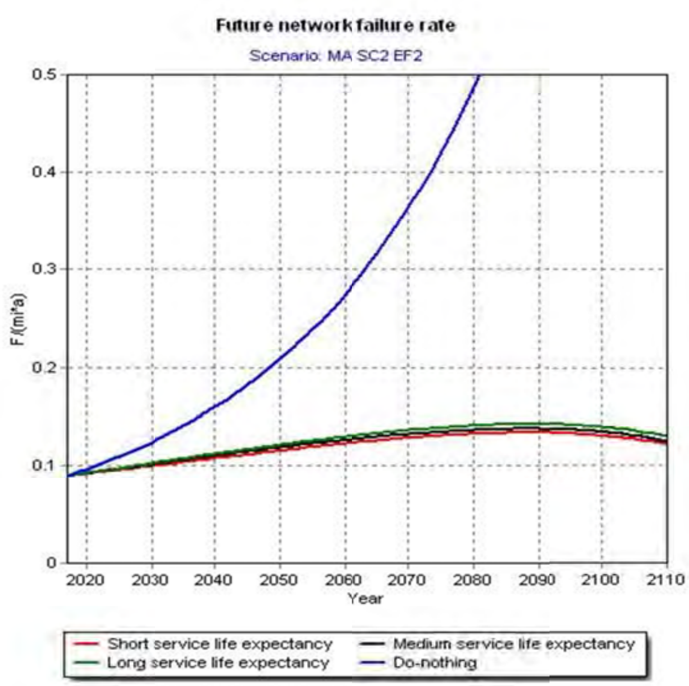

Investment costs for rehabilitation
Scenario: MA NEEDS
Annual costs, DR=0.00%, IR: 0.00%
Costs in $K
Year
Short service life expectancy
Medium service life expectancy
Long service life expectancy

Figure 35 MA Needs Scenario 1 - R&R Length, Break Rate and Investment Cost

The cost ($4 M - $5 M) is seen in Figure 35. It is higher than what has been budgeted ($1.75 M/yr.) while the Break Rate (Figure 35 is lower than needs to be. We built Scenario 2 for each System, by optimizing each cohort in each System (when possible) which was done in Sections 6.1, 6.2, and 6.3. We are adding the length from each cohort in the 3 Systems. The results are shown in the Section 6.4.2.

6.4.2 MA Scenario 2

The R&R lengths are seen in Figure 37. As seen in Figure 36 we are not able to lower the cost to $1.5 - $2 M while keeping a Break Rate and a backlog that are acceptable.
The minimum investment that is projected is $2.6 M that has to slightly increase to $2.8 M by 2070 but, then, would need to be ramped up to $3.8 M by 2100 (including the new mains). See Figure 36.



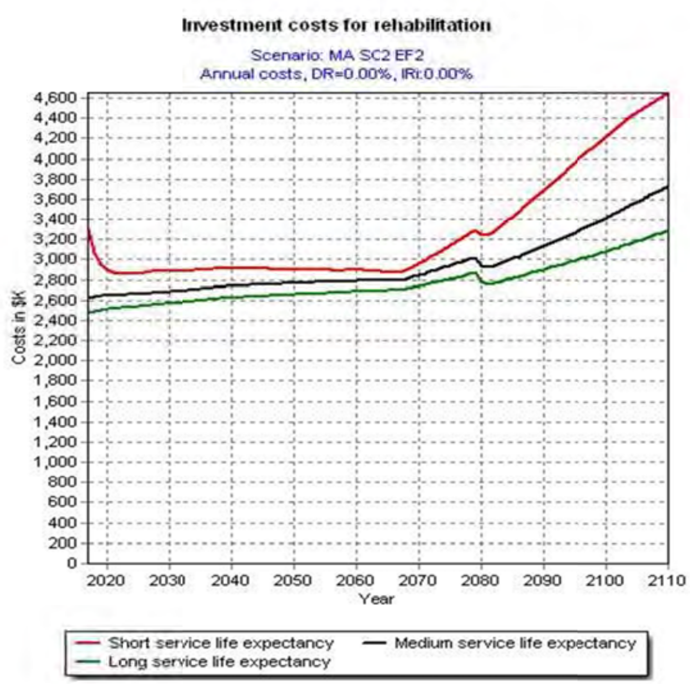


Figure 36 MA Scenario 2 - Break Rate and Investment Cost

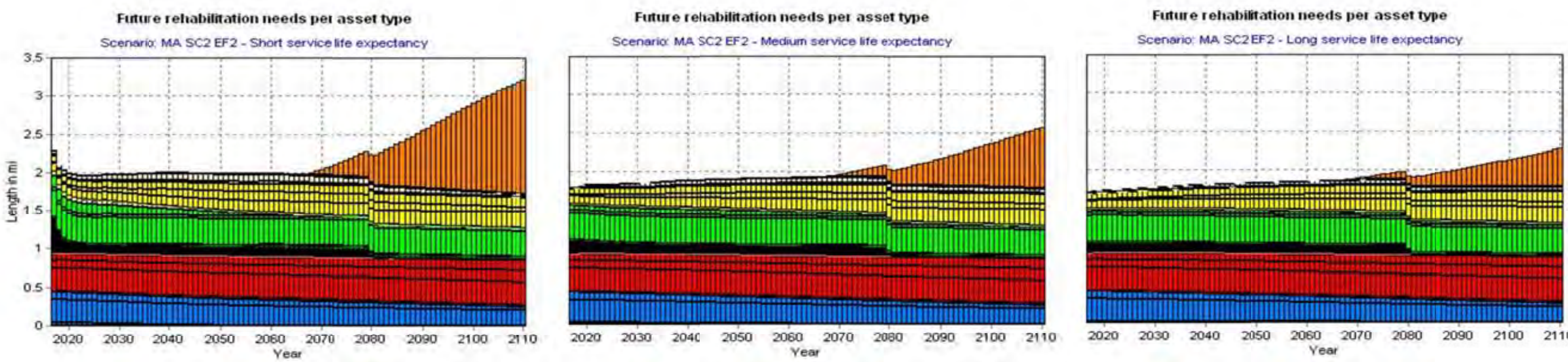


Figure 37 MA Scenario 2 - R&R Length

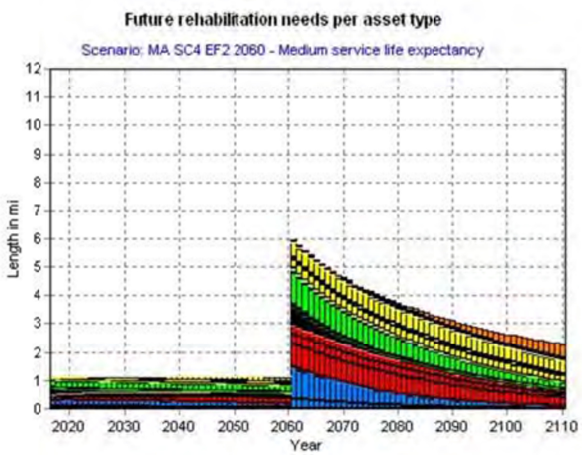
6.4.3 MA Scenario 4

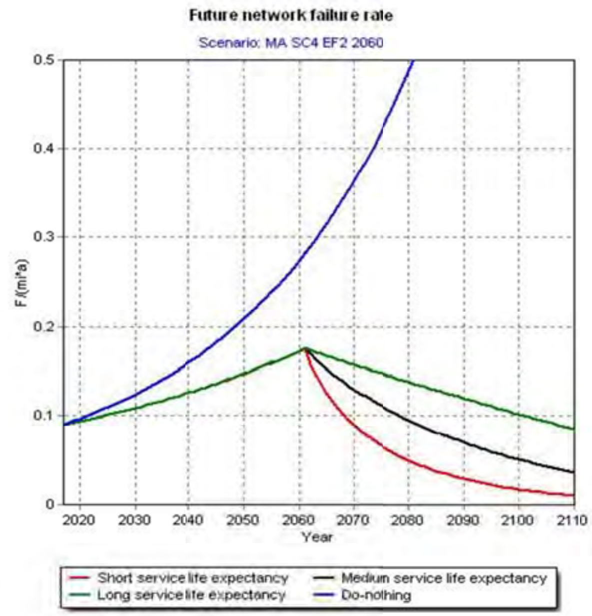
Scenario 4 was created to see what would happen if we were to maintain the currently projected budget ($1.75 M per year) until 2100, and to justify the need for a larger budget. As previously we used the EULs that correspond to the MBR of 0.25 Breaks/mi./yr. threshold and an EF of 2.

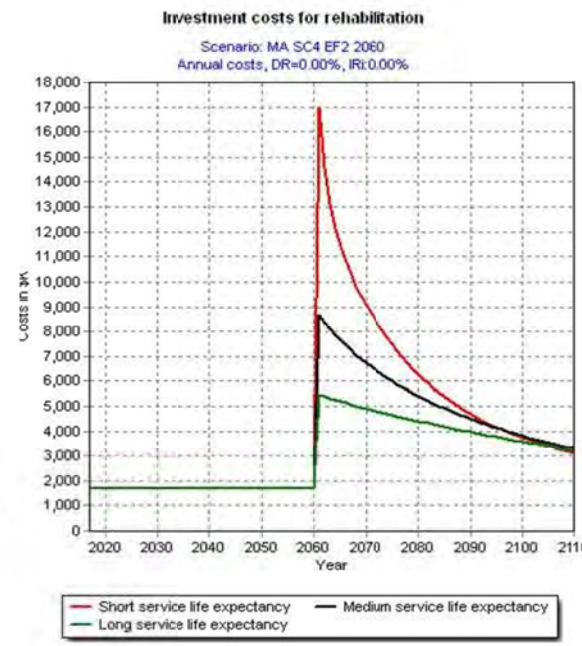
$1.75 M/yr. @ $275/ft. or $1.452M/mi. ➔ 1.2 mi./yr. We distribute that amount to each cohort proportionally to the relative length of R&R in the Needs Scenario. Because of the number of cohorts (27) the software was not able to process a 100-yr. scenario. We had to stop at year 2060. The left-hand part of

Figure 38 shows the steep backlog (close to 6 miles in 2061) that would result with that Scenario. This results in a cost of $8.5 M in 2061 (right-hand

Figure 38). The Break Rate would only climb to 0.17 Breaks/mi./yr. which is acceptable. The issue with this Scenario is managing the backlog. If we had been able to build a Scenario up to 2100, we would show an even higher backlog (similar to the sum of the backlogs seen for each system). The Break Rate wouldalso be much higher.


Future rehabilitation needs per asset type
Scenario: MA SC4 EF2 2060 - Medium service life expectancy
Length in mi
Year


Future network failure rate
Scenario: MA SC4 EF2 2060
Year
Short service life expectancy
Medium service life expectancy
Long service life expectancy
Do-nothing


Investment costs for rehabilitation
Scenario: MA SC4 EF2 2060
Annual costs, DR=0.00%, IR=0.00%
Costs in $K
Year
Short service life expectancy
Medium service life expectancy
Long service life expectancy