MOTT MACDONALD

Rationale for London Additional Expenditure

Factors affecting performance and cost

November 2021

Confidential

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Executive summary

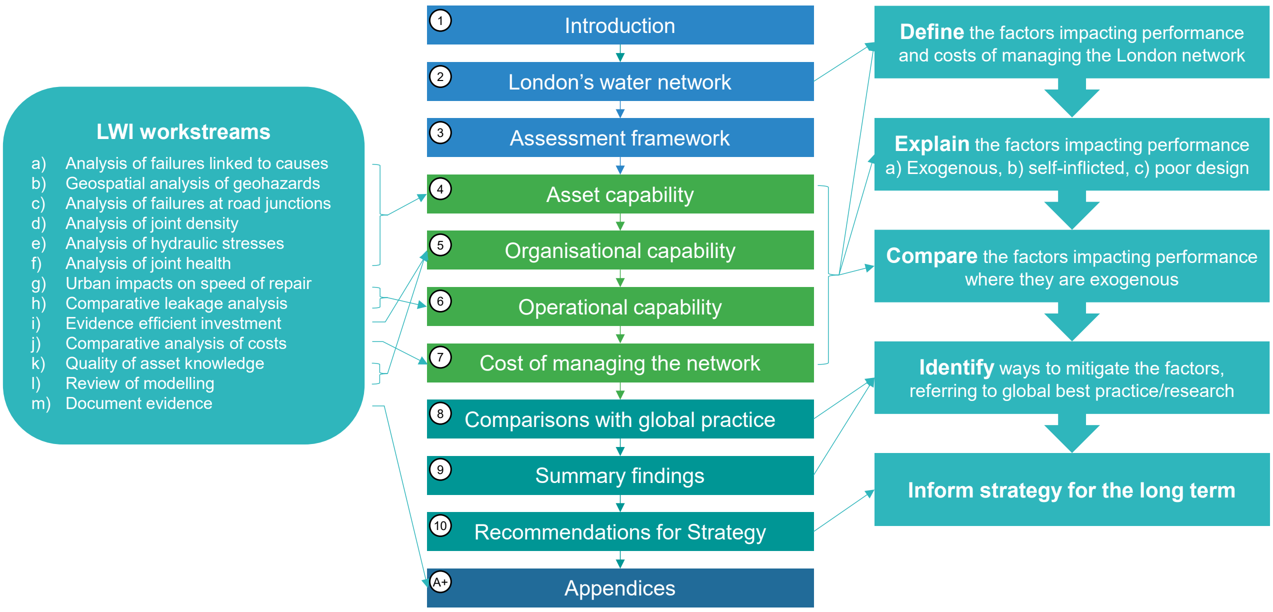
S.1 Introduction

This report documents the London Water Improvement (LWI) investigations undertaken in support of the strategy to improve London's water network. The document has two purposes:

- to strengthen evidence to support the need for investment in London's water supply network, investigate the factors impacting the performance of the network and the costs of managing it and to inform the long-term strategy for London's water supply network and the deliverables for Gate 2 of the conditional allowance.
- to identify ways to improve asset management decision-making

The structure of the report is shown in Figure S.1.

Figure S.1: Structure and purpose of report



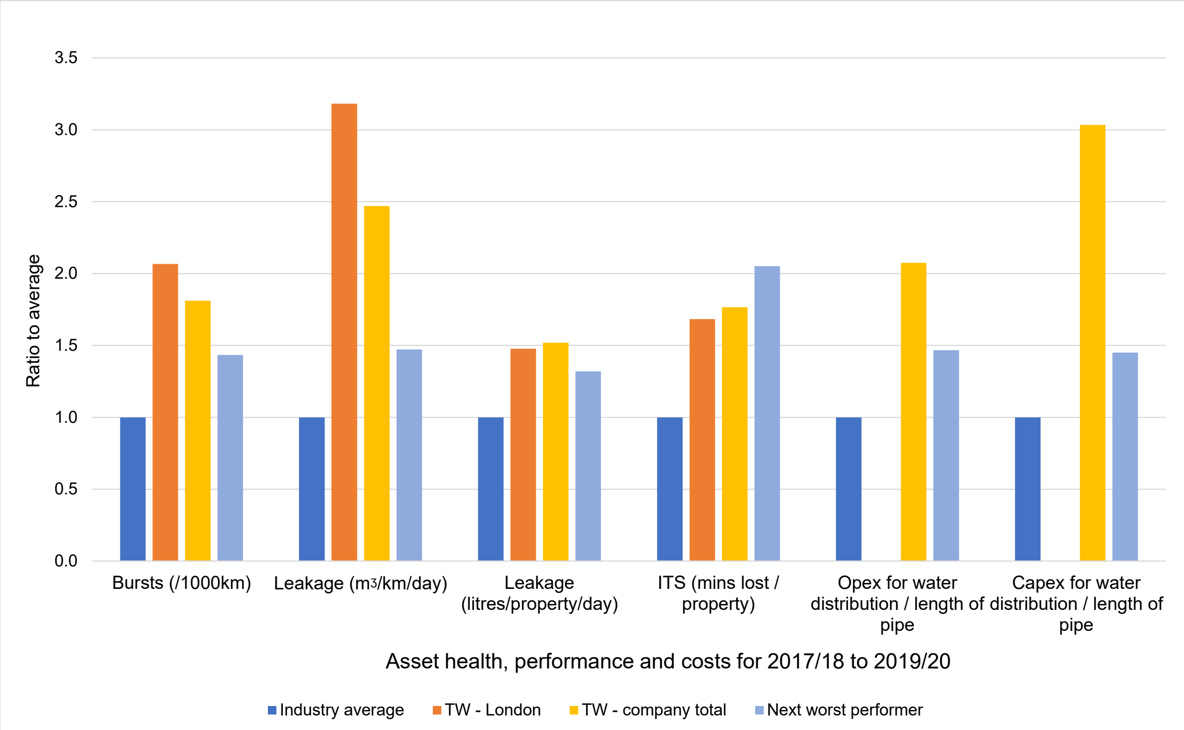
Source: Mott MacDonald

Figure S.1. shows how the findings from 13 workstreams feed into ten chapters of the report and how those inform recommendations for a strategy for London's water network. The report takes a holistic approach, recognising that performance and cost is not only driven by the capability of the assets, but by organisational decisions, operational capabilities, and the cost of working on the network in London. Chapters 4 to 7 cover these core capabilities.

S.2 The problem

The problem that the report investigates is the poor performance of London's water network and its impacts on costs. A comparison of performance and costs with industry averages and the next worst performing company is shown in Figure S.2 for the years 2017/18 to 2019/20. This shows that London's water network is a performance outlier for bursts and leakage but not interruptions to supply, (though performance is worse than average). The poor asset performance is partly responsible for high levels of expenditure, both operationally in repairing the asset base and in capital maintenance.

Figure S.2: Comparative asset health and cost



Source: Mott MacDonald, based on Discoverwater.com for bursts, leakage, and interruptions to supply and APR data tables for costs (Tables 4J and 4P)

Other evidence that London's water mains are in poor health, as described Chapter 4, are that:

- There is a high number of reported (visible) leaks on mains compared with other companies
- Pipe samples show heavy corrosion with through-wall corrosion in many cases
- Locked joints on corroded cast iron pipes are vulnerable to fracture from temperature drops
- High leakage recurrence in poor performing DMAs indicates that pipes are in poor condition
- The network responds poorly to periods of cold or dry conditions, with leakage outbreaks
- There are high numbers of repairs at road junctions, suggesting vulnerability to traffic loading
- There were a high number of high-profile trunk-main failures in AMP6

S.3 Factors driving performance and cost

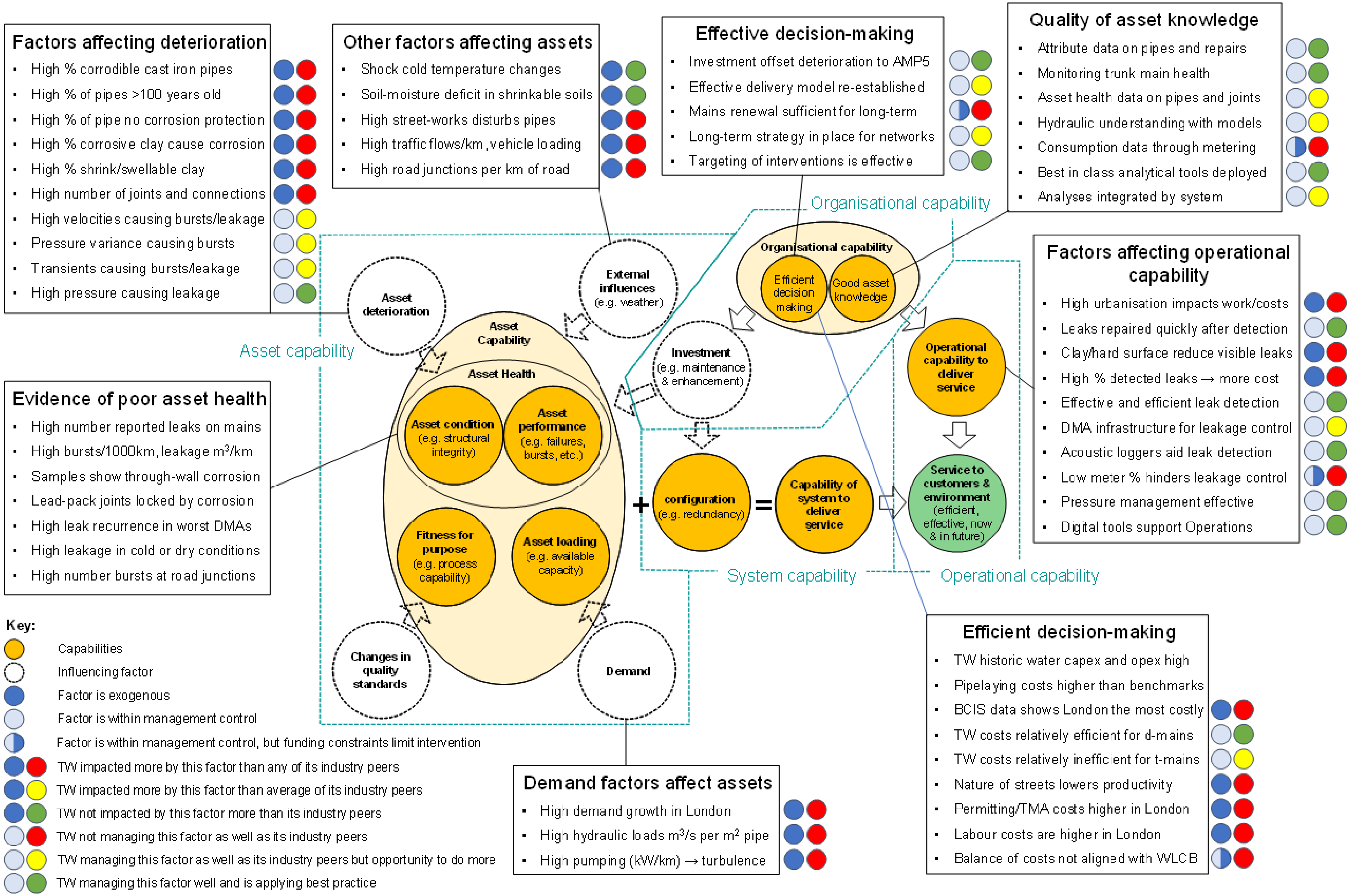
The key factors affecting the capabilities that drive performance and cost in London's water network are shown in Figure S.3, showing whether they are exogenous or within management control and their severity of impact compared with industry peers or TW's success in managing them. We provide a short summary against each of the key areas as follows:

1 Factors affecting deterioration (chapter 4)

The principal reason for the poor health of London's water network is the high rate of deterioration of TW's ferrous pipes and a combination of exogenous factors driving it, such as:

- A high percentage of TW's pipes are made of cast iron, a corrodible material
- A high percentage of them are over 100 years old, predating the first standards (BS 78)
- A high percentage of these older pipes have no corrosion protection
- Many of these pipes sit in corrosive clay soils and have become heavily corroded
- The clay soils are also plastic and shrink and swell in dry and wet periods, rupturing pipes

Figure S.3: Factors affecting performance and cost



- The high number of pipe joints and connections in London's dense urban environment, all of which are potential points of weakness for leaks to occur. The high number of joints relates to TW owning the highest length of pipe over 100 years old where limitations in manufacture meant that pipes were relatively short compared with modern standards

The combined effect of a large portfolio of corrodible materials and very old pipes of variable manufacture, with many joints and connections but limited corrosion protection, in contact with corrosive and plastic clay soils for so long has resulted in through-wall corrosion and propensity to burst and leak. Other companies experience some of these conditions, but as shown in Figure S.3, TW is impacted more by these factors than any of its industry peers (see below).

The poor health of the network makes it vulnerable to sudden drops in water temperature during cold weather, leading to annual outbreaks of leakage. The network is not therefore resilient to freeze-thaw events such as that seen in 2018.

Other factors affect the deterioration and performance of London's network, many related to the dense urban environment and the heavily trafficked streets of London and others related to hydraulic stresses caused by pumping and high demand growth. These are shown in Figure S.3 and evidenced in the body of the report.

The factors affecting asset capability have been considered individually but to prioritise investment TW needs to understand the combination of factors that best explain localised performance. TW's AIM model for water distribution mains does this statistically for some of the key factors driving performance such as pipe material, diameter, age and soils but not for all the factors identified in this report. It would be valuable to undertake some statistical analysis to examine the compounding effect of the full basket of factors identified in this report.

2 Organisation capability and effective decisions (chapter 5)

We assessed the influence of TW's organisational capability and historic decisions on today's poor asset health issues in London's water network. We concluded that:

- TW's historic decisions on a blend of interventions, including mains renewal, to offset deterioration and achieve stable serviceability were effective up to the end of AMP5. Stable serviceability was the regulatory objective for base maintenance up to the end of AMP5 before the introduction of performance commitments and delivery incentives
- TW's decisions were less effective in AMP6 and it had to intervene to modify the alliance models it set up to deliver service and leakage targets by bringing capability back in-house. AMP6 targets were eventually recovered and TW now has an intelligent client model in place that is more effective but not yet mature. It therefore has a yellow designation in Figure S.3
- TW has not renewed as much of its network as other companies or as much as it would have liked owing to affordability constraints. This is shown as red, but funding constrained
- TW does not have a long-term strategy in place for networks, in common with many companies, but is in the process of developing one. This has a yellow designation
- TW has effective processes for targeting interventions at assets that pose the highest risk to service or public safety

The quality of TW's asset knowledge is good with some areas of leading practice and some areas for improvement. These are shown in Figure S.3 and evidenced in the body of the report.

3 Operational capability (chapter 6)

TW has good operational capability but faces several challenges associated with London's urbanised environment, as shown in Figure S.3.

- Despite working in the most densely urbanised environment in the UK, TW has managed to reduce the time to repair pipes once leaks are found to below industry average
- However, the combined effect of hard surfaces through high urbanisation and the clay subsoils means that a lower proportion of leakage presents itself as visible leaks on the surface than elsewhere in the country. This means that TW must detect and repair 50% more invisible leaks for each visible leak than the industry average, which increases TW's leak detection volumes and costs compared with others.
- TW's leakage technicians are effective and efficient at leak detection and TW has installed 27,000 acoustic loggers to aid leak detection efforts which are delivering leakage savings.
- However, TW's DMA infrastructure, although improved, has relatively low operability which effects TW's ability to accurately measure leakage and target detection efforts effectively. TW is implementing a DMA excellence programme to improve operability.
- TW has comparatively low meter penetration which limits availability of good consumption data, but TW has been installing and operating pressure management schemes since AMP3 and has extensive coverage of London's network with pressure managed areas.
- TW has good smart digital tools to support Operations, detect anomalies, and enable rapid response. There may be opportunity to integrate them more with forecasting tools.

4 Efficient costs (Chapter 7: Cost of managing the network)

The main factors impacting the cost of capital works in London are those associated with the highly urbanised environment and the competition for labour in the nation's capital. In Figure S.3 we have summarised these as: the nature of the streets, such as the prevalence of concrete bound layers increasing reinstatement costs and the high density of buried services, the high permitting and traffic management costs, and high labour costs in London

These are exogenous factors impacting the productivity and costs of TW's pipelaying activities and their impact is more severe in London than elsewhere in the country.

When TW costs and benchmark costs are adjusted for location using BCIS[1] location indices, then TW's costs for distribution mains are broadly efficient compared with benchmarks. Trunk mains, however, appear to be inefficient compared with benchmarks by about 35% in London, even after adjustment for location. Our explanation for this is that whereas the BCIS location indices largely explain the London impact on costs for distribution mains, they are insufficient alone to capture the complexities and site-specific factors impacting deep excavation work associated with trunk mains in London. Unfortunately, we were unable to identify the specific factors impacting costs for trunk mains from TW productivity data or to compare these with similar information for benchmarks to quantify the effects. This as an area for future focus

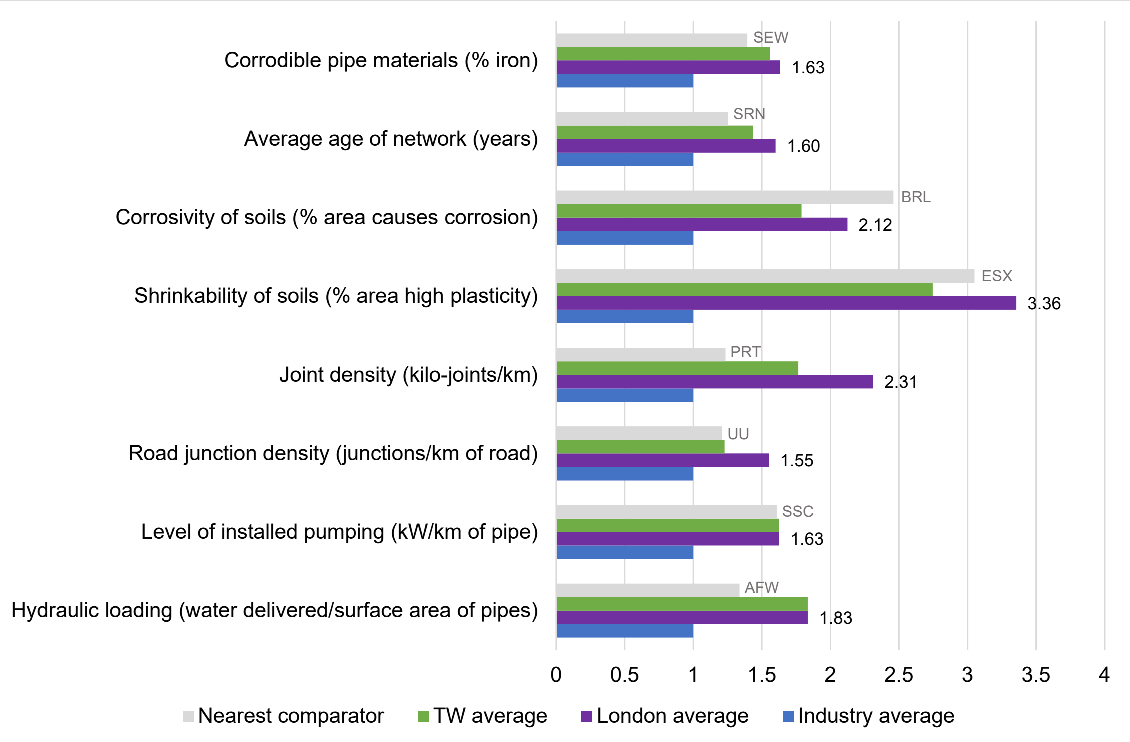
A whole-life cost benefit analysis of London's water network has shown that the current balance of capital and operational costs is uneconomic in the long term and that to reduce operating costs and maximise the benefits from improved service, TW needs to increase the level of mains replacement. We have shown this as red, but funding constrained in Figure S.3

S.4 Comparison of factors driving performance and cost

Figure S.4 compares London and Thames Water with the industry average and nearest comparator values for a selection of the factors listed in Figure S.3. It shows that all the factors impacting the performance of TW's network are more severe for London, but also for TW as a whole, than the average for England and Wales and in most cases the nearest comparator. Note that the nearest comparator company is different for each factor, so there is no other company facing a similar combination of challenges.

[1] Building Cost Information Service

Figure S.4: Comparison of factors impacting asset capability



Source: Mott MacDonald analysis, data based on various data sources listed in Table 4.10

The main exceptional and foundational issue is the material and age profile of the asset base, the scale and age of which marks London out from other networks. This is compounded by various situational factors, which themselves are more extensive and severe than other parts of the country such as the aggressive soils, various exceptional urban environment related factors and hydraulic factors. This has manifested as exceptionally poor asset health, poor performance and high risk (for example sensitivity to weather shock and high-profile catastrophic failures and major incidents) as clearly evidenced over many years making TW an industry outlier in terms of performance and public perception. This situation is likely to deteriorate as the assets age further and increased customer expectations and demands are placed upon them.

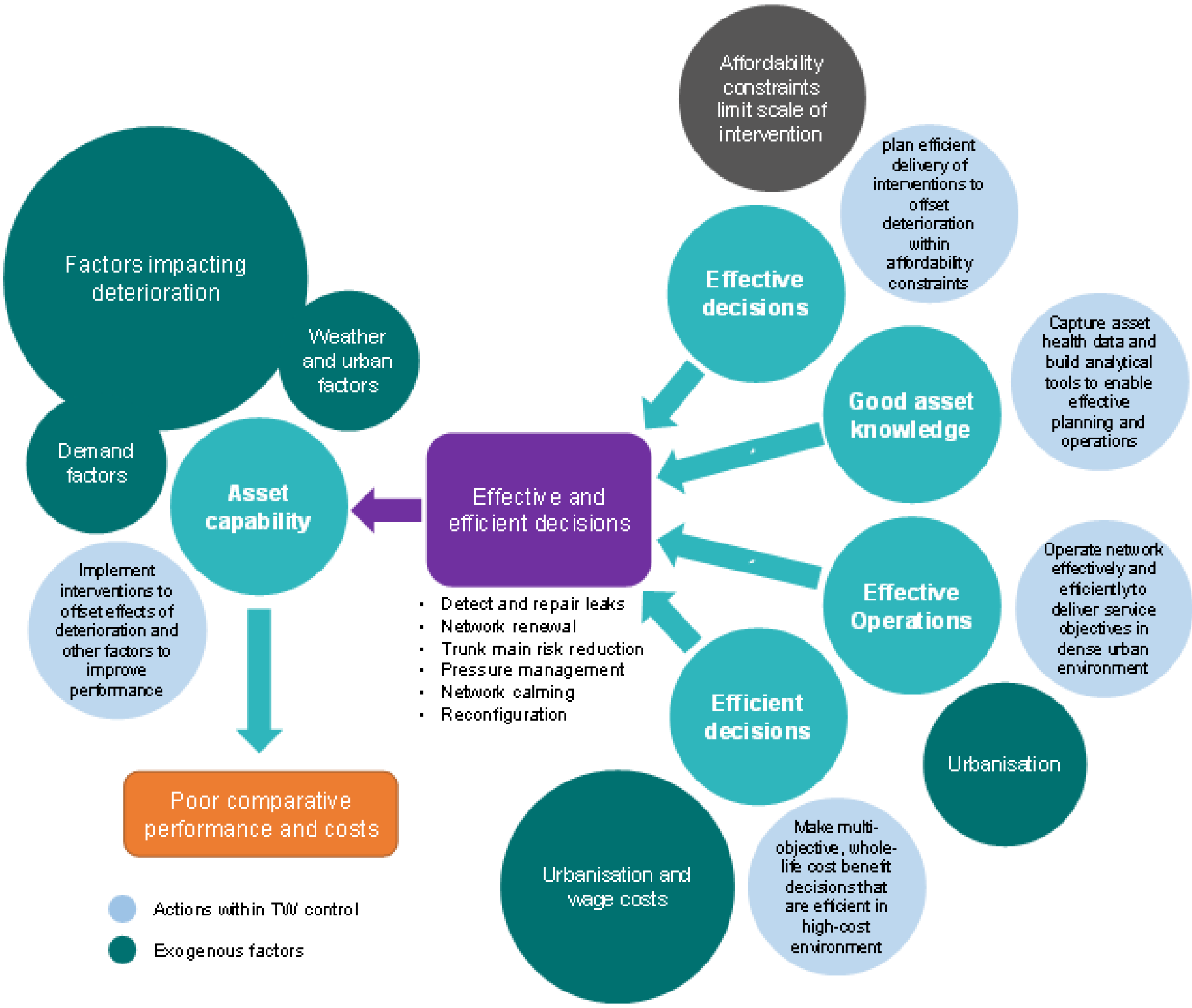
S.5 Management control of factors

TW has sought to control the factors impacting the performance of London's water network in a positive way within the constraints that it operates. In Figure S.5 we have shown how the actions that TW takes to control and improve performance interact with the exogenous factors that are causing the network to deteriorate, or which pose a challenge to cost efficiency.

Figure S.5 shows how the exogenous factors causing the deterioration of the network or otherwise negatively affecting its performance are countered by the interventions that TW takes both operationally and through capital investment. The decisions on which interventions to make and when are determined by the four capabilities of effective decisions, good asset knowledge, effective operations, and efficient decisions. Good asset knowledge is important in making effective decisions, but the scale of intervention has been constrained historically within affordability limits. Operations is effective but affected by urbanisation, both in the costs of repair and leak detection. Decisions can also be efficient but are affected by urbanisation and the high cost of doing construction work in London.

The management actions that TW has taken to date (shown in the pale blue circles) have been successful historically in maintaining service but at a relatively high cost compared with other companies. This is not because TW is inefficient. Benchmarking shows TW's pipelaying costs to be efficient. The cost impacts of urbanisation and wages in London, plus the unique combination of a high proportion of cast iron pipes of exceptional age sitting in corrosive soils, means that TW must expend more effort and cost than other companies to maintain service.

Figure S.5: Factors impacting performance and cost and actions to control them



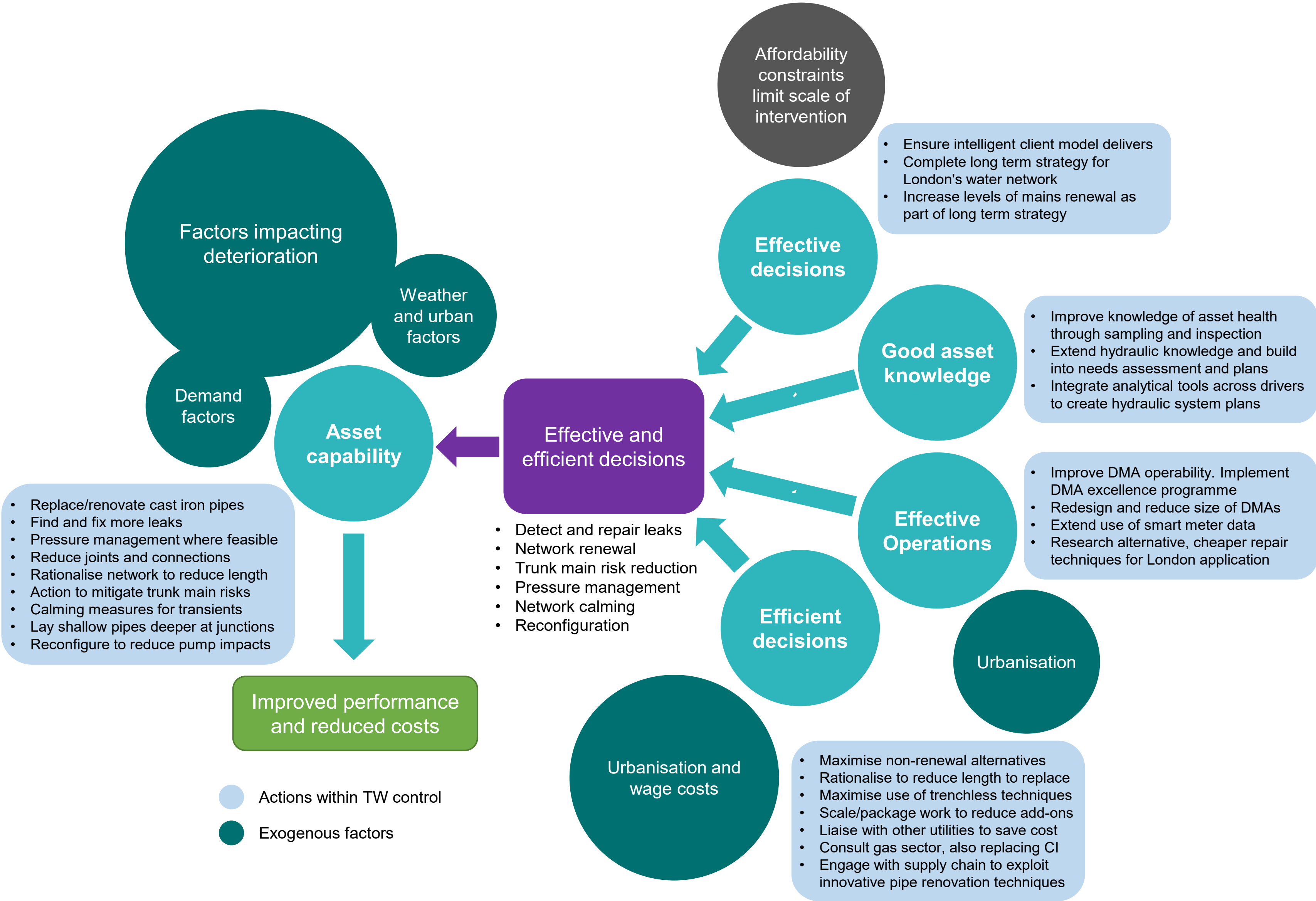
Source: Mott MacDonald

To improve service and reduce leakage, TW needs to increase its efforts to renew and repair its pipes but is constrained from doing so by affordability constraints and the high cost of doing work in London. But the only way to change the current situation is to renew or renovate more of the cast iron pipes in its network with high failure and leakage rates and to do so as efficiently as possible over an extended period to make it affordable and deliverable.

S.6 Mitigating the factors

TW's capabilities for managing the factors within its control generally compare well with its industry peers but there are some capabilities where more could be done that would support better decisions and benefit the balance shown in Figure S.5. We have summarised the actions to mitigate factors impacting performance and costs in Figure S.6. These address the factors affecting performance while minimising the upward pressure on costs from working in London. There are measures listed against each of the five capabilities, summarised from chapters 4 to 7 where more detail can be found.

Figure S.6: Mitigating the factors impacting performance and cost



Source: Mott MacDonald

The measures listed against asset capability include many of those that TW already implements, such as find and fix and mains renewal, but gives some additional attention to pipes at road junctions, especially those found to be shallow compared with TW's asset standards and reconfiguration options to reduce the impact of pumping by creating greater separation between transmission and distribution.

For effective decisions, it is important that the new intelligent client model delivers schemes quickly and efficiently, taking the targeting work from asset management, packaging it appropriately, briefing and appointing contractors and ensuring that the expected benefits are realised. We have also noted a need for a long-term strategy for London's water network, which TW is developing and as part of that a need to increase the level of mains renewal to improve asset health and resilience. The report makes some high-level estimates of long-term sustainable levels of mains renewal and these are higher (at 1000 to 1200 km/AMP) than recent levels of renewal delivered by TW to offset deterioration (650 km/AMP).

The report notes the success of the VMR programme and the sustained benefits and reduced costs achieved from whole-DMA replacement. Equally, it finds that where there are hot-spots of pipe failures at road junctions or high head-loss pipes, then localised renewal may be the best course of action. Overall, we recommend a blend of both approaches where they are supported by whole-life cost benefit analysis.

Against good asset knowledge, we have noted a need to continue to improve knowledge of asset health with in-the-field sampling, monitoring and inspection to supplement the data that TW already has. We have also identified a need for TW to extend its understanding of the hydraulic behaviour of the network and to use that knowledge to help identify needs as well as to design solutions. The analytical tools that TW has could also be integrated to develop long-term hydraulic system plans to consider needs and solutions across multiple drivers

For effective operations, we have focused on improving DMA operability and DMA design to reduce the size of some of London's DMAs. TW already has plans in hand for this as well as making more use of smart meter data when it is available. We have also suggested supporting research into innovative repair techniques to try to reduce the cost and disruption of repairs

Against efficient decisions, we have listed measures to reduce cost. These focus on prioritising cheaper options where available and rationalising the network to reduce the length of main to renew, given the high cost of construction in London. We have also suggested packaging the work to reduce construction add-on costs and liaising with other utilities, such as the gas sector to coordinate work and reduce permitting costs (which TW already does). We also recommend that TW engages with the supply-chain to consider innovative pipe renovation techniques where they offer resilient solutions at lower cost.

S.7 Improving asset management

In investigating the factors impacting performance and cost of London's water network, several asset management improvement themes have emerged:

- Developing and embedding a long-term strategy for managing the health of London's water network that dovetails with long-term plans for water resources and resilience and is adaptive to account for uncertainty
- Having a process to ensure that short term (1 to 3 year) and medium term (5 to 10 year) plans are aligned with the strategy
- Improving knowledge of asset health based on more systematic sampling and inspection, tied into wider reporting of asset health metrics as part of TW's asset information strategy

- Adopting an optimum whole-life cost-benefit (WLCB) approach across multiple objectives to drive long-term investment decisions to ensure intergenerational equity. Ensuring that short and medium-term plans are aligned with this
- Developing a deeper understanding of hydraulics and incorporating it into targeting decisions and eventually developing a hydraulic ‘digital twin’ by linking calibrated models to telemetry
- Developing integrated hydraulic system plans that account for growth, asset integrity, leakage, water quality, operational efficiency, and other water network service objectives
- Capturing productivity data linked to cost drivers to better understand and manage costs
- Improving the capture of benefits from interventions, the sustainability of those benefits and how they compare with expectations at the planning stage
- Driving innovation to improve and lower the costs of internal pipe inspection, and develop novel forms of pipe renovation and repair techniques that can be applied in London’s urbanised environment to renew the network at lower cost

Many of these themes align with the findings from Ofwat’s asset management maturity assessment (AMMA) report[2] which TW is considering in developing its strategic asset management plan.

The improved asset management capabilities will enable the management of asset health and resilience to be more strategically driven and less reactive and be better informed with systematically captured asset health data. An optimised whole-life cost benefit approach will enable improved service at lower costs for customers in the long-term and a hydraulic digital twin will enable a more agile operational response to events in the network. The focus on productivity data, benefit realisation and research into renovation and repair techniques will address the fundamental challenge that London is the costliest place in the country to do construction work and TW needs to find cheaper ways to replace its aging pipe network

S.8 Recommendations

At the end of the report, we draw together the recommendations from the earlier chapters for strategic actions to improve the performance of London’s water network and reduce costs. These are listed in Table S.1 under ten themes from tactical interventions and strategy to mitigating cost pressures and driving innovation and they are categorised into immediate (next year), medium-term (AMP7), and long-term (AMP8 and beyond) priorities. Some of the recommendations are already being actioned by TW or are planned to be and these are highlighted in blue font.

[2] Ofwat, Asset management maturity assessment – insights and recommendations, September 2021

Table S.1: Recommended priority actions

Category	Immediate priorities (next year)	Medium-term priorities (AMP7)	Long-term priorities (AMP8 and beyond)
Tactical interventions	-	- Set triggers for high-frequency same location repairs to alert asset planners - Improve DMA operability through delivery of the DMA excellence programme - Increase the coverage of acoustic loggers and other leak detection technology	- Divide the largest DMAs to improve leakage targeting
Long-term strategy	- Set a long-term strategy for distribution mains with an uplift in the rate of renewal - Set a long-term strategy for trunk mains and the ring main - set a strategy to improve the asset health of the 42" and 48" cast iron trunk mains	-	-
Network policies	- Review policy on the number of customers to be supplied directly by pumping - Review network policies and asset standards more generally prior to renewal design - Assess implications of policy changes for legacy assets and address in the strategy	-	-
Improving asset knowledge	- Improve use of existing hydraulic models - Improve capture of benefits and their sustainability - Improve records for abandoned and renovated pipes	- Investigate causes of failure at road junctions - Capture productivity data linked to cost drivers - Improve knowledge of asset health of pipes and joints through sampling and inspection - Improve use of hydraulic models and coverage - Improve systems/data for surge protection and network calming assets	- Improve use of hydraulic models in Operations
Targeting investment	- Undertake statistical analysis to examine the compounding effect of the basket of factors identified in this report to aid targeting - Refine investment targeting to account for pipe failures at road junctions - Identify high and low velocity pipes in identifying needs - Take greater account of hydraulic effects in identifying investment needs	- Use leakage recurrence in targeting decisions - Take greater account of hydraulic effects - Keep under review pressure management opportunities - Implement a blend of whole-DMA and targeted replacement of distribution mains, where supported by whole-life cost benefit analysis	- Take greater account of hydraulic effects - Keep under review pressure management opportunities - Implement a blend of whole-DMA and targeted replacement of distribution mains, where supported by whole-life cost benefit analysis

Category	Immediate priorities (next year)	Medium-term priorities (AMP7)	Long-term priorities (AMP8 and beyond)
Achieving intergenerational equity	- Use analysis of optimum whole-life cost benefits (WLCB) to determine the best mix of interventions in the long term - Align short-term plans to the WLCB profile	-	-
Improving hydraulic efficiency	- Assess opportunities to improve hydraulic efficiency, especially in pumped systems	- Develop hydraulic system plans that integrate interventions across drivers at a system level	- Develop hydraulic system plans that integrate interventions across drivers at a system level - operationalise hydraulic models
Calming the network	- Continue to explore opportunities to calm the network through transient controls	- Continue to explore opportunities to calm the network through transient controls	-
Mitigating cost pressures	- Explore potential for and cost-benefit case for pressure management and network calming before pipe renewal - Maximise trenchless techniques to limit the use of more expensive open cut where the advantages of trenchless techniques can be fully exploited - Rationalise the network to reduce length of pipe to renew - Scale and package the work to reduce construction add-ons - Co-ordinate with other utilities and engage with stakeholders	- Keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages	- Keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages
Driving innovation	- Adopt a procurement strategy for pipe renovation work that incentivises innovation and cost savings	- Continue research into pipe inspection techniques to enhance knowledge of pipe and joint health - Support research into novel forms of pipe renovation and repair that offer cost savings in the London environment - Pilot the efficacy, costs, and benefits of these to support plans for AMP8 and beyond	- Support research into novel forms of pipe renovation and repair that offer cost savings in the London environment - Pilot the efficacy, costs, and benefits of these to support plans for AMP8 and beyond

Source: Mott MacDonald

These recommendations are already being actioned by TW or included in planned work

Abbreviations and acronyms

AC – Asbestos Cement

AFF/AFW – Affinity Water

AIM – Asset Investment Manager

AL – Active Leaks (detected but not visible)

AMMA – Asset Management Maturity Assessment

AMP – Asset Management Plan

ANG/ANH – Anglian Water

APR – Annual Performance Report

AR – Annual Return

AWWA - American Water Works Association

BCIS – Building Cost Information Service

BEM – Broadband Electro-Magnetic

BGS – British Geological Society

BP – Barrier Pipe

BRL – Bristol Water

BRN/SWB – Bournemouth Water

BS – British Standards

BS EN – British Standards adopted by European Committee for Standardisation

BWH – Sembcorp Bournemouth Water

CAM – Cambridge Water

CAPEX – Capital Expenditure

CI – Cast Iron

CIPRA – Cast Iron Pipe Research Association

CIRIA – Construction Industry Research and Information Association

CMP – Critical Monitoring Point

CPP – Critical Pressure Point

CSL – Customer side leakage

CW – Clean Water

DEV/DVW – Dee Valley Water

DI – Ductile Iron

DG2 – Low water pressure

DG3 – Unplanned interruptions

DMA – District Metering Areas

DMC – Directly Managed Capital

DWSP – Drinking Water Safety Plan

EES – Engineering Estimating System

ELL – Economic Levels of Leakage

ESK – Essex and Suffolk Water

ESPB – Equivalent supply pipe bursts

FBP – Final Business Plan

FD – Final Determination

FMZ – Flow Monitor Zones

GIS – Geographic Information System

GPS – Global Positioning System

GRP – Glass reinforced plastic

HDD/HDY – Hafren Dyfrdwy

HPPE – High Performance Polyethylene

HSE – Health and Safety Executive

ILI – Infrastructure Leakage Index

ITS – Interruptions to Supply

KPI – Key Performance Indicator

LON – London WRZ

LPI – Leakage Performance Information

LWI – London Water Improvement

MIS – Management Information Systems

ML/D – Mega litres per day

MDPE – Medium Density Polyethylene

MOPVC – Molecular Orientated Polyvinyl Chloride

NDT – Non-Destructive Tests

NES/NWL – Northumbrian Water

NIW – Northern Ireland Water

NRR – Net Rate of Rise

NST – Network Service Technician

ODI – Outcome Delivery Incentives

ONS – Office of National Statistics

OPEX – Operational Expenditure

OS – Ordnance Survey

PBI – Power BI

PE – Polyethylene

PMA – Pressure Managed Area

POL - Polymer

PR – Price Review

PRT – Portsmouth Water

PRV – Pressure Reducing Valves

PSC – Prestressed Concrete

PTW – Permit to Work

PVC – Polyvinyl Chloride

RC – Reinforced Concrete

RPI – Retail Price Index

SCADA – Supervisory Control and Data Acquisition

SES – Sutton and East Surrey Water

SEW – South East Water

SI12 – Service interruption up to 12 hours

SIM – Service Incentive Model

SMD – Soil Moisture Deficit

SOM – Site Operating Manual

SoSI – Security of Supply Index

SR – Service Reservoir

SRN – Southern Water

SRV – System Risk Visualisation

SSA – Strategic Supply Area

SSC/SST/SSW – South Staffordshire and Cambridge Water

ST - Steel

SVE/SVT – Severn Trent Water

SWA – Slough, Wycombe and Aylesbury WRZ

SWT – South West Water

SWOX – Swindon and Oxfordshire WRZ

TfL – Transport for London

TMA – Traffic Management Act

TMS – Thames Water (OFWAT abbreviation)

TOTEX – Total Expenditure

TV – Thames Valley (All WRZs excluding London WRZ)

TW – Thames Water

UKWIR – UK Water Industry Research

UPC – Unplasticised Polyvinyl Chloride (see also PVC and UPVC)

UPVC – Unplasticised Polyvinyl Chloride (see also UPC and PVC)

USEPA - United States Environmental Protection Agency

UUW – United Utilities (also UU)

VMR – Victorian Mains Renewal

WRC – Water Research Centre

VS – Visible Leaks

VSD – Variable Speed Drive

WLC – Whole-Life Cost

WLCB – Whole-Life Cost Benefits

WRMP – Water Resources Management Plan

WRZ – Water Resource Zones

WSH – Welsh Water

WSX – Wessex Water

WTW – Water Treatment Works

YKW/YKY/YRK – Yorkshire Water

YoY – Year on Year

ZPA – Zonal Performance Assessments

1 Introduction

Chapter summary

This chapter provides an introduction to the report. It will explain the background as to why the report is being undertaken, the objectives, scope of investigations, data sources and report structure.

This report documents the London Water Improvement (LWI) investigations undertaken in support of the strategy to improve London's water network. In this chapter we introduce the background to the project, the objectives and scope of work, the data sources used, and documentation referred to.

1.1 Background

The performance of London's water network in terms of leakage and numbers of bursts has compared poorly with other water company networks since before privatisation in 1989 and this, in conjunction with the challenges of doing pipe repair and replacement work in the most densely urbanised environment in the UK, has made the network more costly to manage than other networks. Although Thames Water (TW) has long cited reasons for this[3], these are not necessarily accepted by all stakeholders and as a result there is a perception that investment in the network may be inefficient. Unless the underlying drivers of performance and cost are better exposed, confidence in future investment could be undermined.

The PR19 Final Determination illustrates this lack of confidence. It makes provision for a conditional allowance for enhancements to London's water network, contingent on fulfilling a Gated process which enables Ofwat to oversee the investment planning and delivery process and if necessary, intervene to ensure that it is efficient and offers customers value for money. Although the conditional allowance is evidence that Ofwat accepts a need for increased investment in London's water network, the Final Determination states that Ofwat is '*not fully convinced that the performance of the London network is significantly impacted by the factors that the company identifies*'. Further evidence is therefore required to improve Ofwat's confidence in the analysis supporting TW's plans for spending the conditional allowance and for longer-term investment in the network.

A series of investigations were initiated to evidence the factors driving performance and cost in London's water network to support TW's investment plans for the conditional allowance and to inform the strategy to improve the network. This report summarises the findings from those investigations.

1.2 Objectives

The objectives of the work undertaken to support this report are to:

- Strengthen evidence to support the need for investment in London's water supply network.
- Evidence the factors impacting the network and the costs of managing it.
- Provide confidence in plans for AMP7 and the conditional allowance.
- Inform the long-term strategy for London's water supply network.

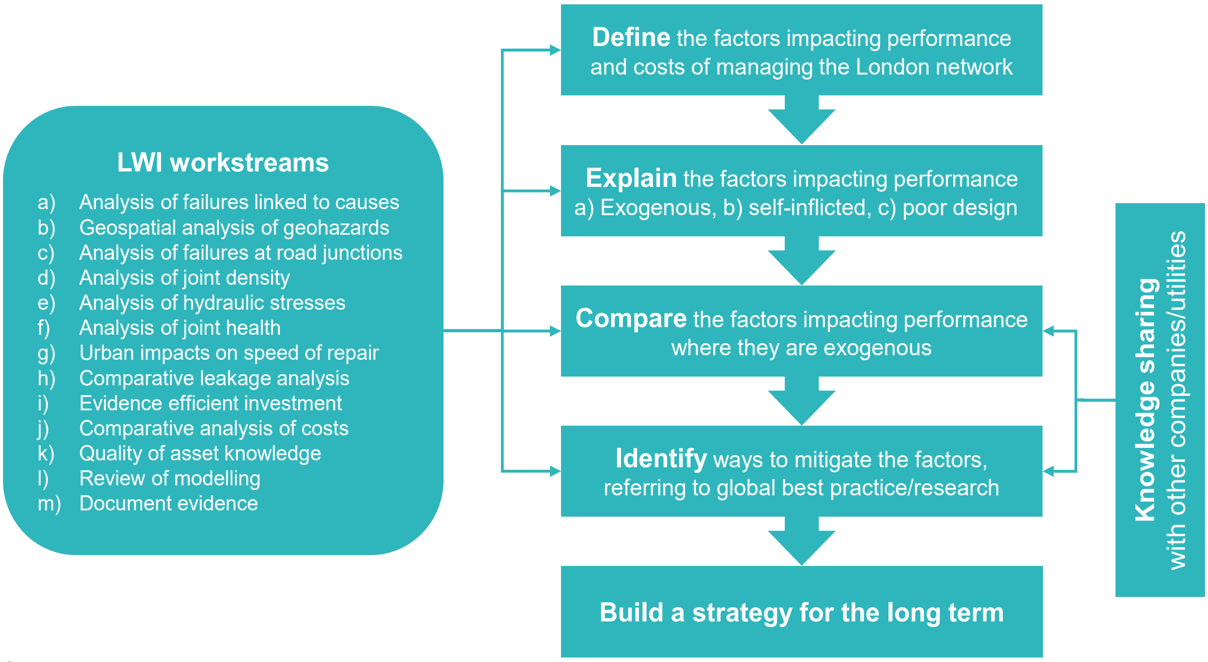
[3] For example, TW's 2001 report: 'London is Different, the impact of London's operating environment on Thames Water's leakage levels

- Provide recommendations which will assist to improve the performance of London's water network and reduce costs
- Inform deliverables for Gate 2 of the conditional allowance, such as the asset management policy, asset management strategy and continuous improvement plan.

1.3 Scope of investigations

Figure 1.1 outlines the scope of work for the LWI investigations and how they support development of a long-term strategy for London's water supply network.

Figure 1.1: Scope of work for the LWI workstreams



Source: Mott MacDonald

The table to the left of Figure 1.1 lists the workstreams that form the scope of work for the LWI investigations. These comprise:

A. **Analysis of failures linked to causes** - to undertake an historical analysis of performance and cost and geospatial analysis of the locations of failure in the context of potential causes.
B. **Geospatial analysis of geohazards** - to compare geohazards such as soil corrosivity and shrinkability between companies and to map them to pipe failures across the London area.
C. **Analysis of failures at road junctions** - to evidence whether traffic is a factor in initiating pipe failure at road junctions, where there is commonly a concentration of fittings and joints.
D. **Analysis of joint density** - to understand how joint density varies across TW's region, how it compares with other companies and whether high leakage per joint figures are correlated with exogenous and/or operational factors.
E. **Analysis of hydraulic stresses** – To develop the evidence that TW's network suffers higher hydraulic stresses than other companies, to understand the impact of hydraulic stresses on pipe failure rates, to evidence the work done by TW to mitigate the effects through calm network policies and hydraulic controls and to assess the importance of hydraulic controls for London's long-term water network strategy.
F. **Analysis of joint health** - to review what data exists on joint health and to review the processes for capturing it in the future from pipe repairs, sampling and inspection.

G. **Urban impacts on speed of repair** - to explore the evidence that more onerous permitting and traffic management in London delays repair of leaking pipes, extending leak-run times.

H. **Comparative leakage analysis** - to understand TW's relative leakage position, both historically and currently and to explain why TW is an outlier on some measures and middle of the pack on others.

I. **Evidence of efficient investment** - to develop the evidence around investment and performance from water infrastructure assets in AMP6 to complete the narrative on historical investment and confirm that TW has fulfilled its obligations and today's performance and cost issues are not the result of low or inefficient investment in the past.

J. **Comparative analysis of costs** - to evidence why unit costs for mains replacement are higher in London yet are nevertheless efficient compared with costs for other companies once the special circumstances of working in London have been accounted for.

K. **Quality of asset knowledge** - To evidence the quality and sufficiency of asset information to reassure stakeholders that investment plans are founded on sound information.

L. **Review of modelling** – to review how the factors impacting network performance and costs are represented in the suite of modelling tools used to determine investment requirements.

The outputs from the LWI workstreams, together with other information, provide evidence to define the factors impacting performance and costs, explain whether those factors are exogenous or not, compare their impact on London and Thames Water with other companies where they are and identify ways to mitigate them. We have drawn information from previous independent studies into London's network as well as comparisons with other UK water companies, international best practice and emerging pipe inspection technologies.

The findings from the investigations have been used to check that TW's plans for investing the conditional allowance monies account for the same factors in targeting investment. This is to give confidence that the plans can deliver their forecast performance. The findings are also being used to aid development of a long-term strategy (multi-AMP) to address the factors and improve the performance of London's water network at reduced cost over future years. They have also informed deliverables for Gate 2 of the conditional allowance such as the continuous improvement plan accompanying the asset management strategy.

1.4 Data sources

We have referred to a wide range of data sources, previous studies and reports. These are categorised by type in Table 1.1 and a full listing is provided in Appendix A.

Table 1.1: Types of data source used to support the investigations

Data source type	Relevance to workstream											
	a	b	c	d	e	f	g	h	i	j	k	l
Annual returns industry data share (tables)												
TW mains repair database (GIS database)												
Clean Water Asset Data (GIS database)												
Distribution mains Asset Investment Manager (AIM) model (database)												
Trunk mains inspection database												
BGS geohazard layers (GIS database)												

Data source type	Relevance to workstream											
	a	b	c	d	e	f	g	h	i	j	k	l
Network pumps and valves database (various files)					■			■				
TW EES cost models										■		
TW business plans and strategy documents			■	■					■		■	■
Investigative reports and tables (independent reviews and TW information)			■		■		■		■	■	■	
Various research reports (by others)			■	■	■	■	■			■		

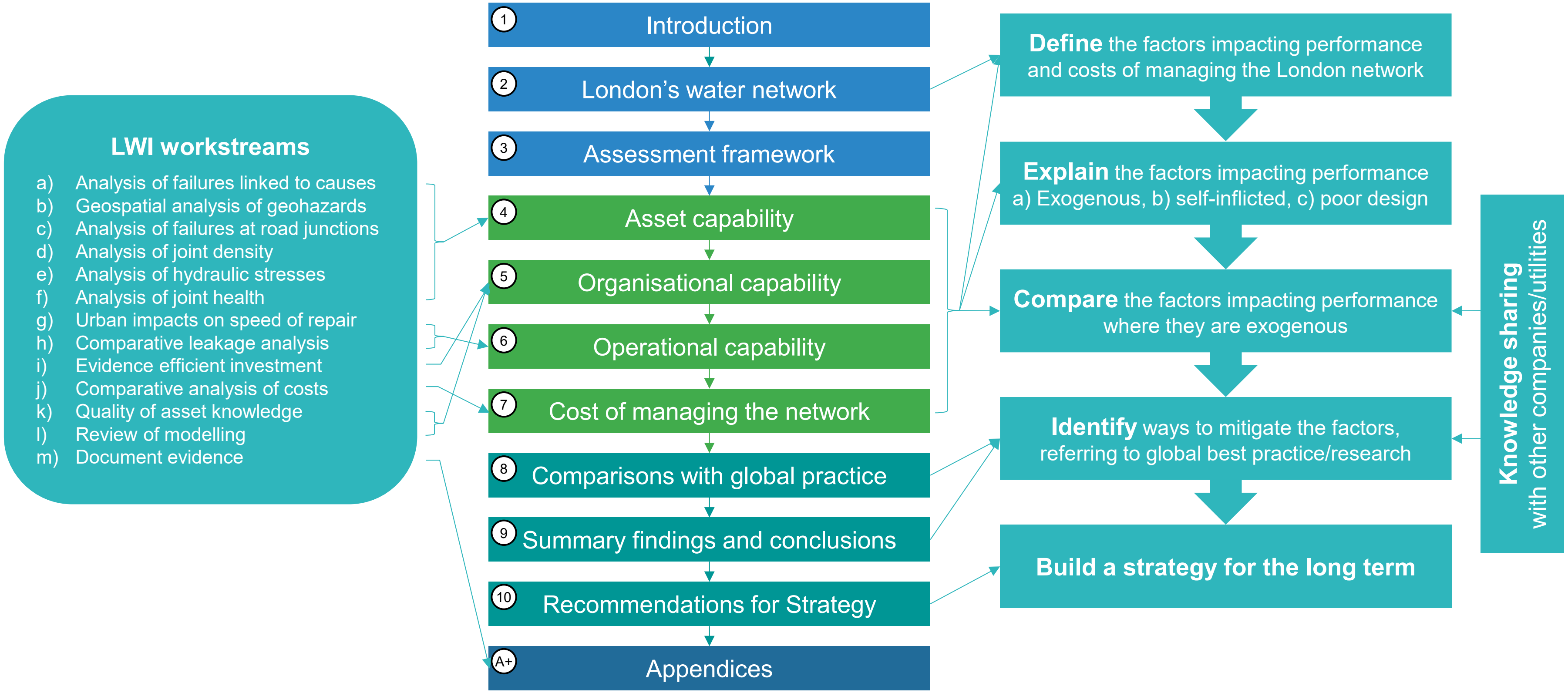
Notes: Data has been obtained from reliable third parties where it is assumed that the third-party has verified and assured it

1.5 Report structure

The report structure is shown Figure 1.2. It shows how the findings from the 13 workstreams feed into the ten chapters of the report and how those inform recommendations for a long-term strategy for London's water network.

There are three introductory chapters to the report (including this one). Chapter 2 describes London's water network and its current performance and cost challenges and Chapter 3 describes the framework that the report uses to assess and compare the factors affecting performance and costs. This is followed by four core chapters that assess and explain the capability of the assets, the organisational capability, the operational capability and the cost of managing the network. These chapters draw insights from the 13 workstreams and other data and evidence from previous studies. Chapter 8 then makes some comparisons with global practices in managing water networks before Chapter 9 uses the assessment framework to summarise the findings and draw some conclusions. Recommendations from the investigations to inform the strategy for London's water network are made in Chapter 10.

Figure 1.2: Report structure



Source: Mott MacDonald

2 London's water network

Chapter summary

This chapter describes London's water network and the performance and cost challenges that are the reasons for the investigations underpinning this report. It also describes the age and make-up of the current pipeline stock and how it has changed since 1990.

The purpose of this chapter is to set the scene and introduce the reader to the TW network, as this will help provide the background understanding required for later chapters of the report.

The key points to take away from this chapter are that:

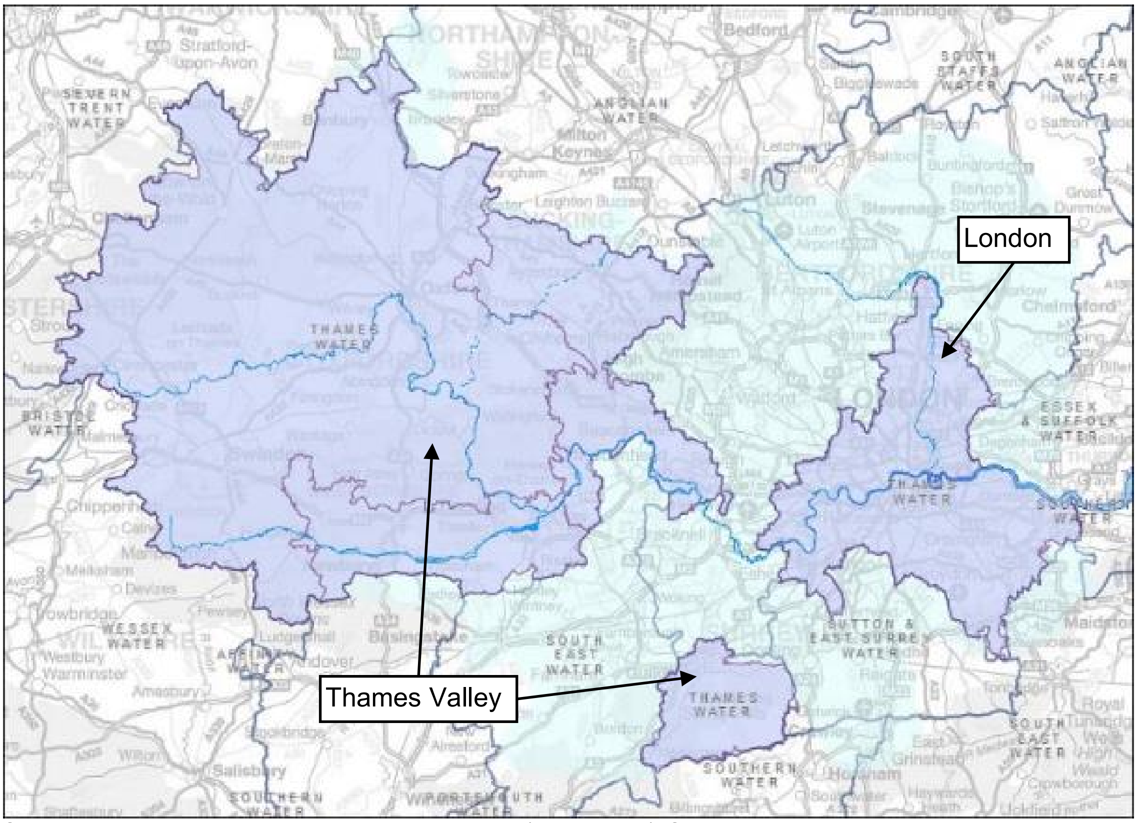
- TW's network is the oldest out of all UK water companies with a high proportion of cast iron pipes.
- The demand for water within TW's region continues to grow with an expected additional population of two million by 2045.
- London's water network in the western and central areas relies the Thames Water London Ring Main which provides redundancy and flexibility. In the east, the water network heavily relies on the old trunk mains network.
- TW have the worst leakage performance out of all UK water companies in terms of litres per property, or litres per kilometre of main.
- TW's London network has the highest burst rate per length of pipe.
- TW's interruption to supply is low for distribution mains as there is good interconnectivity allowing mains to be isolated and the repairs to be undertaken quickly. Trunk mains have a high interruption to supply as the repairs are more complex and isolation can be problematic.
- Pipe technology has changed significantly over the past 100 years, with better pipe materials, joints, and coatings being used on newer pipes.

2.1 The current London water supply network

Every day, Thames Water supplies its 10 million customers with approximately 2,600 million litres of drinking water, mainly sourced from the River Thames and River Lee as well as underground sources in the Cotswolds and Chiltern Hills. To deliver water to 3.8m households and 220,000 businesses, Thames Water operates and manages a large network of assets, which has been developed over 200 years.

Thames Water's supply area covers around 8,000 km^2 (Figure 2.1). The area is divided into six water resource zones (WRZs): London, Swindon and Oxfordshire (SWOX), Slough/Wycombe/Aylesbury (SWA), Kennet Valley, Guildford, and Henley. When this report refers to "London" in the context of the water network, it is primarily referring to the network encompassed within the London WRZ. All of the other TW WRZs are located outside of London and are collectively referred to in this report as the "Thames Valley".

Figure 2.1: The Thames Water area of supply and London water network



Source: Isle Mains Renewal Best Practices workshop (presentation), September 2020

Some key statistics on the asset base are shown in Figure 2.2.

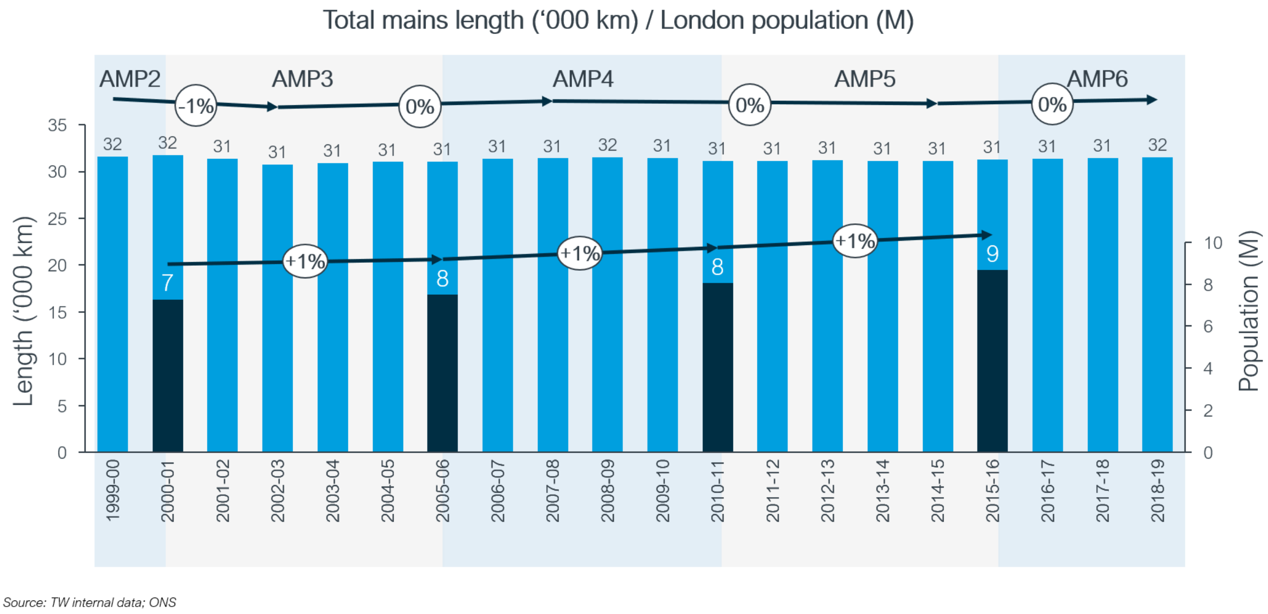
Figure 2.2: The Thames Water asset base – key statistics

Network hierarchy	6 WRZs	12 SSAs	238 FMZs	1,700 DMAs	4 million properties	10 million customers
Asset base	98 Water treatment works	489 Pumping stations (174 raw water, 315 treated)	31,624 km pipes (AR21)	351,639 valves	241 service reservoirs	3,257Ml storage volume in service reservoirs

Source: Based on Isle Mains Renewal Best Practices workshop (presentation), September 2020. Edited by Mott MacDonald for length of pipe.

The overall length of the distribution system has not changed markedly but the population and demand has steadily increased over time (see Figure 2.3).

Figure 2.3: Historic demand growth in London



Source: Isle Mains Renewal Best Practices workshop (presentation), September 2020

The overall length of pipe has remained relatively stable because although new lengths of pipe have been laid to serve growth areas, rationalisation of older pipe networks has taken place during pipe replacement programmes to offset this. The 31,624km of pipes in 2020 now serve a population that is over 30% higher than it was 20 years ago. This is set to continue. According to the forecast in the Water Resources Management Plan 2020 – 2100 (published April 2020), over 2 million more people will live within Thames Water's area by 2045, which is the equivalent of the whole population of Birmingham and Leeds moving into the area.

2.2 The ring-main and key trunk-main supply routes

The London WRZ is supplied primarily (80%) from the River Thames and River Lee via storage reservoirs. The quantities of water that can be abstracted from the River Thames depend on the relationship between the quantities stored in the reservoirs, the need to ensure a residual freshwater flow in the River Thames over Teddington weir, and the time of year. The remainder of supply is made up of groundwater abstractions, particularly from the chalk aquifer. In addition, the Thames Gateway desalination plant at Beckton can abstract and treat brackish estuarine water from the Thames Estuary.

Treated water is conveyed to an integrated distribution system, a key feature of which is the Thames Water London Ring Main which runs underneath central London and provides flexibility by connecting the Thames and Lee water supply systems (Figure 2.4).

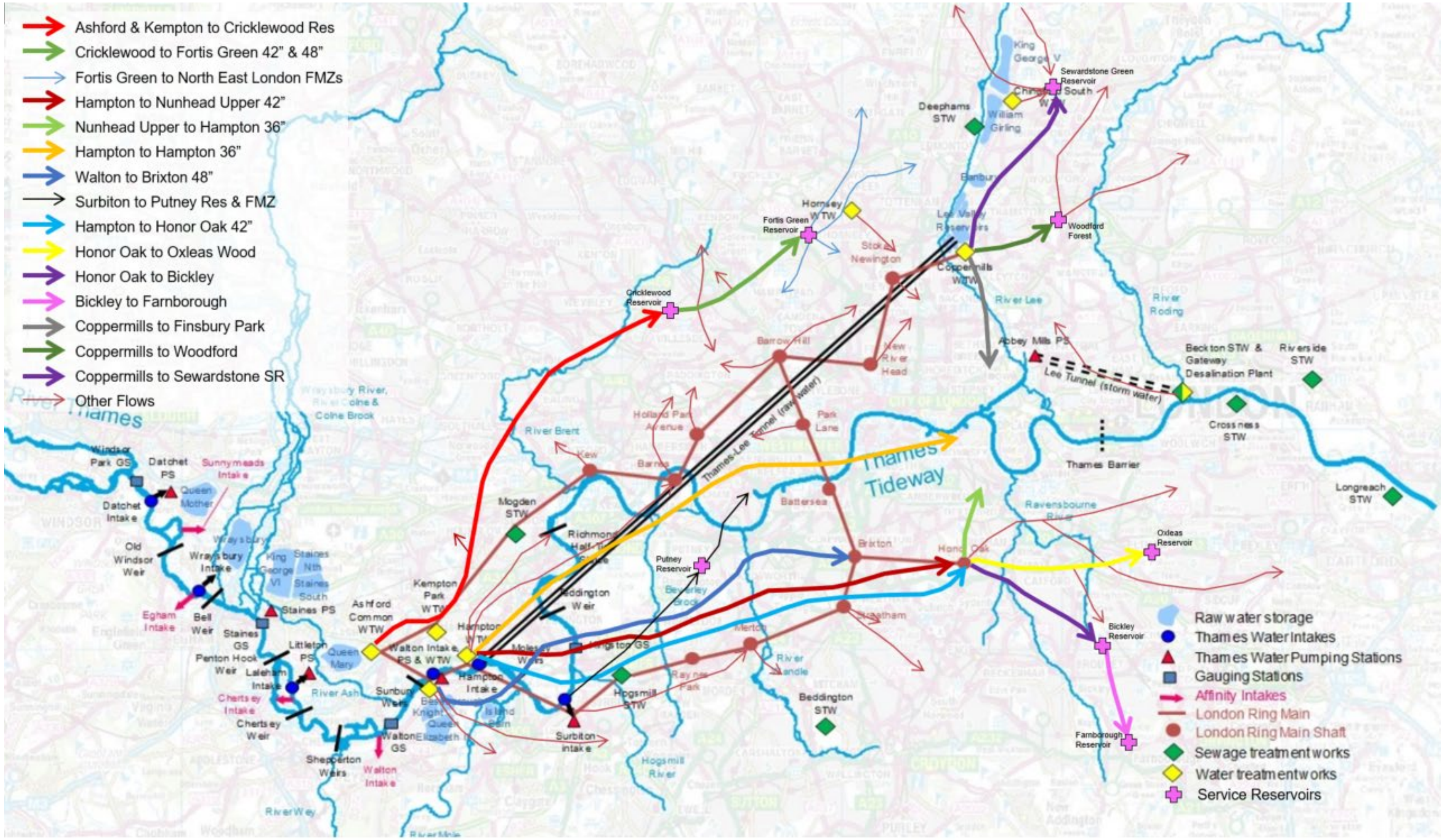
The Ring Main links the Hampton, Walton, Ashford and Kempton water treatment works (WTWs) clustered on the Thames upstream of Teddington Weir, and transfers treated water to the central London area. It also connects to Coppermills WTW in the north west with water being able to transfer both out of the ring main or into the ring main from Coppermills. The main loop was constructed between 1988 and 1994 to serve as an alternative transfer system to Victorian trunk mains suffering increasing leakage and bursts and an increasing demand. The Ring Main extended the operational life of the old high-level trunk mains by reducing the flow demands placed on them and by facilitating their isolation for maintenance through providing redundancy.

However, the London WRZ still relies on the old trunk mains network – especially the North East (NE) and South East (SE) regions which are not supplied by the Ring Main:

- The mains running from Ashford and Kempton to Cricklewood service reservoir (SR), and from there to Fortis Green SR
- The mains running from Honor Oak SR to several FMZs in the SE (eg. Oxleas Wood, Bickley and Farnborough)
- The mains running from Coppermills to Woodford SR and Sewardstone SR and feeding the NE region

In addition to the lack of redundancy in these areas, there is a forecasted water resource deficit driven by demand growth in the NE and by a lack of sufficient water resources in the SE, which is putting more strain on these assets. TW is developing strategies to address supply sufficiency and resilience and this work is outside the scope of this report.

Figure 2.4: The Thames Water ring-main and principal supply routes



Source: Thames Water WRMP19 Transmission Network Blueprint – London (Stage 2) (13 November 2017)

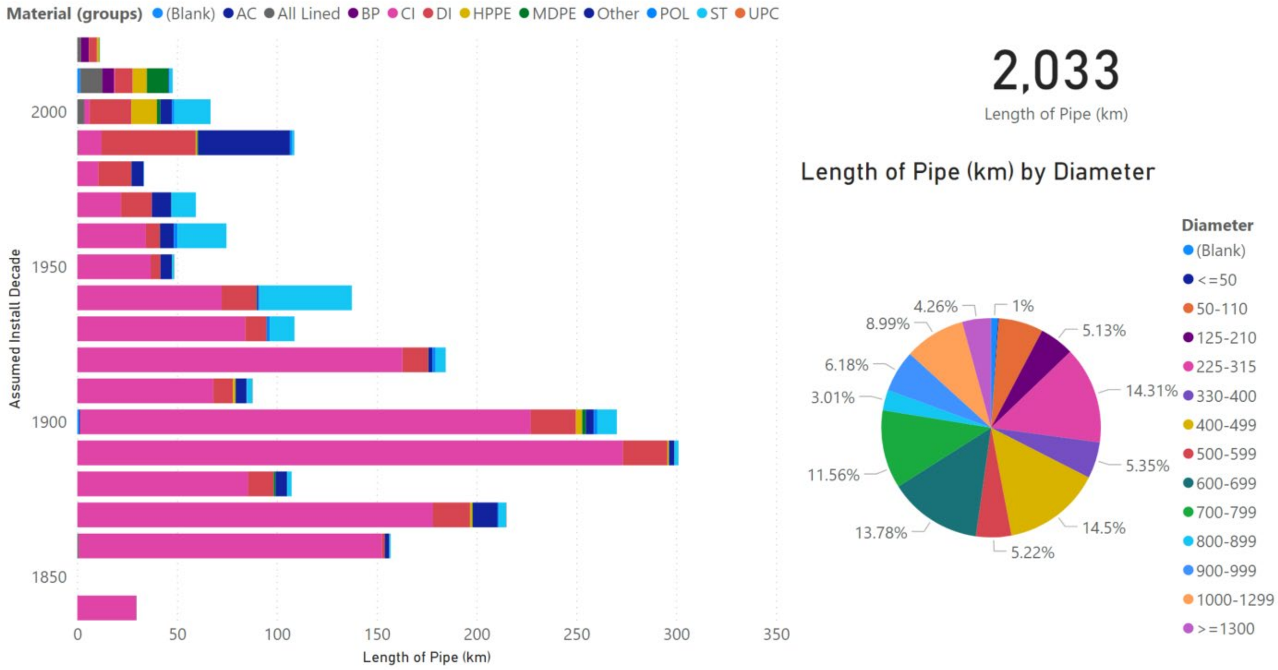
In TW's asset standards, a trunk main is defined as the following

Trunk mains are water mains which if they burst or become non-operational are likely to have an important and long-lasting impact on supplies or are capable of causing significant damage to people and/or property and include (but not limited to) the following:

- *Transfer mains, both gravity and pumps, irrespective of size, which move water from treatment works to service reservoirs or zones or between zones*
- *Principal mains, irrespective of size which move water between DMAs within zones*
- *Distribution mains of 200mm diameter or more in Western and 300mm diameter in London*
- *Raw water mains, pumped or gravity feeding reservoir or water treatment works.*

TW GIS asset records have been used to review the existing TW network. The existing trunk mains supply system in London is approximately 2,000km in length, which is one of the longest trunk main networks of all the companies in England and Wales. In addition, approximately 1,300km of that is older than 100 years old. The size of trunk mains varies between 12 inches (approximately 300mm) to diameters larger than 2 metres (see Figure 2.5). There are also some trunk mains within TW GIS which are shown as less than 300mm in diameter which presumably meet the trunk main definitions above. These smaller sizes are mainly principal mains.

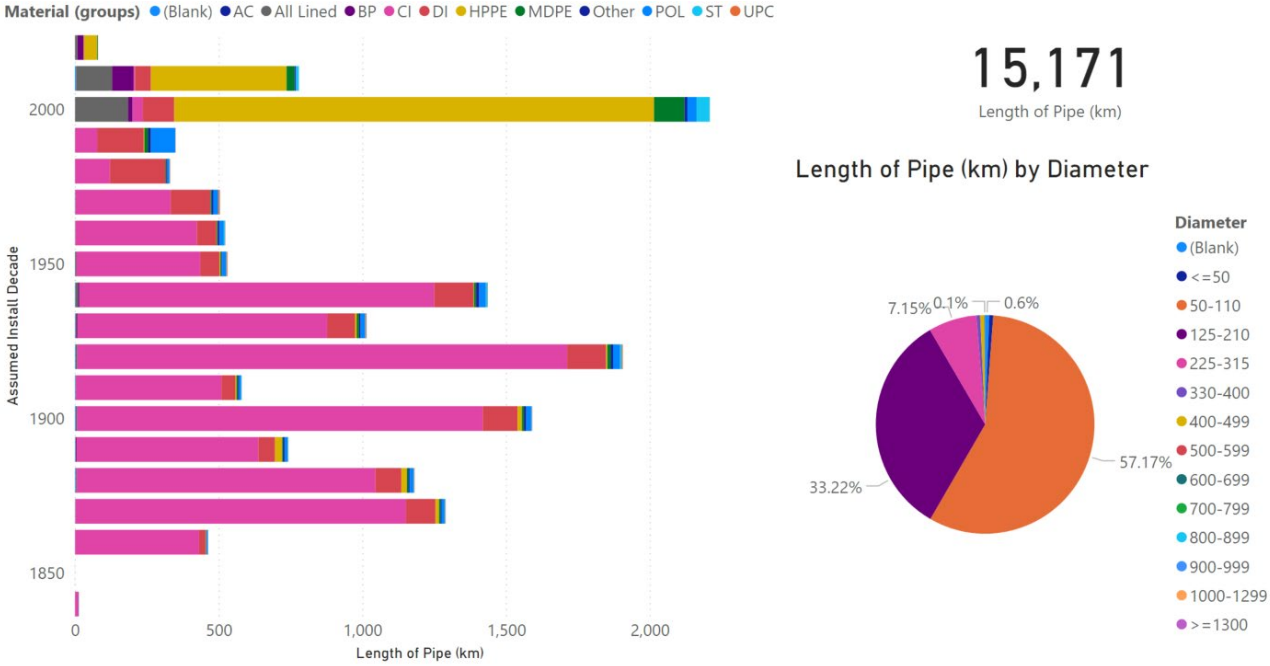
Figure 2.5: Key details of the Thames Water trunk mains system – London



Source: Mott MacDonald analysis of TW asset record GIS files

The water distribution system in London is split into multiple flow monitoring zones (FMZs) and district metering areas (DMAs). These zones are supplied either directly from water treatment works and trunk mains or via service reservoirs, which balance the fluctuating demand from the distribution system. London's water distribution pipe network is approximately 15,200km in length, consisting primarily of cast iron pipes, many of them over 100 years old (see Figure 2.6).

Figure 2.6: Key details of the Thames Water distribution mains system - London



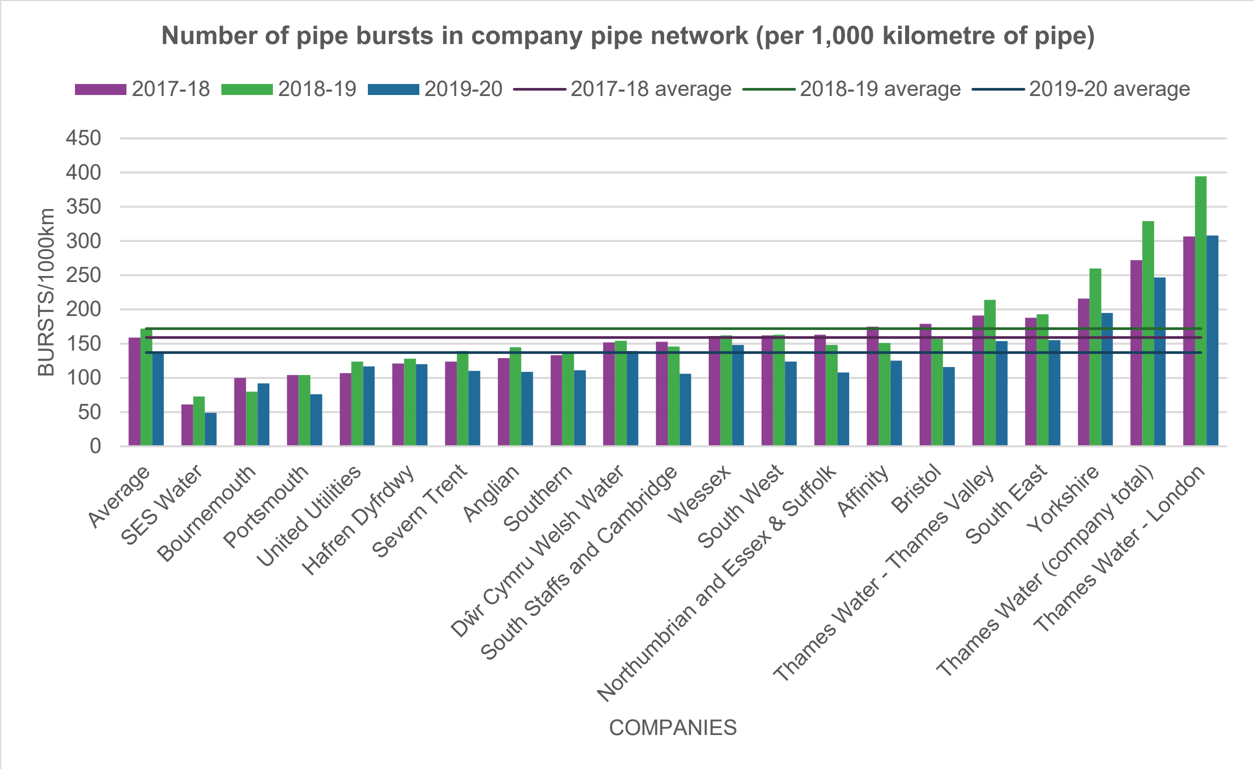
Source: Mott MacDonald analysis of TW asset record GIS files

From the GIS review, in the Thames Valley there are approximately 1,900km of trunk mains and 12,700km of distribution mains. In total the TW network length is approximately 31,624km as recorded in 2020.

2.3 Comparative performance of London’s water network

London’s water network is in much worse condition than other water supply networks in the rest of the country. This can be inferred by the underperformance in comparison to other water companies. The relatively older and poorer condition of London’s water network results in much higher numbers of bursts per km in London and for Thames Water as a whole than other companies, despite TW renewing or refurbishing pipes at a comparable rate to the rest of the industry (as shown later in this report). This is shown in Figure 2.7.

Figure 2.7: Comparative performance of London’s water network (bursts)



Source: discoverwater.co.uk
Thames Water Thames Valley / London figures based on Mains Repair Reporting (from Thames Water)

As can be seen from Figure 2.7, TW is an industry outlier for mains bursts in all the years shown. There is some natural variance in bursts between years for all companies, but 2017/18 and 18/19 stand out as poor years for many, including TW. This was likely caused by the so-called ‘beast from the east’, a severe cold weather snap in February 2018 which was followed by several other cold periods. TW’s network is particularly vulnerable to temperature changes and this shows in the 2018/19 performance. Rates of pipe failure, and the factors causing failures are analysed and explained in chapter 4 in detail.

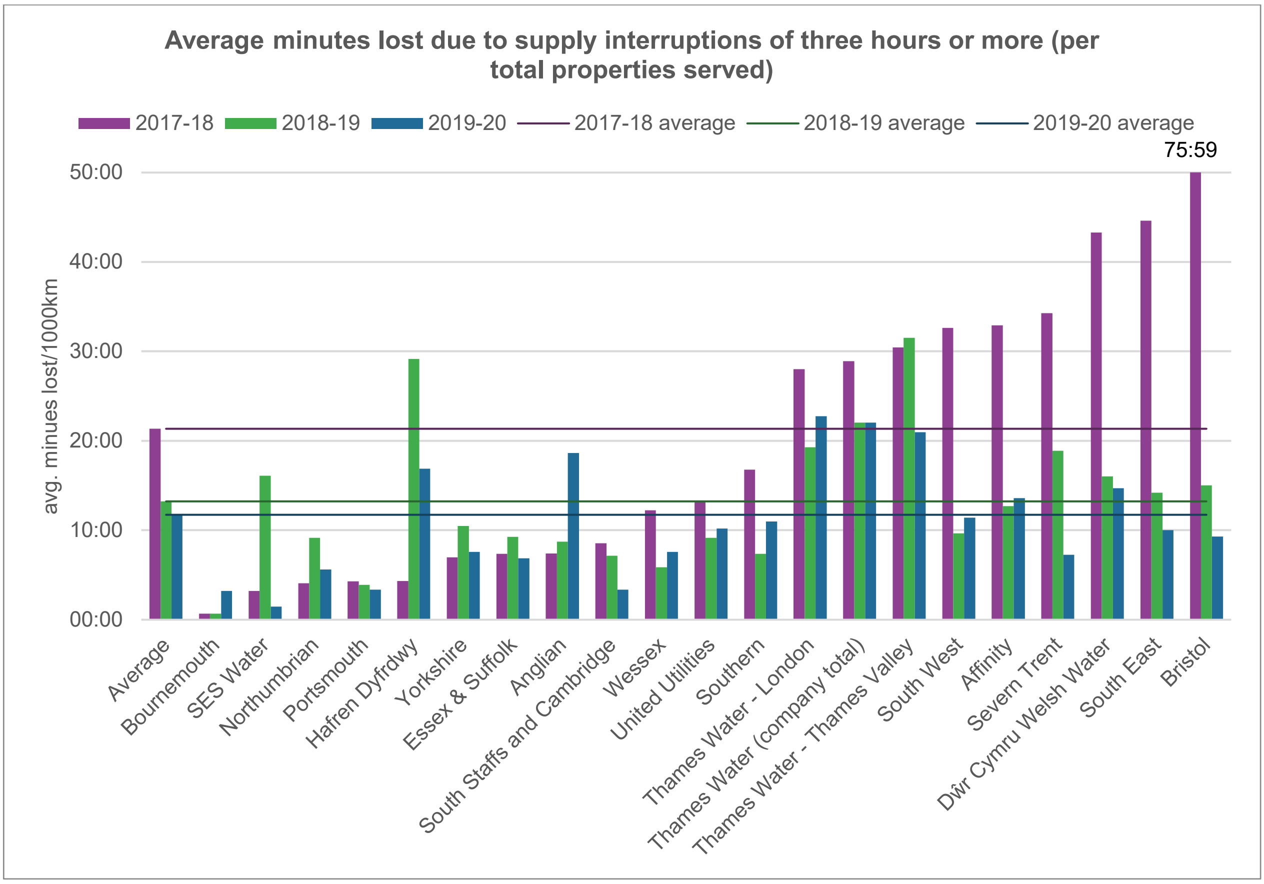
The poor condition of the network also results in higher leakage than other companies as shown in Figure 2.8. Although leakage has been falling recently, based on 2019/20 data Thames Water and London remain outliers compared with the rest of the industry. This is the case for both the m^3/km/day measure and the litres/property/day measure, although the high density of properties in London reduces the gap for the latter measure. It can be seen that TW’s leakage performance is the worst in the industry, 120% higher than industry average for the m^3/km/day measure and 36% higher than industry average for the litres/property/day measure. TW’s leakage performance is discussed in chapter 4 and chapter 6 in detail.

Figure 2.8: Comparative performance of London's water network (Leakage)

Source: discoverwater.co.uk

The poor condition of the network also impacts performance in controlling interruptions to customers' supplies, as shown in Figure 2.9.

Figure 2.9: Comparative performance of London's water network (Interruptions)

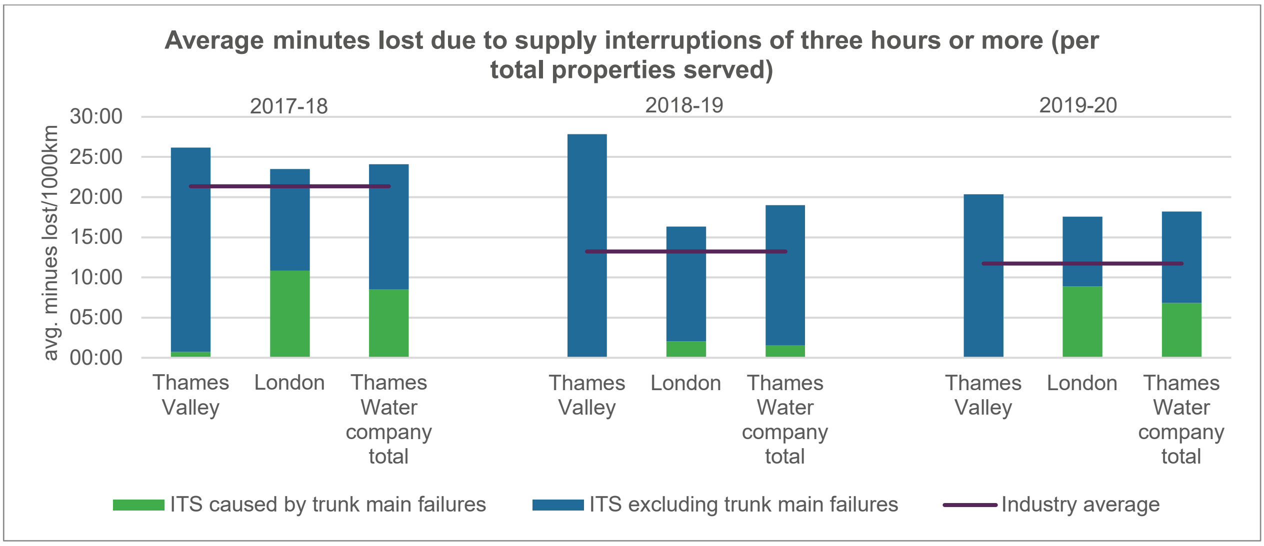


Source: discoverwater.co.uk
Thames Water Thames Valley / London figures based on Supply Interruptions Download and SI4 Calcs (from Thames Water)

Although TW's performance is consistently worse than average for the years shown, other companies have had bad years in which their performance was worse than TW's. This supports the observation that performance against this measure is sensitive to occasional failure of a relatively small number of events (e.g. trunk- main burst, unplanned outages at WTWs or pumping station, service reservoir drawdown etc.) that have a significant impact on many customers at once, sometimes for extended durations. Again, the impact of the 'beast from the east' weather event is apparent in the performance figures for many companies in 2017/18.

TW's trunk main network consists largely of old cast iron pipes and, like its distribution network, is vulnerable to periods of cold weather. This affects TW's interruptions to supply performance as these assets frequently cannot be quickly isolated, repaired and put back into service. To show that it is the performance of TW's trunk main network that is impacting its interruptions to supply performance, Figure 2.10 shows TW's performance for interruptions to supply if trunk main failures are excluded from the analysis.

Figure 2.10: Interruptions performance excluding trunk-main failures



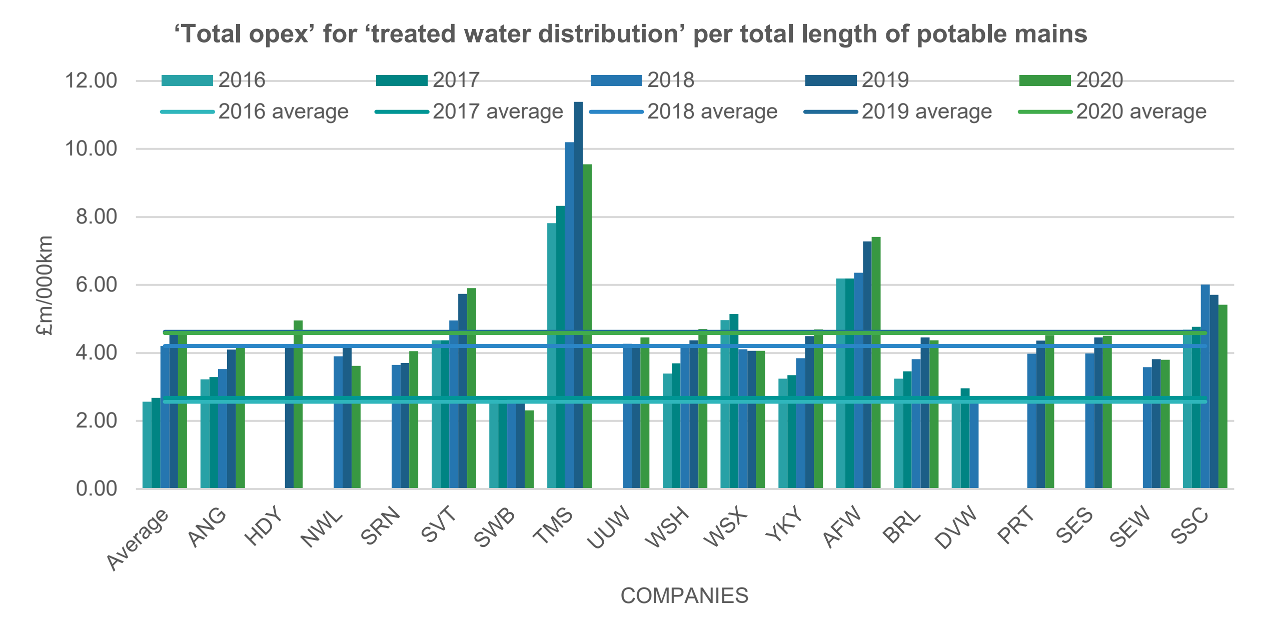
Source: Thames Water, Supply Interruptions Download and SI3 Calcs (from Thames Water)

This shows that barring the worst trunk-main failures, London's water supply has one of the best interruptions to supply performance. This shows that the London's water distribution network has good connectivity, enabling bursts to be isolated and repaired quickly and limiting interruptions to supply to a few hours in most cases. However, this contrasts with the trunk main network which cannot be isolated and repaired quickly and in too many cases interrupts the supply of many customers for extended durations.

Evidence of poor asset health, the factors causing it and the poor relative performance described above is given in Chapter 4 of this report.

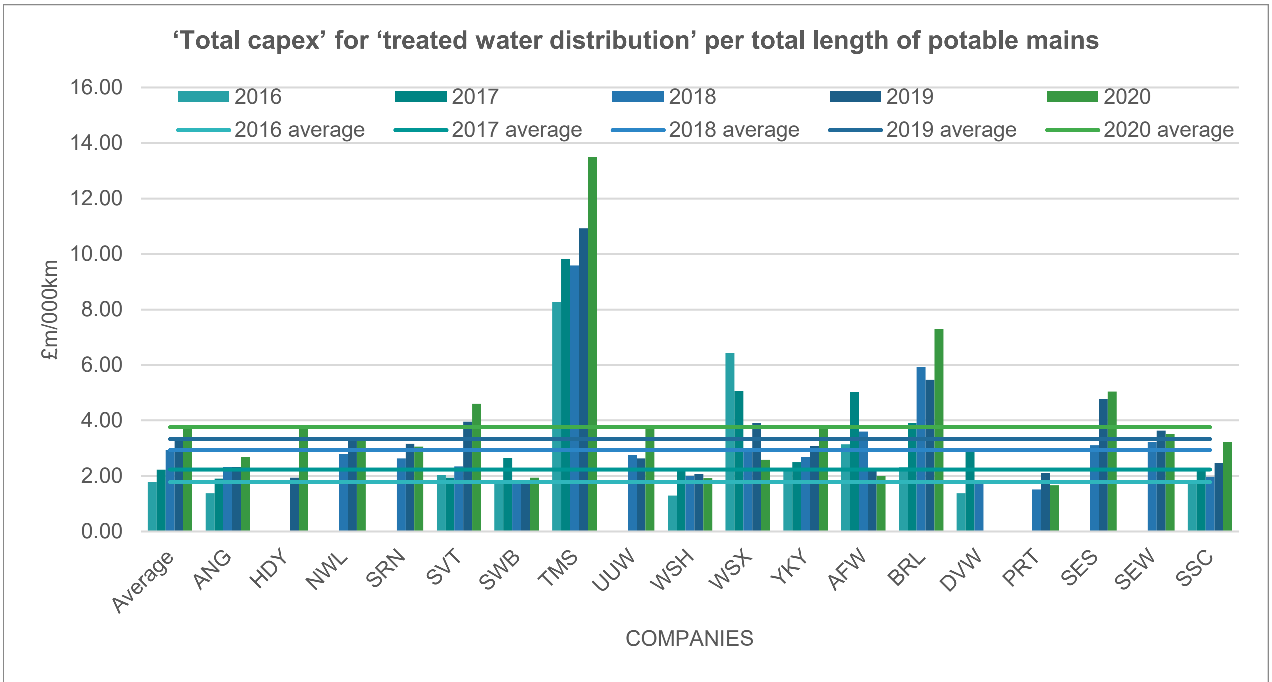
One of the consequential effects of the poor condition and performance of London's water network compared with other companies is that the cost of managing the London water network is higher than other companies, owing to the greater volume of repairs. This is evident in Figure 2.11 which compares reported operational expenditure on water infrastructure in AMP6 per 1000 km of pipe (where Thames Water is shown as TMS). Figure 2.12 compares capital costs on the same basis.

Figure 2.11: Comparative opex for water infrastructure



Source: APR data-tables for 2015/16 to 2019/20 (opex for treated water distribution Table 4J, mains length Table 4P)

Figure 2.12: Comparative capex for water infrastructure



Source: APR data-tables for 2015/16 to 2019/20 (Totex for treated water distribution Table 4J, mains length Table 4P)

Figure 2.11 and Figure 2.12 show that for both opex and capex, TW's costs in AMP6 were much higher per unit length of pipe than any other company, 100% higher for opex and 200% higher for capex. Interestingly in Figure 2.11, the next highest opex company is Affinity Water, who also incur above-average costs and they also manage part of their network in north west London, experiencing some of the same issues.

It is easy to understand from Figure 2.11 and Figure 2.12 why Ofwat might consider TW to be inefficient in managing its water infrastructure costs and clearly it is important to understand why TW's costs are so much higher than other companies. This question is explored in Chapter 7: Cost of managing the network and although AMP6 costs were atypically high, the conclusion is that the poor condition of London's water network is a key causal factor in TW's comparatively high costs.

This report will also show that the effort and expenditure required to sustain a level of network performance in London that is acceptable to customers is unsustainable and inefficient in whole-life cost terms if TW continues to manage the network in its current condition. The oldest and poorest performing parts of the network need to be gradually renewed to restore a cost-efficient balance between repair and replacement.

Further evidence of the increased costs of managing the London water network, as described above, and some observations on a more efficient whole-life cost position are given in Chapter 7 of this report.

2.4 Historical development of the network and current pipeline stock

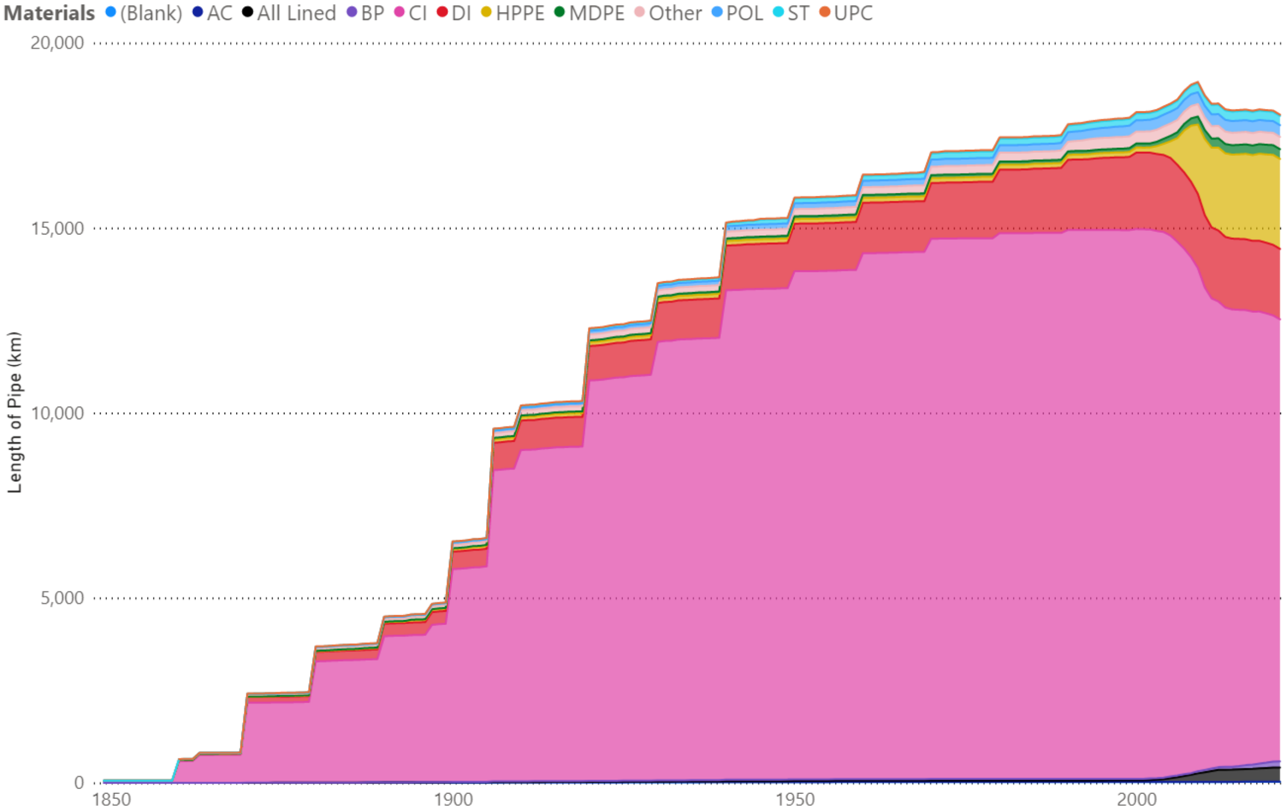
London's water supply system has been developing for centuries, but very little of it predates the great fire of London in 1666 because, being constructed of wood and lead before that date, most of it was destroyed in the fire. Many private water companies were established across London in the eighteenth and nineteenth centuries and these were subsequently nationalised in 1903 to form the Metropolitan Water Board, the predecessor to Thames Water Authority and then Thames Water. The infrastructure that Thames Water manages today includes many of the pipes originally built by those private water companies in the nineteenth century. The oldest pipes recorded on TW's asset register date back to 1800.

Figure 2.13 shows TW's pipeline stock as it exists today, including many pipes from the 1800s. This does not show how the network evolved as it does not include the pipes installed in the 1800s or earlier that were subsequently replaced or abandoned. Retention of records of abandoned pipes only started 30 years ago.

Figure 2.13 shows that the majority of TW's pipes are cast iron, many of them laid in the 1800s and early 1900s. Ductile iron became the preferred material for new pipelines from the 1960s but cast iron remained the dominant material in use as it does today. Plastic pipes (PE) have only been introduced in recent decades and this has resulted in a change in the TW's asset stock in the last 30 years. Such is the length of cast iron pipe however, it remains the dominant material in use today, predating privatisation in 1989.

There is some uncertainty about the precise install date for the older pipes in TW's asset stock. Many are allocated to the most appropriate decade in TW's GIS database. This explains the steps in pipe-length shown in Figure 2.13.

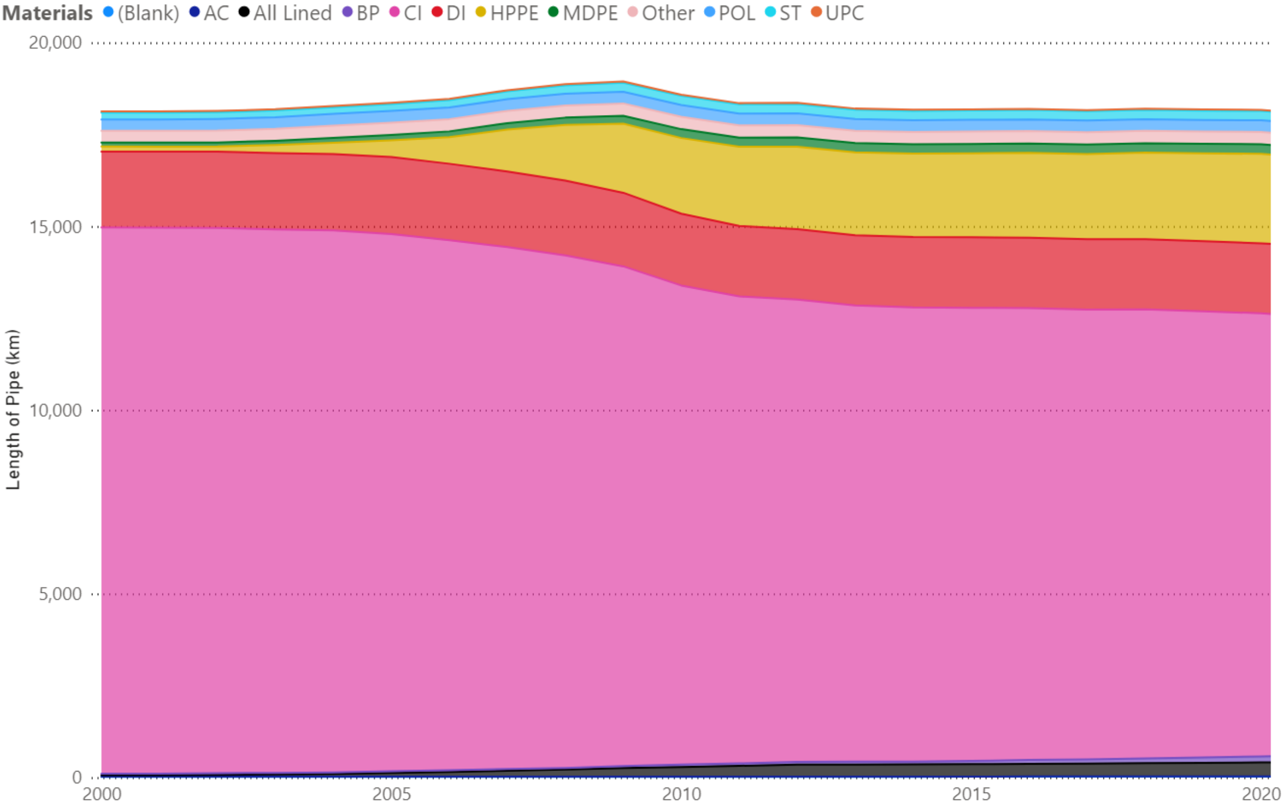
Figure 2.13: Length of pipe (km) by material and age in TW's asset stock for London



Source: TW GIS database and TW GIS data CW asset data processed in PBI

Figure 2.14 shows the impact of pipe renewals in the last 20 years on the pipe stock in London.

Figure 2.14: Pipe stock by material in London since 2000

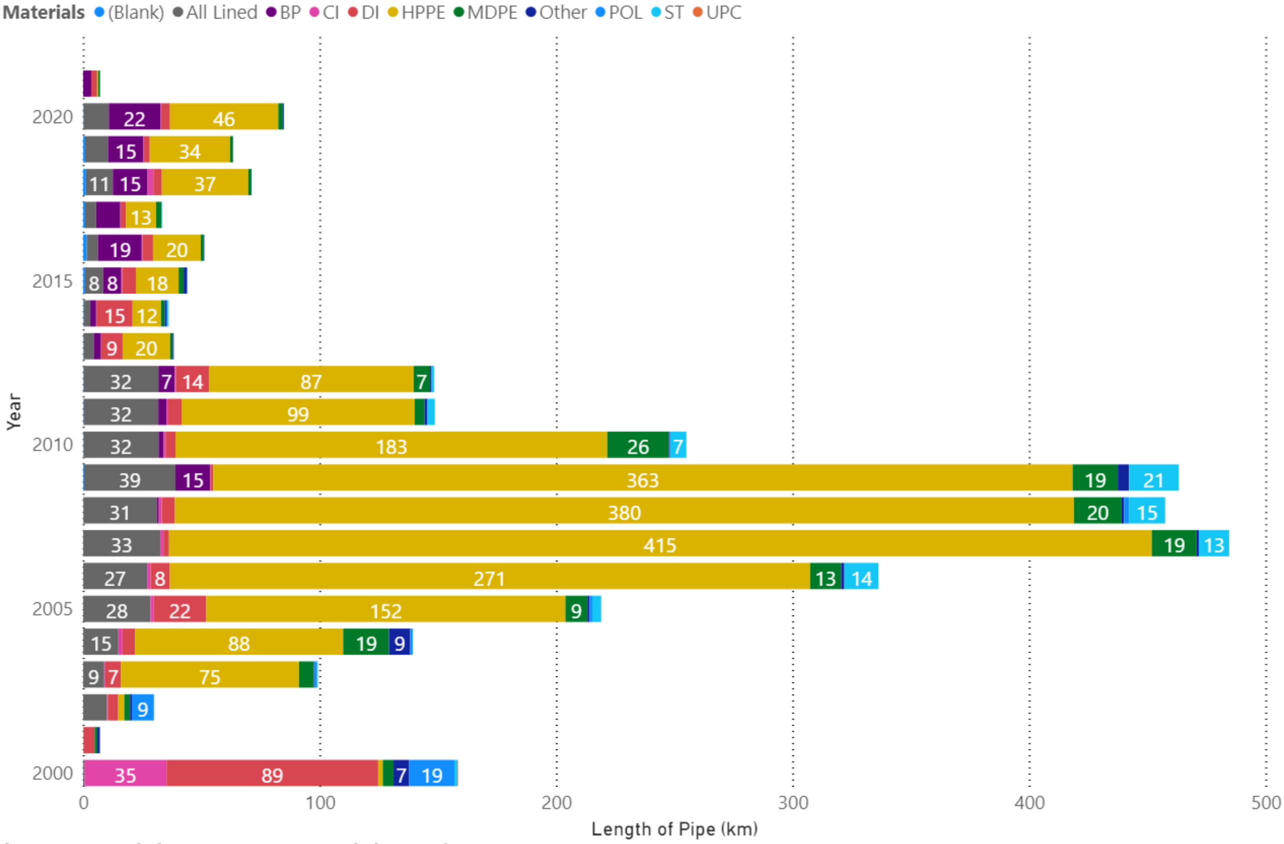


Source: TW GIS database and TW GIS data CW asset data processed in PBI

Figure 2.14 shows that since 2005 the proportion of the pipe stock in London that is cast iron (shown in pink) has decreased as it has been replaced by primarily HPPE pipes (shown in cream). This reflects the effect of the Victorian Mains Renewal (VMR) programme in AMP4 (2005 to 2010) in which whole DMAs of cast iron pipes in the worst condition were replaced in North and South London with HPPE pipe. Ductile iron is the other significant pipe material (shown in purple) with smaller quantities of MDPE, AC and PVC. The length of cast iron pipe in London has reduced from 15,000km to 12,500km. The overall length of the TW network also reduced during the VMR period as design rationalisation took place.

Figure 2.15 shows the length of new pipes and their materials laid each year since 2000. This shows that a much greater length of pipe was renewed in AMP4 under the VMR than has been replaced since in AMP5 and AMP6. Most of the pipes laid were HPPE and this material is also used to line some cast iron pipes. Smaller quantities of MDPE and steel pipe were also laid.

Figure 2.15: Length of pipe (metres) installed in London since 2000



Source: TW GIS database and TW GIS data CW asset data processed in PBI

In total, based on the data available, 3,501km of pipe (primarily HPPE) has been installed in London since privatisation is still in use, which represents 19.3% of the current pipe stock . This means that 80.7% of the current pipes in London were installed before privatisation. Pipe renewal rates, and their impact on performance are discussed in chapter 4 and chapter 5 in detail.

The majority of London's water mains are made of ferrous materials, predominantly cast iron, but also spun iron and more recently ductile iron. Manufacturing methods and the standards governing manufacture and jointing methods have evolved over the decades and have had an impact on the properties and features of the pipes.

Early cast iron pipes (pre 1850s) were manufactured using a horizontal casting process with the lengths limited to approximately 4-5ft. The horizontal casting process relied on an internal sand baked core with iron rod reinforcement to form the mould for the surface of the pipe inner circumference. The cores would support their own weight in the manufacturing process, and any bending of the core would cause an uneven pipe wall thickness – a common defect in many pipes of this age. The manufacturing process was improved in the 1850s with the introduction of a vertical casting method which became the predominant method of manufacture. The improved process allowed the manufacture of longer pipe lengths (9-12ft), but some issues with uneven wall thickness were still present as the central mould was not always placed centrally. The process was standardised in 1917 with the introduction of BS 78 – specification for cast iron pipes and special castings for water, gas, and sewage. In the 1920s a new centrifugal casting method was introduced whereby the pipe was manufactured within a spinning mould, bringing about the term spun iron. The method of centrifugally casting is still in use today for ductile iron pipes, albeit with improved manufacturing processes, machinery, and quality control.

Despite the introduction of the centrifugal casting method in the 1920s, the metallurgy of the molten grey iron remained the same and therefore spun iron between the 1920s and 1960s still maintains many of the material properties of cast iron. In the 1960s, ductile iron was introduced and became the preferred material and is still used today. Today, manufacture of ductile iron pipe is in 5-6m lengths as set out in BS EN 545.

Pipe protection measures have also developed over time. Many older cast iron pipes were uncoated and as a result suffered from corrosion issues, and in particular internal tuberculation which effected hydraulic capacity. In 1874 Dr Robert Angus Smith developed a method for internal lining of water pipes using coal tar, and this was specified in the 1917 version of BS 78. However, over time the water penetrated the tar coating and tuberculation ensued. Modern day ductile iron pipework uses a zinc external coating and cement mortar lined internal coating. The first cement lined cast iron pipe was used in the USA in 1921, however coal tar coatings and linings still featured heavily throughout the century. Even the early standards for ductile iron pipes from BS 4772-1971 allowed the use of coal tar coatings and as a result these coatings have been used up until as recently as the 1980s.

Further to pipe advancements, jointing technologies have changed significantly in the last 250 years. The first major advancement came in 1785 with the invention of the bell and spigot joint which was used extensively up to the 1950s. The joint void was typically stuffed tight with a fibrous material such as jute, and then caulked or hammered with molten lead to form a tight seal within the belled-out end. The method was an improvement on previous jointing techniques and allowed flexibility and movement within the joint. However, today many of these joints suffer with lead protrusion which is a common source of leakage in the water distribution network.

In 1956, a new joint was developed, referred to as the push-on-joint, which was a major advancement in joint technology. The joint utilises a rubber gasket within the belled-out end which compresses when joined to form a tight seal. The push-on joints are quicker and easier to install on site, they remove the element of human error involved in lead packing a bell and spigot joint, and have proved to provide strong resistance against leakage, even at high water pressures.

As a result of the age of TW’s pipeline asset stock, many of the pipes which are still in use today were installed before advancements in manufacturing processes, improvement in material selections, changes to joint technology and also industry standardisation. The impact of this is discussed later in the report in chapter 4 by comparing against failure rates.

3 Assessment framework

Chapter summary

This chapter describes an assessment framework for describing the factors impacting the performance and cost of managing London's water network. It sets out a need to adopt a holistic approach that considers organisational and operational capabilities alongside those of the assets and the factors that affect them.

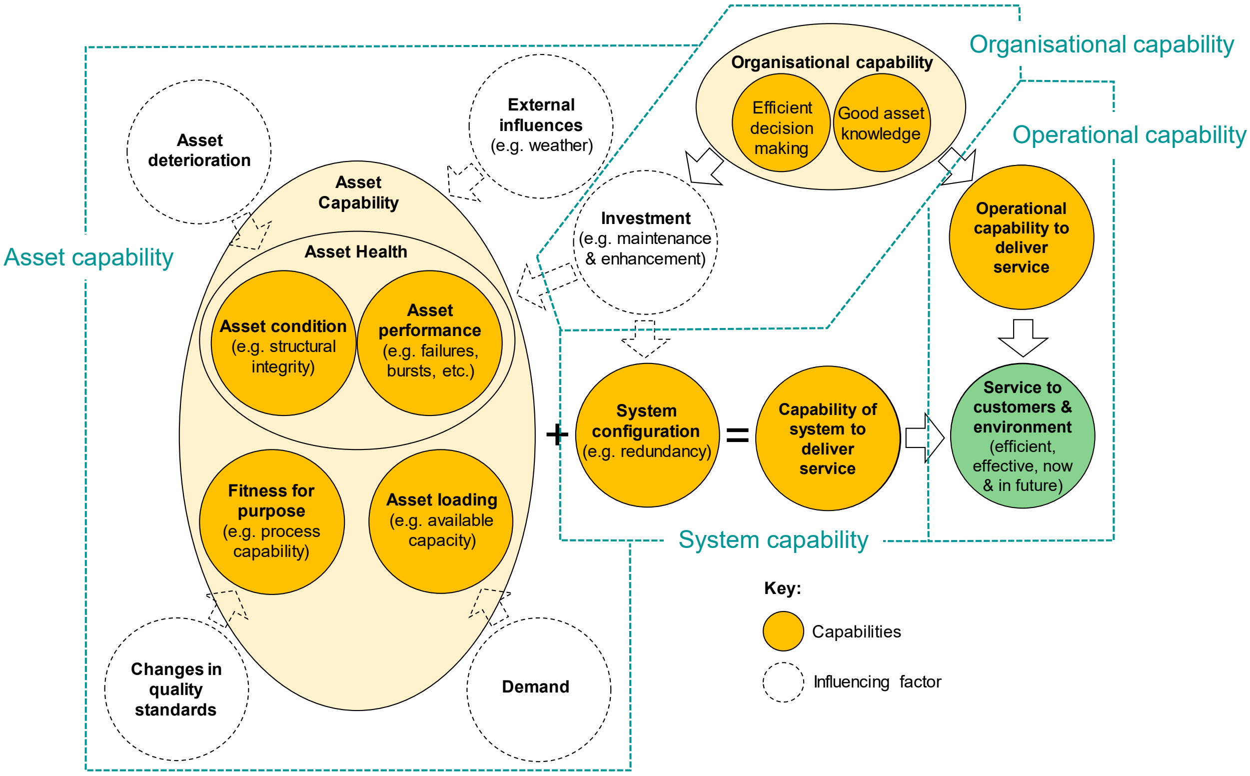
The purpose of presenting the assessment framework in this chapter is to introduce the reader to the concept of the framework and how it is used to assess the capabilities and factors that are influencing the performance of London's water network. The framework will be used to strengthen evidence to support the need for investment and to inform strategy. Part of the assessment will involve a comparative analysis which is important for determining what TW can and cannot control through better management of the network.

3.1 Asset and organisational capabilities driving performance and cost

Managing the costs, asset health, performance and customer service for a water network is complex with many interrelated processes, some of them within the water company's control, some of them not. To avoid focusing on some factors and excluding others in understanding what is driving performance and cost in London's water network, we have used an assessment framework based on a diagram from a 2012 UKWIR report on serviceability[4] - see Figure 3.1. Mott MacDonald were the authors of this report.

[4] UKWIR, Serviceability methodologies (12/RG/01/4), 2012

Figure 3.1: Capabilities driving performance and cost



Source: Mott MacDonald, based on UKWIR, Serviceability methodologies (12/RG/01/4), 2012

Figure 3.1 illustrates the capabilities required to deliver services to customers, comprising individual asset capabilities, system capabilities, organisational capabilities and operational capabilities. A weakness in any of these capabilities places service and/or efficiency in jeopardy. Clearly weak asset capabilities caused by poor asset health will affect asset performance directly, and may also affect customer service if system and operational capabilities are insufficient to respond effectively to mitigate the consequences. In addition, poor organisational capability resulting for example, from weak information, may prevent the efficient investment decisions required to improve asset or system capability, and poor operational capability may affect service to customers even if the assets themselves are capable. The objective is to achieve a good balance of capabilities to deliver effective and efficient services to customers.

Figure 3.1 also identifies a number of factors that affect capabilities over time, both positively and negatively. These factors cover many of the areas of interest for this report, such as asset deterioration, external influences beyond the company's control and decisions to invest in the assets to counter these effects.

We have used an expanded version of Figure 3.1 to document and assess the factors affecting management of London's water network that have emerged from the investigations listed in Chapter 1 and other evidence.

3.2 A framework for structuring the findings and guiding the strategy

The framework in Figure 3.1 provides a means of structuring the findings from this report and guiding the strategy. By showing the linkages between assets, capabilities, decisions and customer service, the framework shows that to understand and manage the drivers of performance and cost one needs to:

- Take a holistic approach, not just focus on assets and asset health
- Recognise the dependency with organisational capabilities – today's circumstances arise from yesterday's decisions
- Recognise that a wide range of factors influence network performance and management, some of them exogenous and some of them within management control. The problem is complex and multi-faceted.

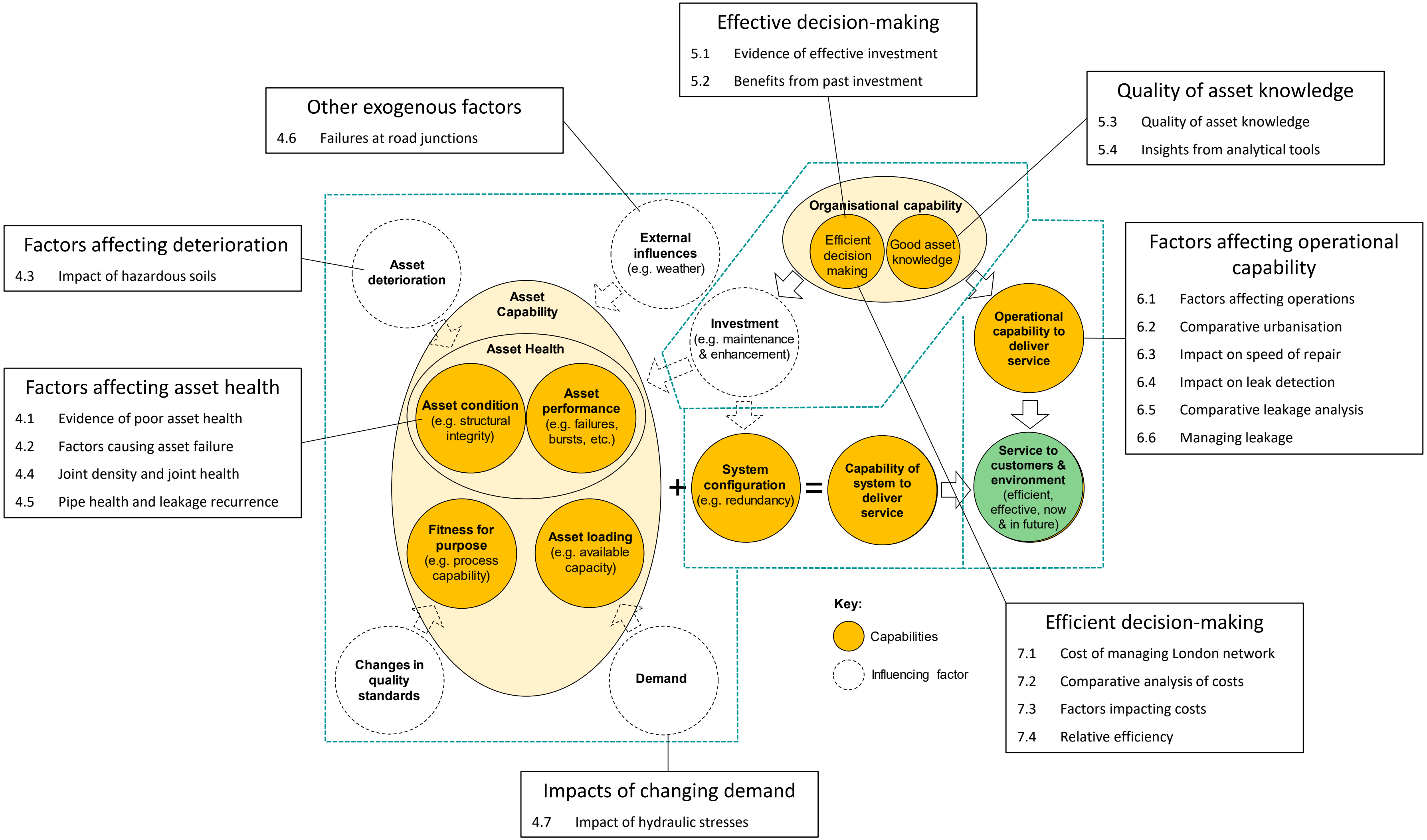
This report therefore uses the framework to a) document the evidence and findings and b) inform the strategy. Note that we have specifically excluded assessment of system capabilities in this report. The development of system capabilities overlaps with water resource planning, and planning for growth and resilience. These are the subjects of other TW programmes of work and will be reported separately.

Using the framework described above, Figure 3.2 presents a summary of the factors which influence the performance and costs of managing London's water network and the chapter sections in this report which investigate and evidence them. The list of factors is based on prior evidence and documentation, consultations with TW staff and our wider experience of good industry practice. This report expands on each of the factors and assesses whether:

- There is good evidence that the factor applies to and impacts TW's network operations in the London area,
- There is good comparative evidence that the factor affects TW more than other companies and places it at a disadvantage
- Further study or investigations are required to support these conclusions.

The primary purpose of the assessment framework is to assess the capabilities and factors that are influencing the performance of London's water network to strengthen evidence to support the need for investment and to inform strategy. The comparative analysis is important context for this in determining what TW can and cannot control through better management of the network.

Figure 3.2: Factors influencing the performance and cost of managing London's water network



Source: Mott MacDonald, based on UKWIR, Serviceability methodologies (12/RG/01/4), 2012

4 Asset capability

Chapter summary

This chapter identifies the factors affecting asset capability in London's water network, the evidence supporting their inclusion in the analysis and what they mean for the strategy going forward. We also compare the factors affecting London's network with networks in other parts of the country and assess Thames Water's ability to control them.

The key topics presented in this chapter are briefly summarised below:

- Factors impacting performance
  - Evidence of poor asset health include: high number of reported leaks; pipe samples show heavy corrosion with through-wall corrosion in many cases; lead-pack joints on many older cast iron pipes have become locked; high leakage recurrence in the worst performing DMAs; network responds poorly to periods of cold or dry conditions.
  - London's network has several factors affecting pipe deterioration including: a high proportion of cast iron pipes – a high percentage of which are installed in corrosive soils or soils susceptible to shrink swell; a high proportion of older pipes, many of which installed pre-standardisation; high number of pipe joints and connections; diurnal pressure variance exceeding 25m; occurrence of transients in the network during normal operation.
  - Other factors affecting asset capability include: drops in water temperature during cold weather; changes in soil-moisture deficit lead to shrink or swell effect; high density of utilities results in more street-works activity; London's streets experience the highest traffic flows in the country resulting in high vehicle loading; London has the highest number of road junctions per km of road in the UK and this is where vehicle loading is most acute through acceleration and braking forces.
  - Demand-related factors affecting asset capability include: London has experienced higher demand growth than anywhere else in the country, TW experiences nearly twice the hydraulic load any other water company; the flat topography leads to a high level of pumping which may lead to surge and turbulence in the network.
- Comparing the factors impacting asset capability
  - A comparative analysis of a selection of these factors shows that the main exceptional and foundational issue is the material and age profile of the asset base, the scale and age of which marks London out from other networks.
  - This situation is likely to deteriorate as the assets age further and increased customer expectations and demands are placed upon them.
- Mitigating the factors impacting asset capability
  - We present several ways in which the above factors could be mitigated. The suggestions relate to: corroded cast iron distribution mains in aggressive soils; joints and connections; pipe wall thickness of trunk mains; hydraulic factors; weather resilience; street works disturbance; traffic loading at junctions; demand factors.
- Priority actions for sustained improvements in asset capabilities
  - We have suggested priority actions to improve asset capability along the following headings: tactical interventions; long-term strategy; network policies; improving asset knowledge; targeted investment; calming the network; improving hydraulic efficiency; driving innovation.

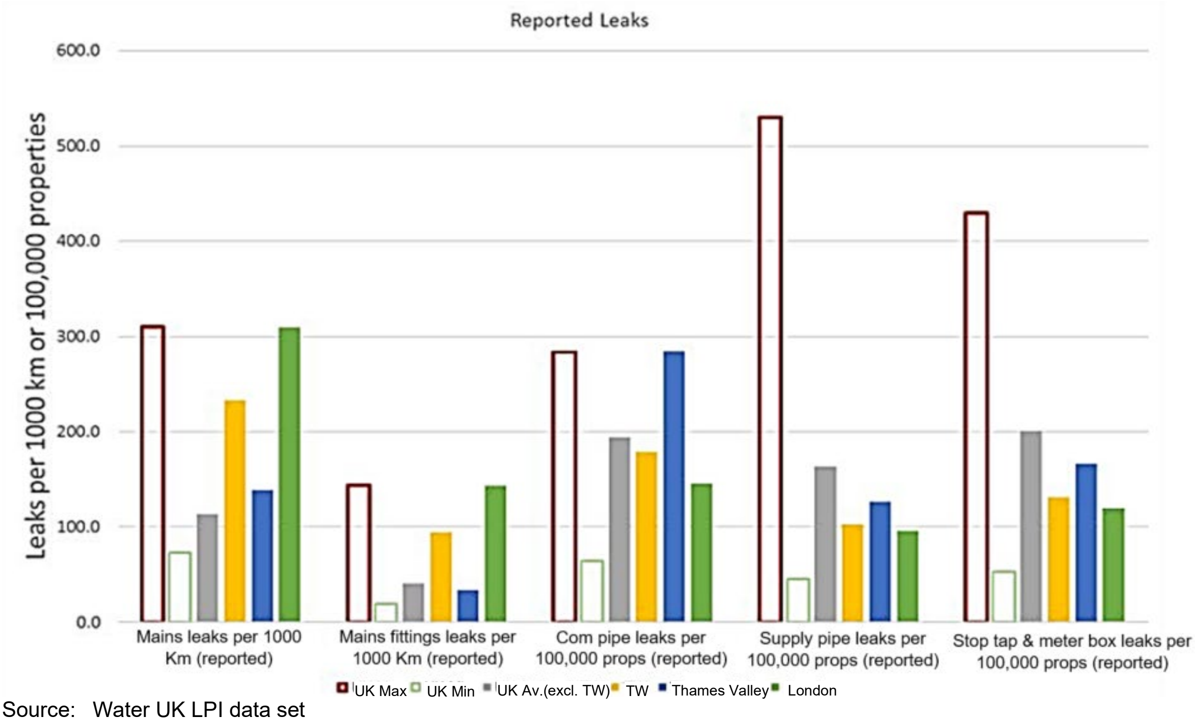
4.1 Evidence of poor asset health

There is good evidence that TW's water network assets are in poor health compared with England and Wales as a whole. This is evident against a range of dimensions, including high relative burst numbers and high leakage breakout numbers.

Figure 2.7 in Chapter 2 shows the high relative burst numbers. TW has the worst performing network against this measure, having burst numbers that are 80% higher than the industry average based on results for 2017/18, 2018/19 and 2019/20[5]. The next worst company has burst numbers that are approximately 40% above average, making TW an outlier.

Figure 4.1 shows the average number of reported leaks for mains, fittings and service pipes based on Water UK Leakage Performance Information (LPI) data[6]. Reported or visible leaks are repaired following a report of a visible leak by a customer, member of the public or water company staff. Reported leaks reflect the state of the network and are not biased by leak detection effort.

Figure 4.1: Comparison of reported (visible) leaks by category



Source: Water UK LPI data set

Figure 4.1 shows that London experiences the highest number of visible leaks on mains and fittings when expressed in per 1000 km terms, at approximately three times the average for other companies. Thames Valley is closer to the industry average but the value for TW as a whole is still twice the industry average for mains and fittings. The poor performance of London's water network is not therefore offset by the better performance of the Thames Valley network. The number of leaks on communication pipes, customer supply pipes and stop taps are more in line, if not slightly less, than industry averages.

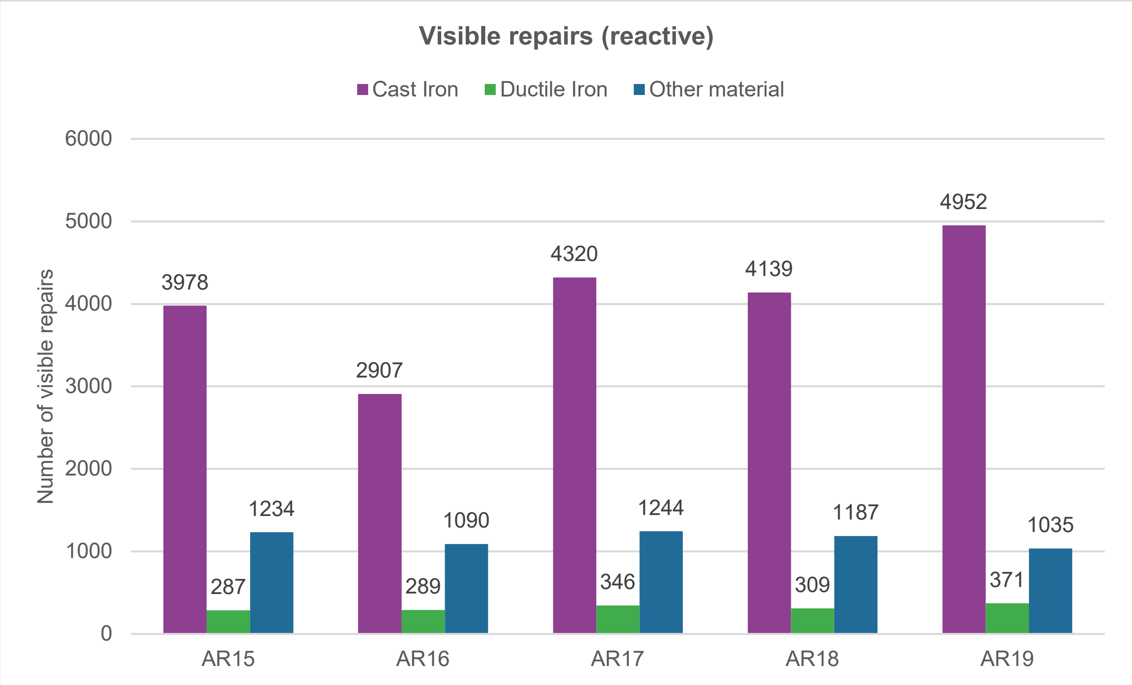
Analysis of TW's reported (visible) leak repairs show that the majority of repairs occur on cast-iron pipes as shown in Figure 4.2. Cast iron is the predominant material in TW's area and is also

[5] Based on figures published at www.discoverwater.co.uk

[6] LPI data are reported by companies to Water UK on a voluntary basis and Water UK share collated industry data amongst members. The LPI dataset here covers the years 2003/04 to 2013/14 when companies stopped reporting the data

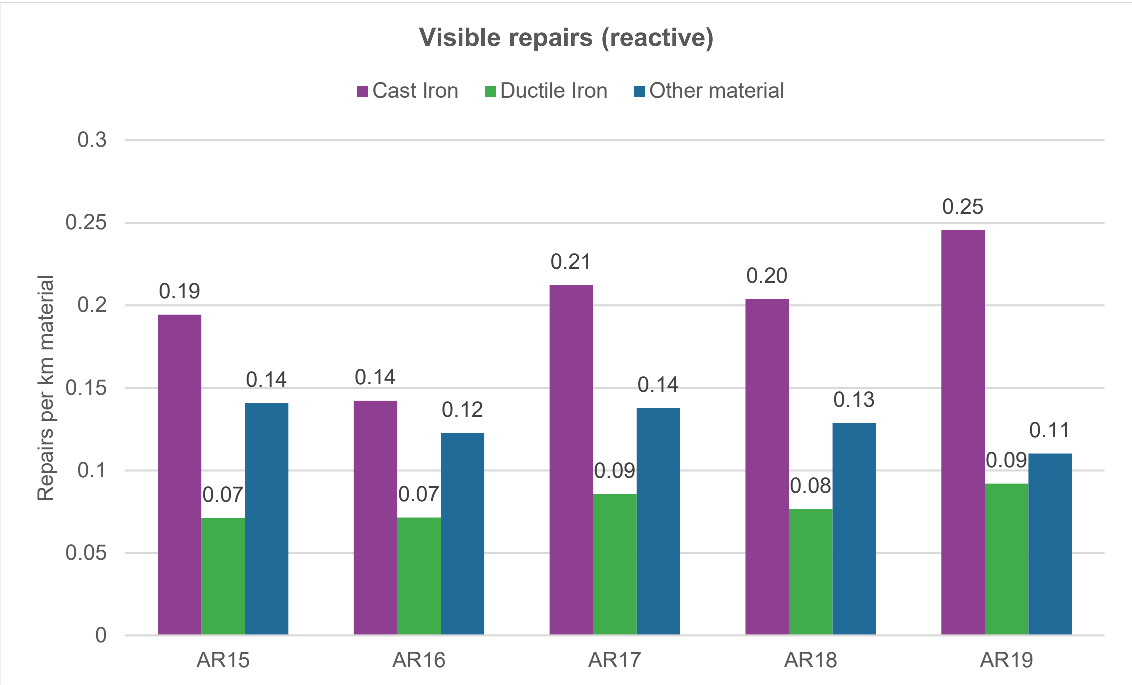
the oldest pipe material in the worst condition. A significant number of failures also occur on ductile iron pipes, which are younger but are of thinner wall construction. Visible leak repairs on cast iron pipes are higher than other materials and are reasonably stable as shown in Figure 4.3. An analysis of failure rates is presented in section 4.2.

Figure 4.2: Analysis of visible leak repairs by material (TW as a whole)



Source: Thames Water: Annual Return data from 2015 to 2019

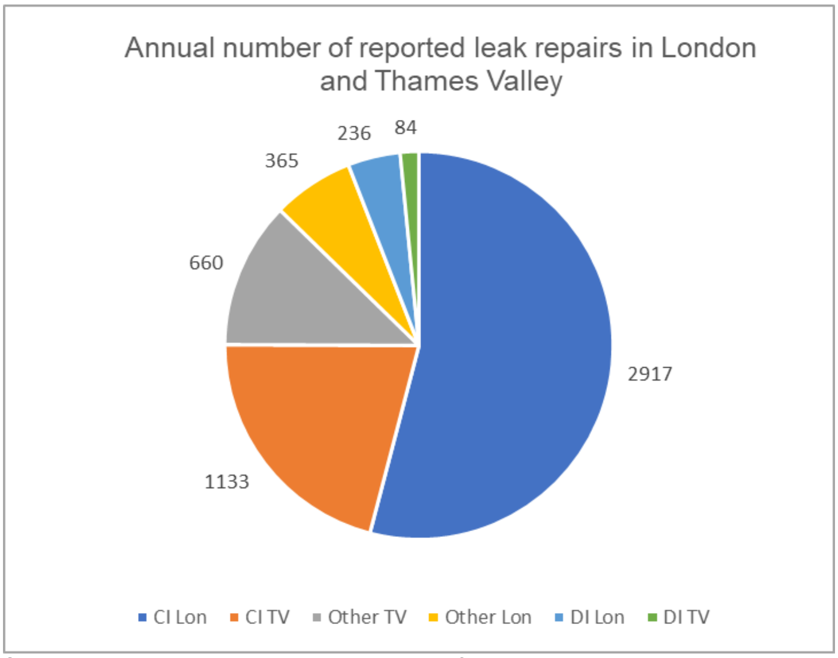
Figure 4.3: Comparison of visible leak repairs by material (TW as a whole)



Source: Thames Water data

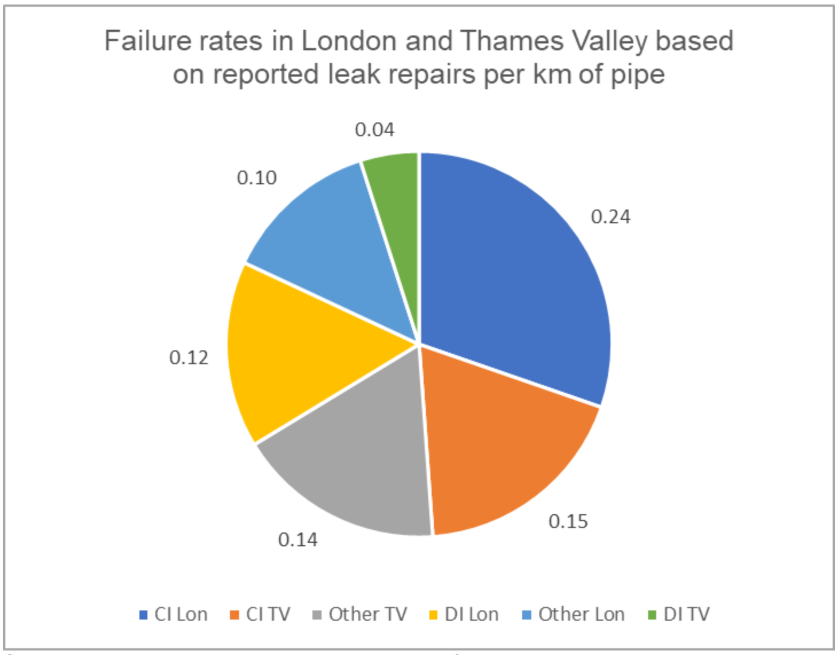
Far more repairs of reported (visible) leaks are undertaken in London than in the Thames Valley, as shown in Figure 4.4, and failure rates are also higher in London than Thames Valley as shown in Figure 4.5.

Figure 4.4: Comparison of reported leak repairs in London and Thames Valley



Source: Thames Water: average 5 years' data for AR15 to AR19

Figure 4.5: Comparison of reported leak repair rates in London and Thames Valley



Source: Thames Water: average 5 years data for AR15 to AR19

This analysis confirms that failure of cast iron pipes is the main problem that TW faces and that it is greatest in the London area. In the Thames Valley areas, other materials have a bigger role, but cast iron is still the dominant source of visible repairs.

To understand the reasons why cast-iron pipes have been failing so frequently, TW has assembled a large database of pipe samples which shows that many of its pipes are heavily corroded. TW appointed consultants in 2017 to analyse its pipe sample data to estimate remaining life and asset renewal rates from pit-depth data.

The report[7] analysed pit-depth data from laboratory test reports on 982 pipe samples collected over AMP3, 4 and 5. It confirmed that the high burst numbers that TW experiences result from corrosion, reducing pipe wall thicknesses below minimum levels to sustain normal operational use. Typically, TW tend to struggle more with external corrosion rather than internal corrosion due to the corrosive nature of the soil, and the fact that the internal water quality is treated to reduce internal corrosion issues. Using a method that took the average of the worst five pit depths to measure material loss through corrosion, the report estimated the remaining life, deterioration rates and renewal lengths for ferrous materials (cast iron, spun iron and ductile iron) and concluded that the long-run constant renewal rate required to keep pace with deterioration was 0.5%, equating to 510km of ferrous pipe per five-year AMP period. It also calculated the variable renewal rates required in each AMP period to keep pace with deterioration and concluded that rates need to average 0.7% for the next 50 years (740km per AMP) after which rates can gradually reduce to lower levels.

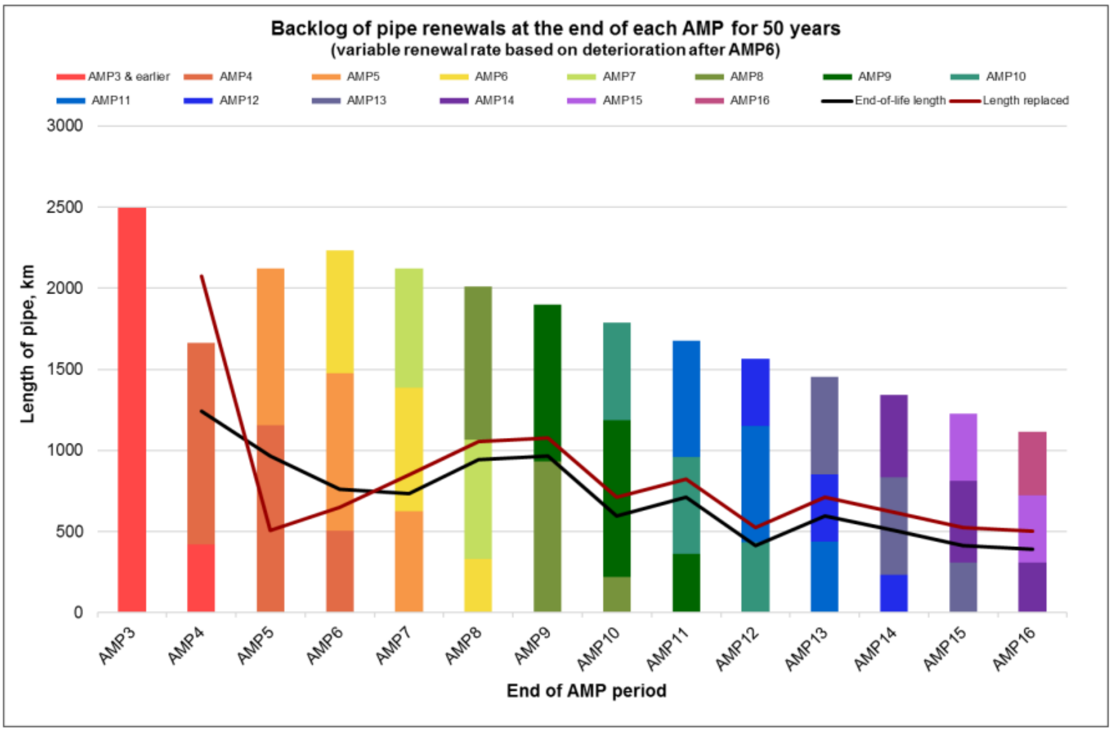
Statistical modelling of burst rates using TW's AIM model for water distribution mains forecast a need to replace 650km of pipe per AMP to keep pace with deterioration and maintain service. This lies between the estimated renewal lengths forecast from pipe sample data.

The report also identified that some pipes in the network have zero remaining life, i.e. their wall thicknesses are forecast to be too low to sustain operational use. Accounting for actual renewal activity in AMP3 to AMP6, it calculated that there is a backlog of 2,234 km of ferrous pipe that had reached end of life but had not been replaced. Figure 4.6, taken from the report, shows the variable rate of renewal required to offset deterioration and address the backlog over 100 years.

Figure 4.7, also taken from the report, shows how the backlog of life-expired pipes grows and then falls if pipes are replaced at a constant rate of 650km per AMP.

[7] DNV-GL, Water mains material deterioration – update, 2017

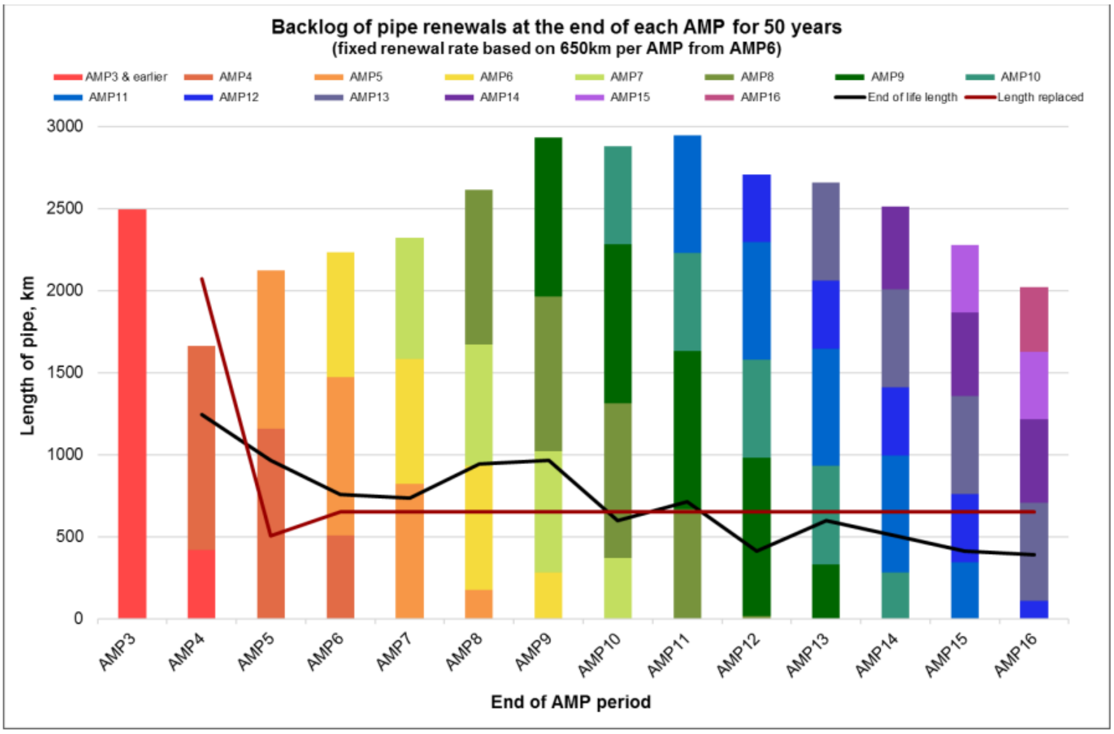
Figure 4.6: Variable rate of renewal to offset deterioration and address backlog



Source: DNV-GL, water mains material deterioration – update, 2017, p30

Figure 4.6 shows, (based on an analysis of pipe sample data), that if pipes are renewed at a rate that mirrors the rate at which pipes are forecast to reach the end of their serviceable lives as a result of corrosion, and an allowance is made to gradually replace the backlog, then approximately 1050km of pipe needs to be replaced in AMP8 and AMP9. After this, rates of renewal can fall gradually to less than half this by 2070, by which time the backlog will be halved. This rate of renewal would be a significant uplift on recent rates of renewal in AMP5 and AMP6, but about half that achieved in AMP4 for the VMR programme.

Figure 4.7: Constant rate of renewal to offset deterioration and impact on backlog



Source: DNV-GL, water mains material deterioration – update, 2017, p30

Figure 4.7 shows that if pipes are renewed at a constant rate of 650 km each AMP, then the backlog is forecast to increase steadily until AMP11 before falling to current levels by 2070. If this materialised, it would be accompanied by an increase in opex to fix increased numbers of bursts and there would likely be a deterioration in service. This would not be a good outcome either operationally or for customers.

In summary, the analysis of pipe sample data confirms that:

- TW's ferrous mains are in poor condition owing to internal and external corrosion (although external corrosion is more problematic).
- The constant renewal rate to keep pace with deterioration is 0.5%/annum averaged over 200 years, equivalent to 510 km per AMP.
- The variable renewal rate to keep pace with deterioration as cohorts of pipes reach the end of their life is 0.7% averaged over the next 50 years, equivalent to 740 km per AMP.
- The variable renewal length required to keep pace with deterioration and gradually replace the backlog of life-expired pipes is 1050 km in AMP8 and AMP9, falling to 500 km by 2070.
- Constant renewal of pipes at a rate of 650 km per AMP is insufficient to prevent the backlog of life-expired pipes growing by 30% by AMP9 and does not fall to current levels until 2070.
- The variable renewal rate is fairer from an intergenerational perspective in gradually improving performance for future customers by removing the backlog, whereas the constant renewal rate allows the backlog and performance issues to worsen for future generations.

The report also makes the important observation that many of the samples used in the study were obtained from areas of network known to be in poor condition and that the sample set could be considered to be biased, though it is not known by how much. It is also noted that no further sample results have been added to the database since AMP5 (2014). Given the value of the pipe sample database and analysis of pit depths in validating TW's statistical models and other tools for forecasting investment requirements, it is recommended that a new non-biased programme of pipe sampling be implemented, and analysis of pit depths repeated subject to considerations of scope, cost and disruption.

Apart from the pipe sample database, there is other evidence that TW's cast iron pipe stock, which is larger than that of any other company in England and Wales, is inherently vulnerable to fracture with changes in water temperature owing to corroded and inflexible lead joints. A study undertaken by the University of Surrey on corroded pipe samples provided by TW[8] found that in a fully restrained situation, which can occur in service when joints are locked, tensile stresses arise with a decrease in temperature that are high enough to fracture a corroded pipe. In situations where tensile stresses lead to joint slippage, leakage through the joint was observed. Figure 4.8 shows some typical pipe samples used in the study.

Figure 4.8: Corroded 4" cast iron pipes used in 2010 University of Surrey study

Source: University of Surrey, Thermally induced strains and stresses in cast iron water distribution pipes

It is likely that many of the bursts that occur on TW's cast iron pipes during changes in water temperature or soil movements, occur owing to failure mechanisms identified in the University of Surrey study. This is further evidence that London's network is fragile and in poor condition.

4.2 Factors causing asset failure

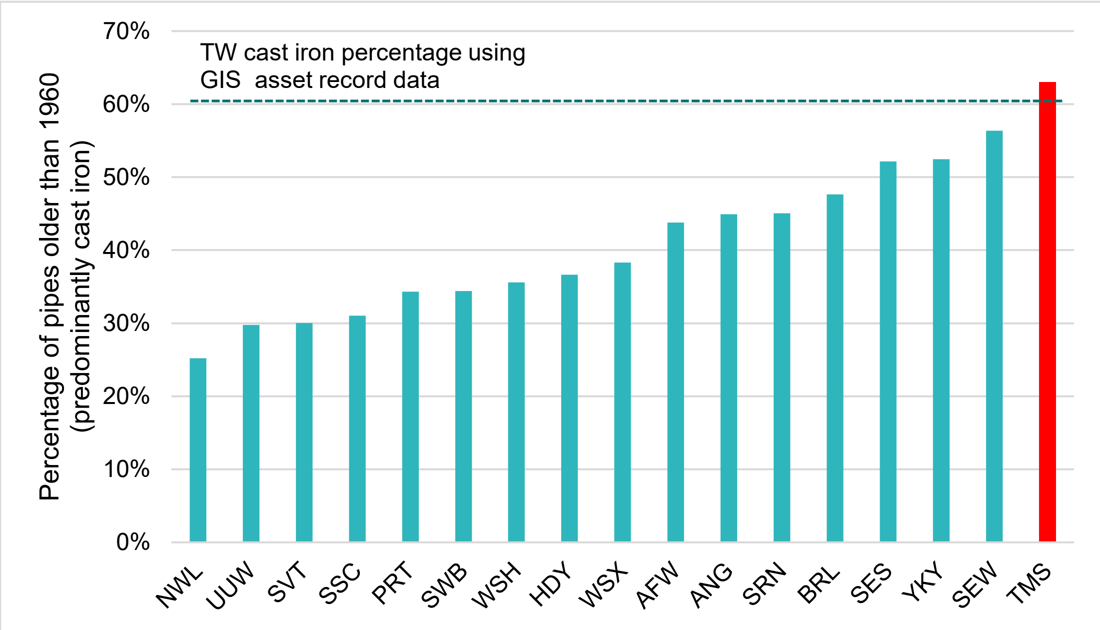
The previous section established that London's network is in poor condition and this is reflected in its performance. In this section we examine pipeline failure rates and some of the factors causing them.

Firstly, a high proportion of TW's pipeline assets are made of corrodible ferrous materials, in particular cast iron. In fact, TW's network is estimated to have one of the highest proportions of cast iron in England and Wales. To review this we have used AR20 data and have reviewed the length of pipe installed prior to 1960s, as a proxy for percentage of cast iron. This is as cast iron was the predominant material before this point, and although there may have also been other pipe materials in use at this time (AC, uPVC, Lead), the lengths of these pipes are limited. The use of this proxy has been validated against TW's GIS asset records which indicate that 60% of

[8] University of Surrey, Thermally induced strains and stresses in cast iron water distribution pipes, 2010

the network is cast iron; this compares to 63% as estimated using the pre-1960 metric. As the difference is only small, this appears to be a reasonable proxy. The comparative assessment between water companies of proportion of pipes older than 1960s is shown in Figure 4.9.

Figure 4.9: Proportion of pipes older than 1960



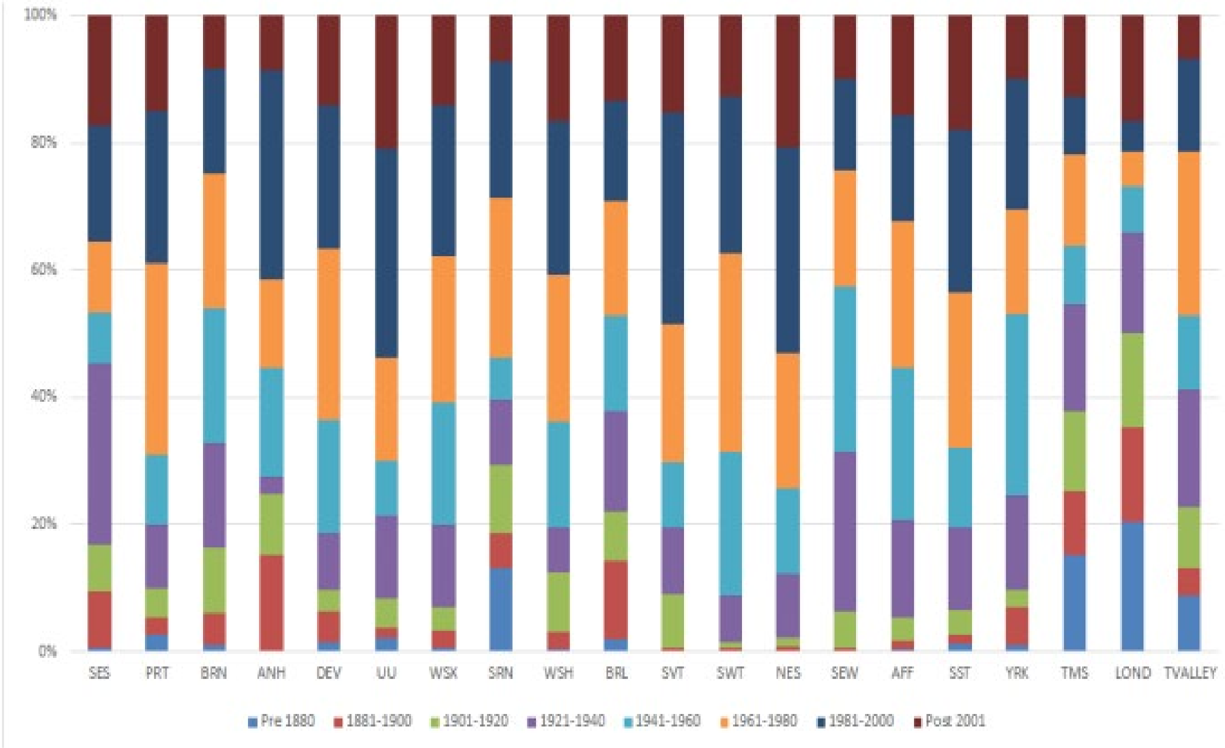
Source: AR20 data

Cast iron pipes, being ferrous, are susceptible to corrosion over time in the wrong conditions.

TW's network and London in particular is the oldest pipe network in England and Wales as shown in Figure 4.10. This shows that 20% of London's network is pre 1880 and 50% of its network is pre-1920, which is when the first standard for cast iron pipes was published (BS78, 1917). Before that date, pipes were manufactured to variable dimensional and metallurgical standards. The company with the next oldest water network is Southern Water with 13% of pipes pre 1880 and 30% pre-1920, but its pipes do not reside in corrosive clay soils as London's do. No other company has more than 2% of its pipes older than 1880.

Comparative rates of renewal are discussed in chapter 5.

Figure 4.10: Comparison of mains age across the industry



Source: Ofwat cost assessment return, Table 5 Lines 27-34, 2016-17

Most of London's water network is laid in aggressive clay soils and in section 4.3 it is shown that there is a higher prevalence of aggressive clay soils in the London area than there is nationally. This combination of corrodible pipe materials residing in corrosive soils for a long number of years means that many of TW's pipes (and their joints) are in a corroded state and prone to failure. There are a number of failure mechanisms which are explored in subsequent sections of the report, but fundamentally a high proportion of the network is old and in a corroded and weakened state, making it susceptible to conditions that would not normally trouble pipes that were in good condition.

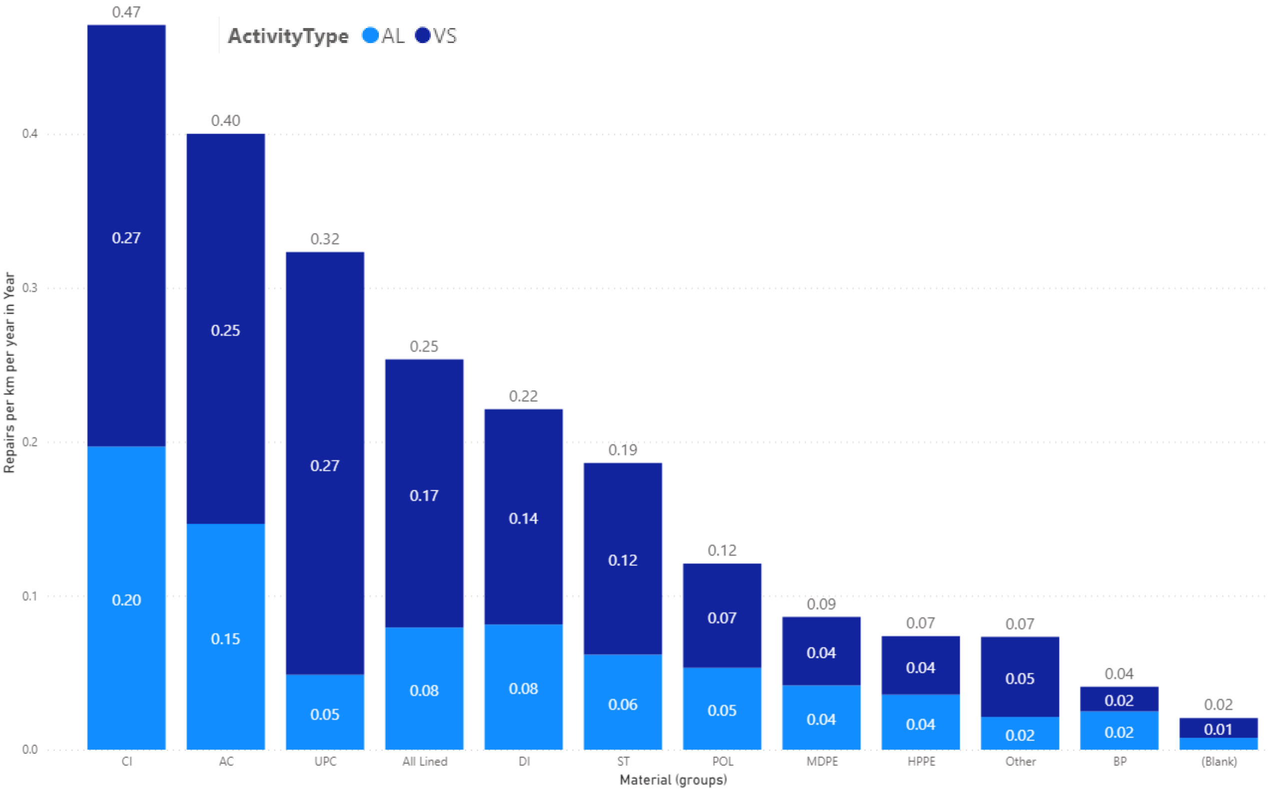
To confirm that corroded ferrous pipe materials are causing the greatest issues, Figure 4.11 shows failure rates by material in repairs per km per year in London based on repair data from 2004 to 2020. It shows repair of visible leaks (VS) and detected leaks (AL) separately, but when combined it shows that cast iron pipes have the highest failure rate of all materials in London followed by AC and UPVC. London has relatively small quantities of AC and UPVC pipe (0.02% and 0.17% respectively in 2020), but they have similar visible failure rates to cast iron.

The proportion of visible to active leakage varies between materials, but generally they both fall in ranking order from left to right in Figure 4.11. The exception to this is UPVC which has a much lower repair rate for detected leaks than visible leaks. It could be due to:

- Leak detection techniques being generally more successful on ferrous than plastic materials
- UPVC pipes tend to fail suddenly and catastrophically making them more likely to be visible
- Areas targeted for active leakage control being biased to certain pipe materials.

The other important thing to note in Figure 4.11 is that PE pipes are much less likely to fail, and Barrier Pipe failure rates are nearly half again of HPPE, though this is based on a smaller sample of pipe lengths. TW's PE pipe stock is of course much newer, so this is expected. The modelled long-term performance of PE pipe suggests a long life-time, but how these pipes actually stand the test of time is yet to be seen.

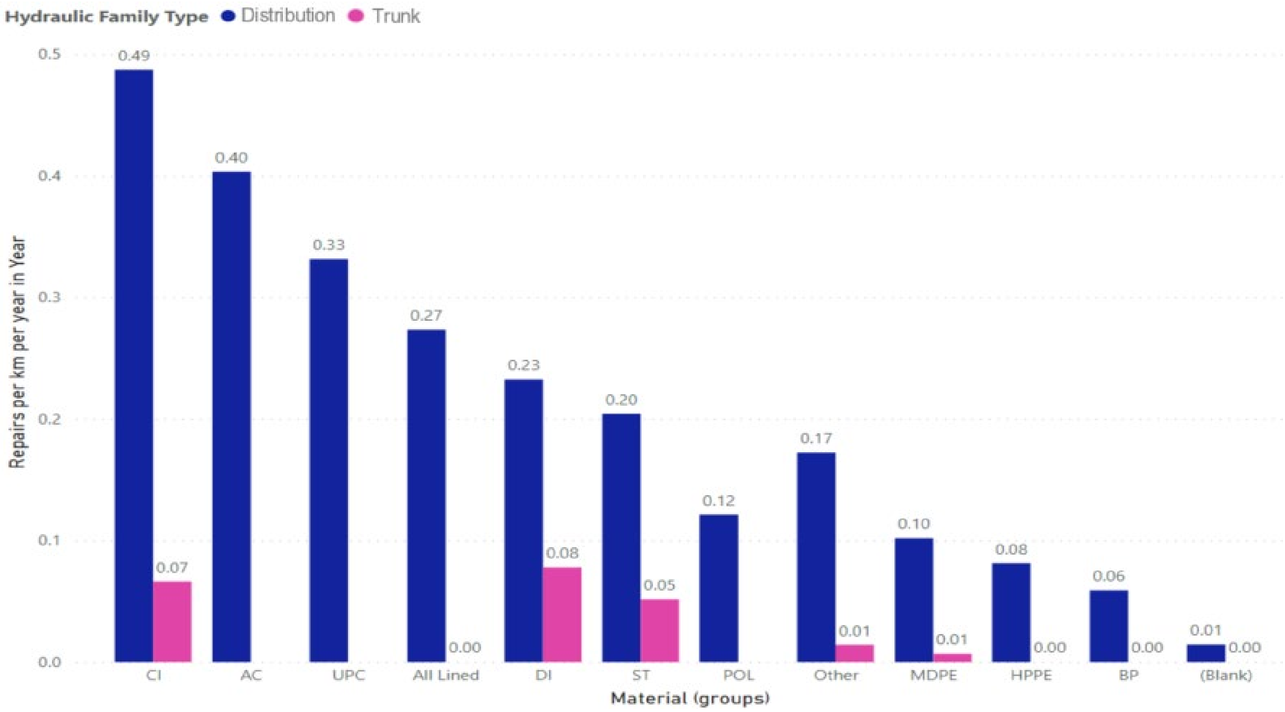
Figure 4.11: Failure Rate by Material (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI.

Figure 4.12 shows that the material of the pipe has less influence on failure rates for trunk mains compared with distribution mains in London.

Figure 4.12: Failure Rate by Pipe Type and Material (London only)

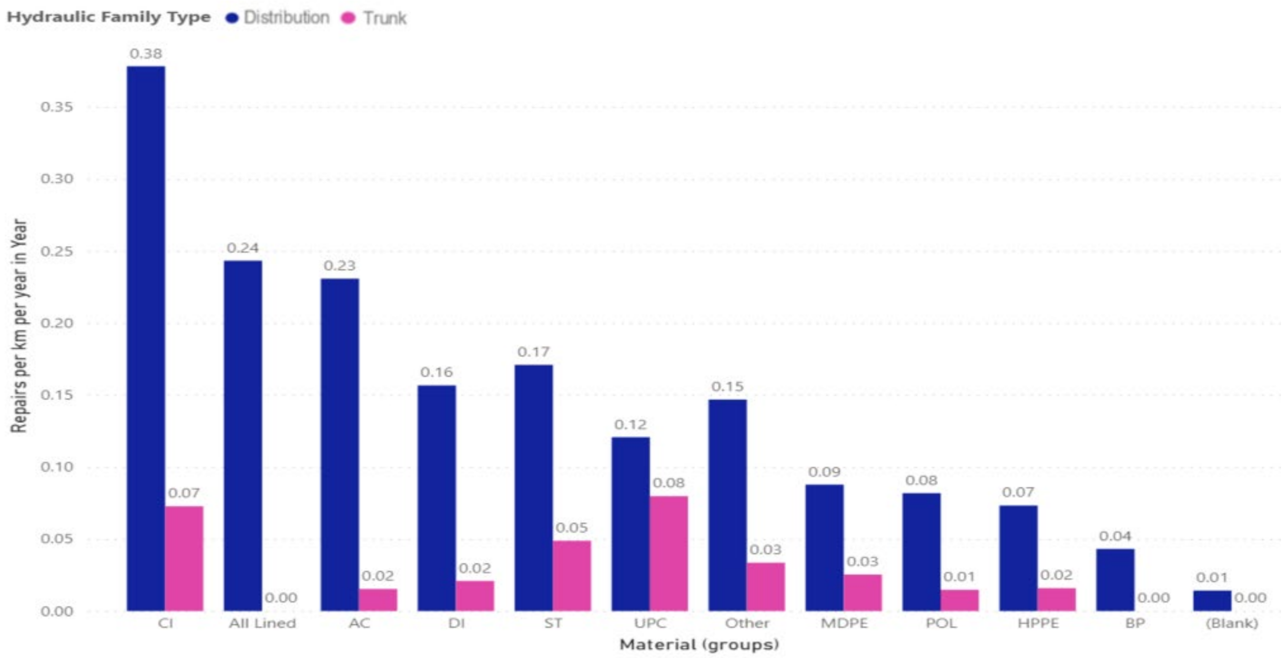


Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI
Note: Pipe Type information is not available for most replaced pipes, so this is only representative of still active pipes

Trunk mains fail less frequently than distribution mains. Part of the reason for this could be as they have larger diameters.greater wall thicknesses (structural benefits as well as greater corrosion resistance), are installed at greater depths so are less impacted by the effects of traffic loading and may be less likely to be installed underneath roads, along with many other reasons, so this explains the lower failure rates in Figure 4.12. Equally, as the number of failures on trunk mains is much lower, the analysis may be less reliable. In London, ferrous materials are least reliable, being the oldest and most corroded, whereas MDPE is much more reliable, though its application is normally limited to smaller diameters.

When the whole of the Thames Water region is considered (as shown in Figure 4.13), ductile iron and HPPE are shown to be more reliable but uPVC is the least reliable material, even more so than cast iron.

Figure 4.13: Failure Rate by Pipe Type and Material (Thames Water area)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

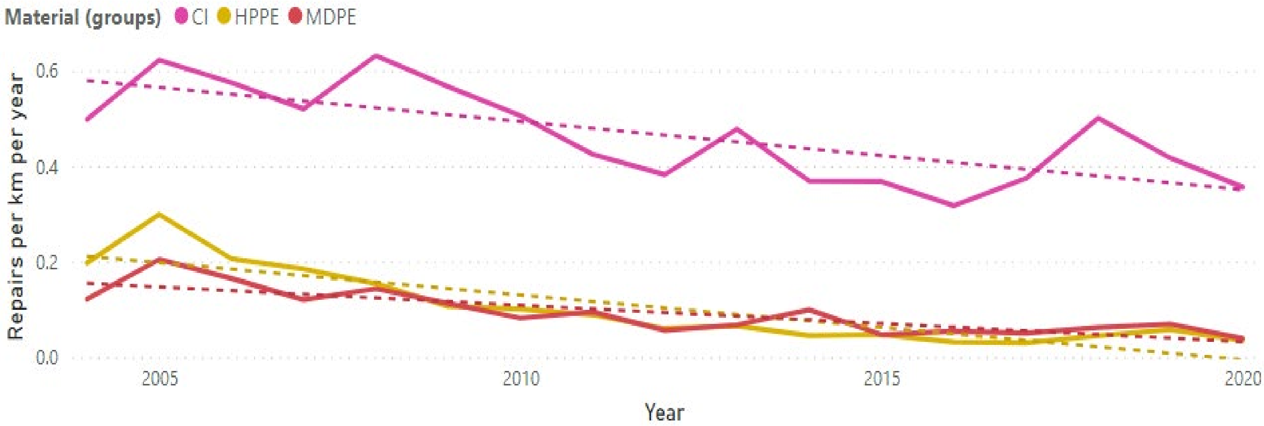
Although failure rates for trunk mains are much lower than for distribution mains, they are still significant. The analysis shows that each km of cast iron trunk main (the predominate material) has a 7% chance of failing each year. For the 1,432km of cast iron trunk main that TW operates in London, that is equivalent to 100 failures per year. Although a lot of those failures may be smaller leaks that can be managed (fixed) prior to customer impact, there is a risk that some of these trunk main failures will have higher impact. Given the potential impact on customers through public safety risk, damage to critical national infrastructure, potential flooding, extended interruptions to supply, and reputational damage, , that is too high, and investment should be targeted at gradually improving reliability towards a more acceptable failure rate of 1% to 2%/year.

Trends in failure rates are shown Figure 4.14. This shows the overall (active and visible leakage) failure rate for Cast Iron, and PE pipes from 2004 to 2020.

Figure 4.14 confirms that PE pipes are much more reliable than cast iron pipes but also that the overall failure rate for these materials shows a similar trend downwards over time. For cast iron pipes, the VMR programme from 2005 to 2010 replaced many of the ‘burstiest’ pipes in the worst performing DMAs, affecting a reduction in failure rate in the following period (2010 to 2015). This reduction extended into AMP6 with continued targeting of poor performing pipes and other measures to reduce bursts and leakage such as pressure management. The spike in cast iron failures in 2018 reflects the ‘Beast from the East’ weather event, but this was still lower than the failure rate observed in most years prior to 2010.

PE pipes will also have benefited from measures such as pressure management, but there is also evidence (see later) that they become more reliable as they age in the first 20 years. The lack of a spike in failure rates for PE pipes in 2018 suggests that PE pipes (or at least young PE pipes) are more resilient to weather-related shock events, however it is not conclusive that this is due to the pipe material, its age or other factors. It does suggest, however, that as London’s cast iron network is gradually replaced with modern HPPE and MDPE pipe, it will become more resilient to freeze-thaw events.

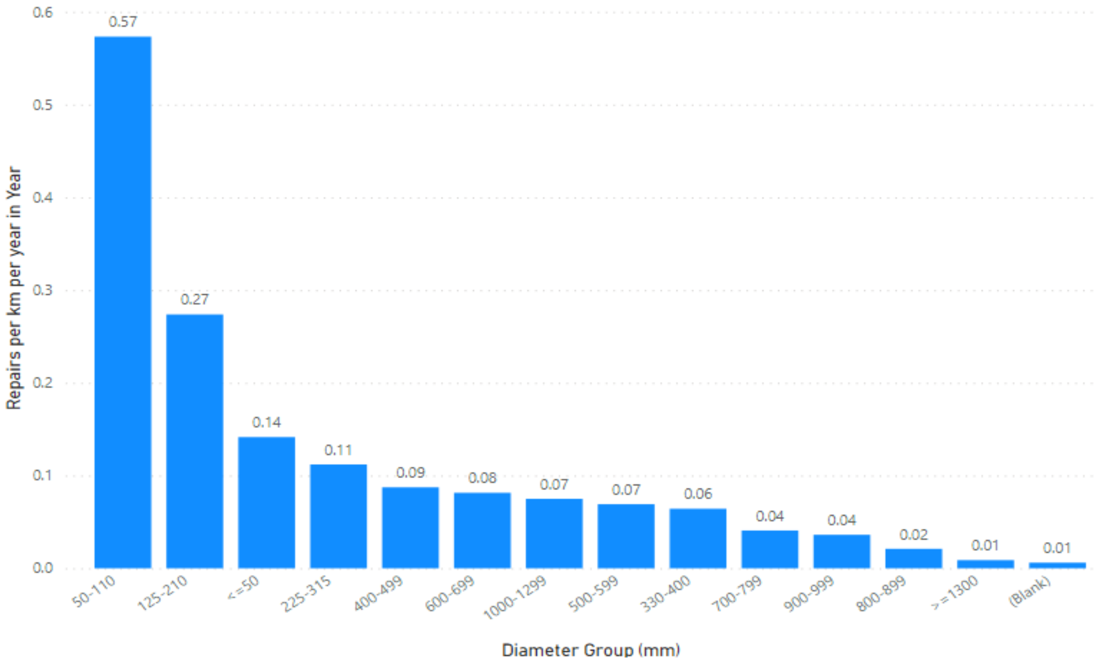
Figure 4.14: Failure Rate by Material by Year (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI
Note: AC and uPVC are not included as the relatively small lengths of pipe makes the yearly failure rate too erratic

Analysing failure rates by diameter (Figure 4.15) shows as expected that smaller diameter pipes (50-110mm and 125-210mm) have much higher failure rates than larger diameter pipes. However, the smallest diameter band (<50mm) has a much lower failure rate, perhaps because there is much less of it than other size bands. Larger diameter pipes have thicker walls, and it takes longer for corrosion to remove enough metal for the pipe to fail and smaller diameter pipes are laid at shallower depths and have many more house connections, fittings and other potential points of weakness.

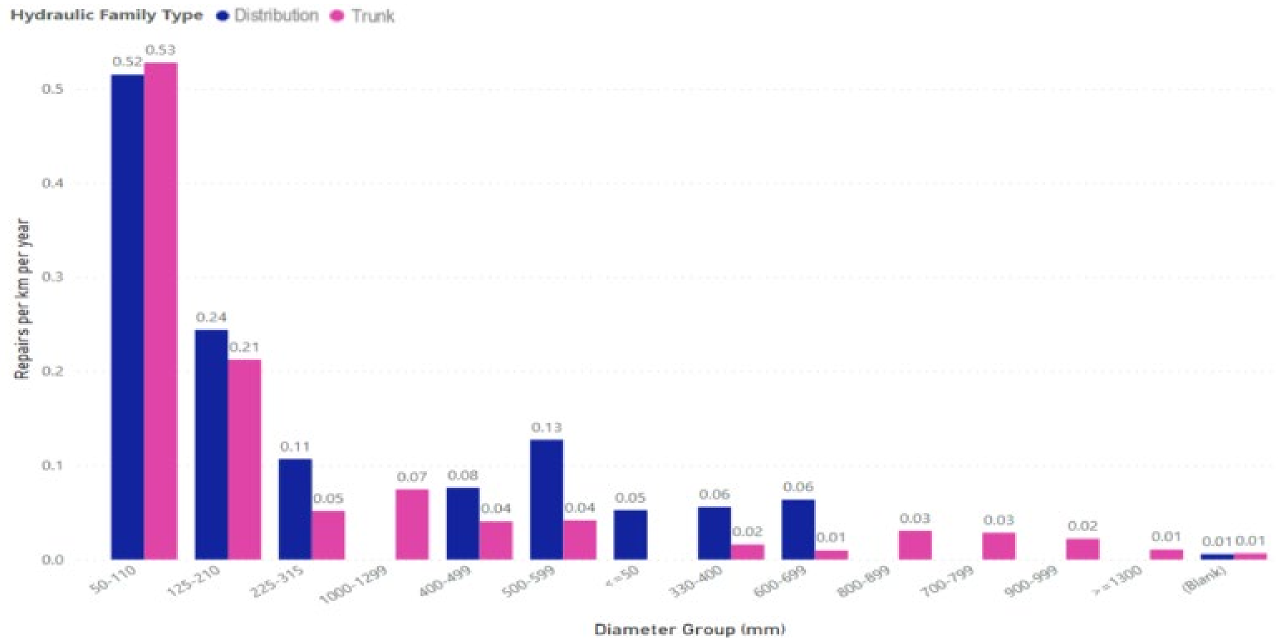
Figure 4.15: Failure Rate by Diameter (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

Although Figure 4.15 confirms the difference in failure rate between large diameter and small diameter pipes, the ranking of failure rates does not match the ranking of diameters. Pipe diameters in the range 1000mm to 1299mm have a higher failure rate than 330mm to 400mm pipes or 700mm to 799mm pipes. Figure 4.16 shows that this is true for trunk mains also.

Figure 4.16: Failure Rate by Diameter and Pipe Type (London only)

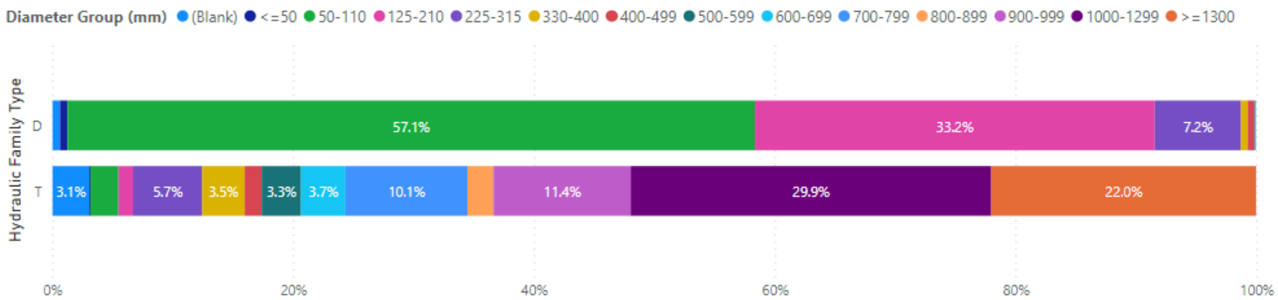


Source: GIS and mains repair database, 28 April 2021 processed in PBI
Note: Pipe Type information is not available for most replaced pipes so this is only representative of still active pipes

Trunk mains with diameters in the range 1000mm to 1299mm (including 42” and 48” pipes) have a higher failure rate than any other diameter of trunk main, including the 225mm to 315mm pipes at the small end of the trunk main range. This is concerning as 1000mm to 1299mm is a common size range in London’s trunk main stock and consists mainly of aging cast iron pipe.

Figure 4.17 shows the diameter make-up of London’s trunk mains and distribution mains. This shows that over 90% of distribution main diameters are in the range 50mm to 210mm and that over 75% of trunk mains are greater than 700mm in diameter. Pipes in the 1000mm to 1299mm diameter band represent 30% of the trunk main network.

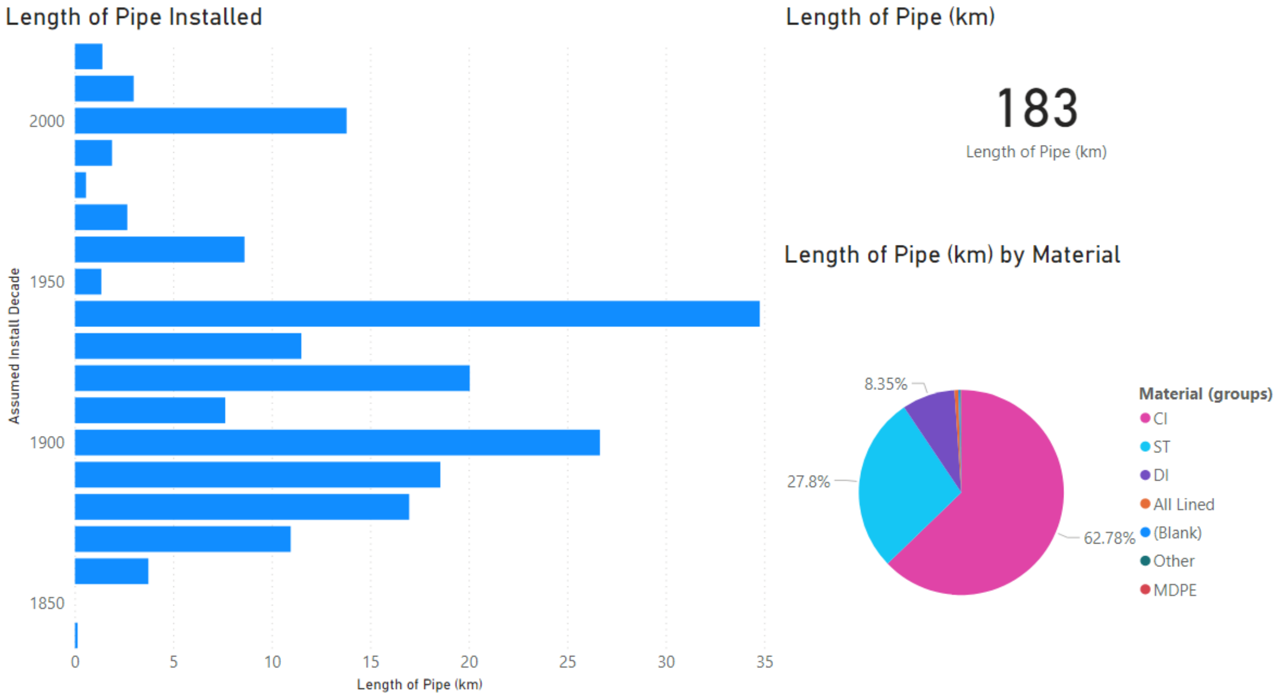
Figure 4.17: Proportions of trunk main by diameter (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

The material make-up and length of pipe by date laid for the 1000mm to 1299mm diameter group is shown in Figure 4.18.

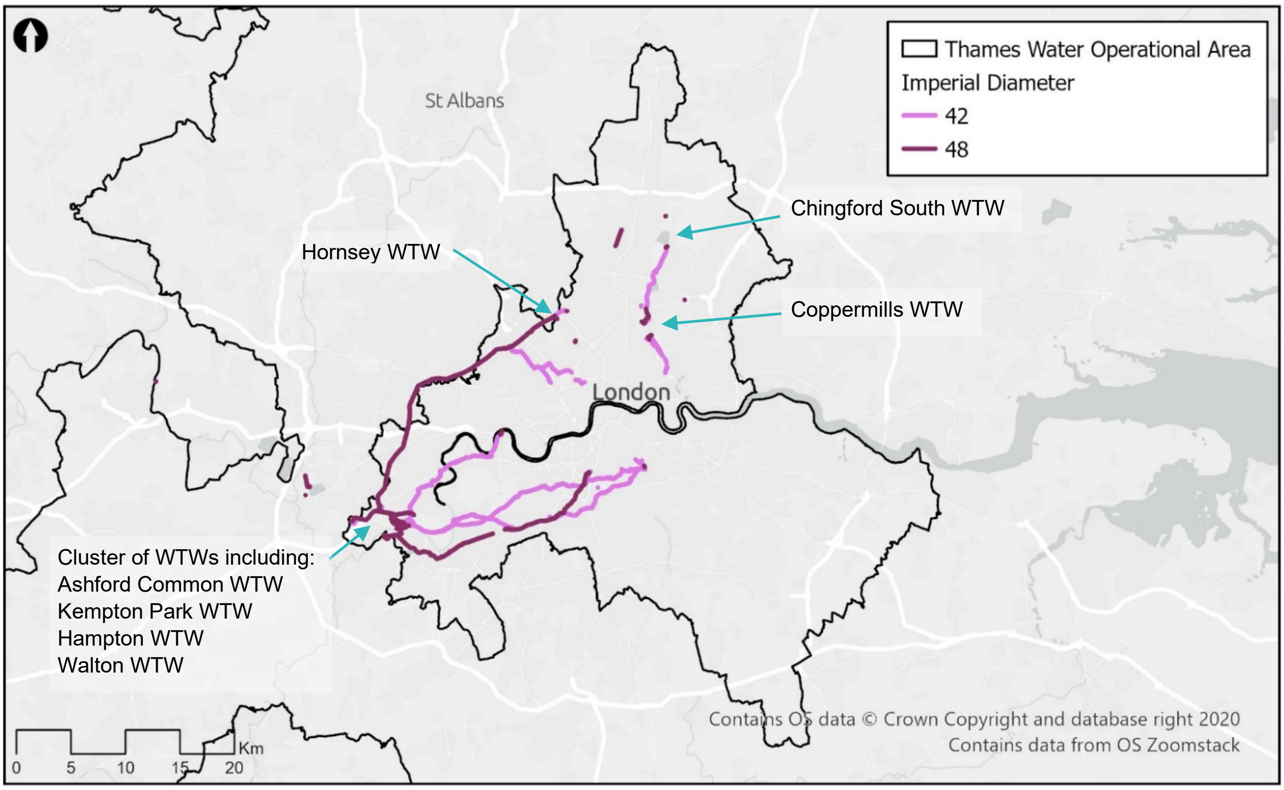
Figure 4.18: Materials, lengths and installation dates for 1000mm to 1299mm trunk mains



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

The total length of trunk main in the 1000mm to 1299mm diameter range is 183 km and 63% of it is cast iron and 28% of it is steel. 54% of it is over 100 years old and 15% was installed in the 1940s during or after the second world war when London suffered bomb damage. Pipes in this diameter range, given their failure frequency, materials and history are worthy of specific investigation and intervention strategy. Their locations are shown in Figure 4.19.

Figure 4.19: Locations of 1000mm to 1299mm trunk mains



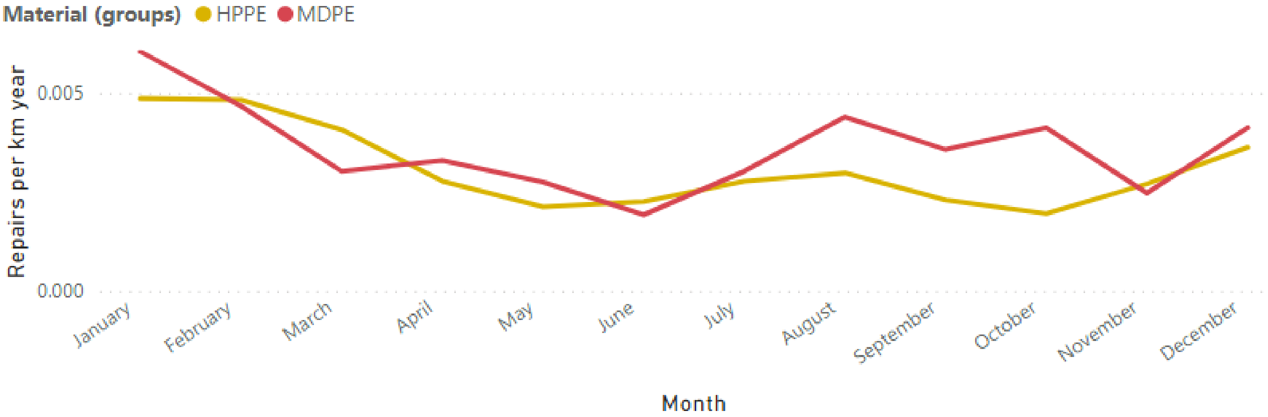
Source: TW GIS data - CW asset data

As can be seen from Figure 4.19, the trunk main diameter band 1000mm to 1299mm is critical to London's supply network, including the principal west to east supply routes from the treatment centres in the west. These supplement and supply areas that are not ordinarily covered by the TW ring main, but the ring main can be used to mitigate risk of loss of supply if needed. Particular areas which have resilience issues include the north east and south east of London. Given the elevated failure frequency for this size band and the criticality of these mains, it is recommended that they have their own intervention strategy.

Seasonal variations in failure rates were investigated to see if, as expected, there are more failures during colder winter months. Figure 4.20 and Figure 4.21 show that for cast iron this is the case and also for PE pipes, though less pronounced. This shows the vulnerability of cast iron pipes to water temperature shocks and the joint failure mechanisms studied by the University of Surrey and noted above (see Figure 4.8).

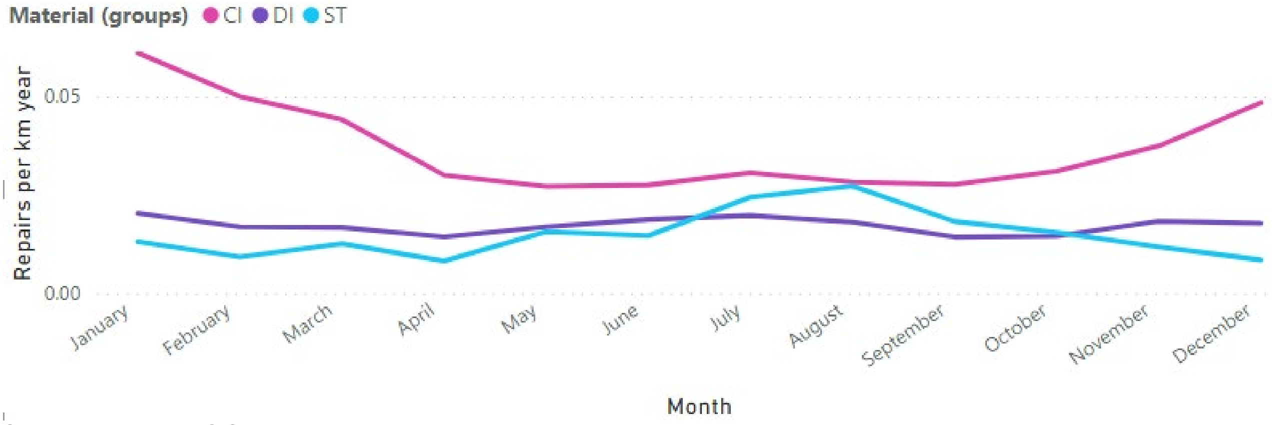
However, ductile iron and steel pipes have been included in Figure 4.21 to show that this is not true for all materials. Ductile iron failures appear to be independent of the time of year and steel even shows the inverse effect, with a higher failure rate in the summer months.

Figure 4.20: Failure Rate by Month for PE Pipes (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

Figure 4.21: Failure Rate by Month for Ferrous Pipes (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

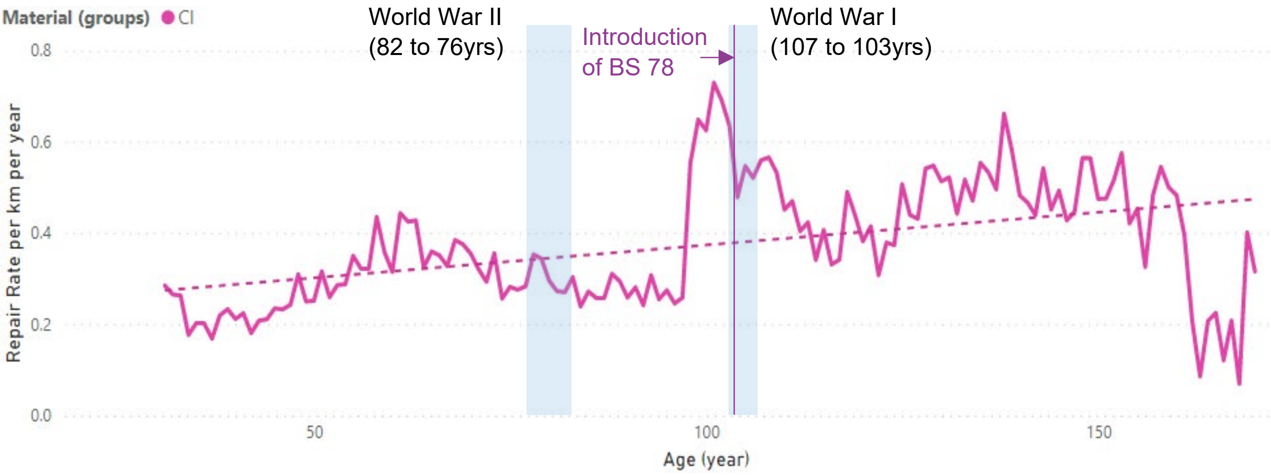
The higher failure rates on steel pipe in the summer months may relate to soil movement caused by shrinkage under dry conditions or that leaks become more visible in summer months.

By looking at the age of pipes when they have burst, it is possible to look at how pipes are deteriorating as they age. However, when doing this it needs to be recognised that other factors can cause failure and there is uncertainty on the true install date of the oldest pipes.

Figure 4.22 below shows that for cast iron, failure rates increase with age and those pipes over 100 years old are much more likely to fail. The dip in failure rate for pipes over 150 years old is due to the small number of pipes of this age. There is also a small peak in failure rates for pipes of 60-70 years of age which corresponds with pipes installed around and just after the second world war. This may be due to poorer quality spun iron pipes owing to material and skills shortages following the second world war. These still however perform better than those over 100 years old.

The significance of the 100-year-old threshold for cast iron pipes is that this coincides with the publishing in 1917 of the first standard for cast iron water pipes in Britain with BS 78 and the switch in manufacturing technique from vertically cast pipes to centrifugally spun pipes. It is also a time when coatings were applied to pipes, whereas prior to that pipes generally had no corrosion protection. BS 78 specified for the first time standard dimensions for pipe diameter and wall thicknesses and four pressure classes, A to D. Centrifugally spun iron pipes were of better dimensional and metallurgical quality than vertically cast pipes which often suffered from off centre bores resulting in one side of the pipe being thicker than the other. It is likely, therefore that the difference in manufacturing quality between vertically cast and centrifugally spun pipes, the use of coatings and the introduction of BS 78 around 100 years ago is reflected in the step-change in failure frequencies evident in Figure 4.22. This analysis suggests the need to apply different degradation curves for cast iron depending on the year it was installed. This should be considered within AIM analysis if not already included. It may also be beneficial to use this information to consider the effectiveness of whole DMA renewal versus targeted renewal based on the age of the pipe.

Figure 4.22: Failure Rate of Cast Iron Pipes by Age



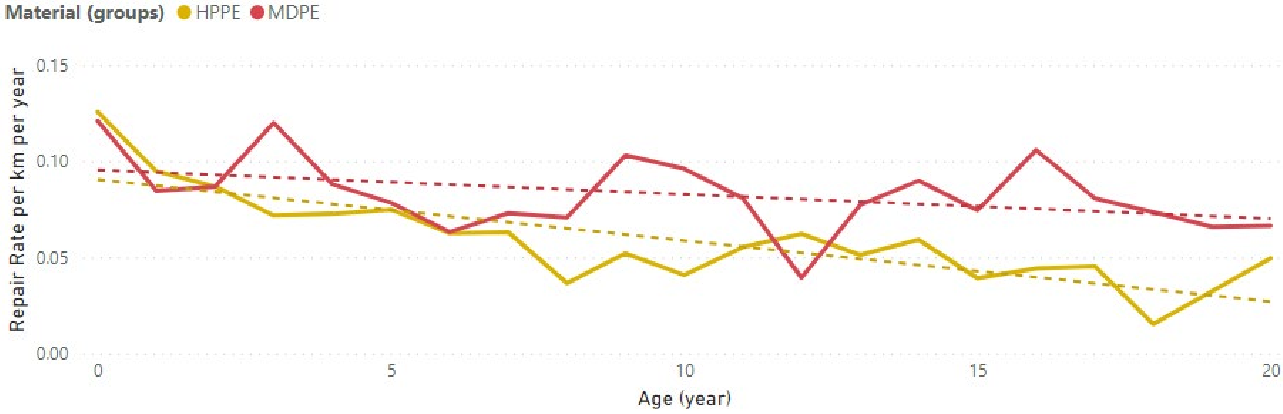
Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

Figure 4.23 shows the failure rates for PE pipes by age. These show a failure rate that is improving as pipes age, with HPPE aging better than MDPE (though it needs to be noted there is much less MDPE, so the results are less reliable). This appears to show the 'burn-in phase' of a typical deterioration bathtub curve, where failures often go through three phases:

- Burn-in: failure rates go down as install problems or manufacturing defects are resolved
- Steady state: failure rates stay fairly static and usually low
- Deterioration: at a point in the asset's life the aging of the asset leads to deterioration of the material and failure starts to occur more frequently.

The data shows that the much newer PE pipes have come through the burn-in phase and may be entering the steady state phase, whereas the much older cast iron pipes that they are replacing are in the deterioration phase. There is no evidence from the data that failure rates for PE pipes have started to increase, which would have indicated that they were entering the deterioration phase of their lives.

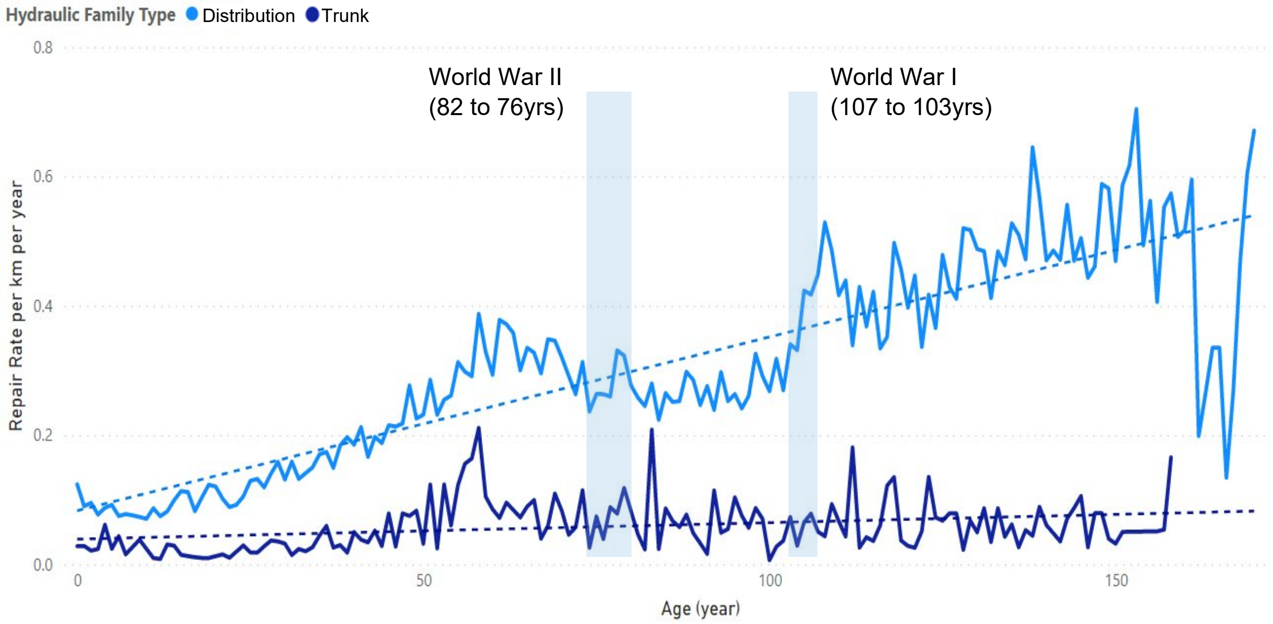
Figure 4.23: Failure Rate of PE Pipes by Age



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI

Figure 4.24 shows that age is a factor in deterioration for both distribution and trunk mains but is much slower and less pronounced for trunk mains. This could be explained by the fact that most distribution mains are of a smaller diameter compared to trunk mains that on average have larger pipe diameters and wall thicknesses. Smaller diameter pipes have a higher failure rate (see Figure 4.15) so deterioration of these pipes will show more significantly.

Figure 4.24: Failure Rate of Pipe Types by Age



Source: GIS and mains repair database, 28 April 2021 processed in PBI
Note: Pipe Type information is not available for most replaced pipes so this is only representative of still active pipes

From Figure 4.24 it can be concluded that:

- Distribution mains and trunk mains have very different failure frequencies and trajectories and thus justify different intervention strategies. Distribution mains will have an economic replacement rate when the rate and cost of repair and the consequences therefore become unacceptable. Trunk mains deteriorate slowly and are costly to replace, so it may not be economic to replace them. However, trunk mains pose a serious risk if they do fail, so a strategy of careful monitoring of asset health and prioritised intervention to manage the risks from failure is more appropriate.

- Smaller diameter distribution mains in London deteriorate significantly with age, with the average failure rate increasing by 0.1 repairs/km/year every 40 years, which is equivalent to 80 bursts/year across TW's water network or 2.5 bursts/1000km.
- Distribution mains should be replaced at a rate aligned with deterioration, accounting for the cost of renewal, cost of repair and the benefits of avoiding service disruption.
- Priority should be given to pipes over 100 years old as these have the highest failure rates and are closest to the end of their serviceable life as indicated by pit-depth analysis.
- Trunk mains only deteriorate with age gradually and failure frequencies are generally low but can vary markedly (noting the higher failure frequencies for 42" and 48" diameter pipes).
- As trunk main failure frequencies are comparatively low on average, they should be replaced on a targeted basis where the consequential risk from failure is high and pipe condition is known to be poor.
- Otherwise, trunk main interventions should focus on managing the consequences of infrequent failure accounting for criticality with respect to service disruption, property damage through flooding and other impacts on London's traffic and businesses. We note that TW puts considerable effort into trunk main monitoring for this purpose (see section 4.5).

The analysis of other factors impacting failure are explored in subsequent sections.

4.3 Impact of hazardous soils

There is clear evidence that London's network, which predominantly consists of ferrous materials, in particular cast iron, is in poor condition owing to its age, manufacturing quality and corrosion as a result of the effects of aggressive soils. We have undertaken an analysis to compare geohazards across the industry to show that London and Thames Water as a whole are affected by hazardous soil conditions more than other companies. We have also demonstrated a correlation between hazardous soils in the Thames area and repair density, showing that aggressive soil conditions are an important factor in causing pipe failure and leakage and one which affects London more than any other part of the country.

The London area is dominated by clay soils that are corrosive to ferrous materials and shrink and swell with changing moisture conditions causing disruption to pipes and joints. Other water companies also have hazardous soil conditions within their boundaries, so to compare them we:

- Obtained BGS geohazard data for a range of soil hazards. BGS provide geological information about potential ground movement or subsidence for the entire country;
- Obtained OS large urban area map data to identify areas within water company boundaries where we would be sure that water mains would be located;
- Ran a GIS analysis to quantify the areas of hazardous soils of different severities within urban areas within company boundaries; and
- Compared the proportional areas of hazardous soils in TW with other companies.

The results of this analysis are given in Table 4.1 and Table 4.2.

Table 4.1: Comparison of the distribution of hazard classification in Thames Water compared with other companies

Hazard	%age difference between TW and other water companies in terms of area within hazardous soil				
	A	B	C	D	E
Collapsible Deposits	-1.9	0.6	1.7	-0.4	0.0
Compressible Ground	3.0	-1.6	-0.2	-3.8	2.6
Landslides	0.3	3.6	-3.4	-0.4	-0.1
Running Sand	-1.8	7.0	-2.4	-2.7	0.0
Shrink Swell	-3.7	-25.9	-6.5	36.2	0.0
Soluble Rocks	-1.2	0.6	0.4	0.4	-0.2

A= No hazard
B= Very low
C= Low
D= Moderate
E= High

Note: Colours are scaled such that red indicates largest negative percentage change value and green indicates largest positive change value. Oranges indicate not much difference.
Source: Mott MacDonald analysis of BGS data for large urban areas (OS definition)

Table 4.2: Comparison of the distribution of corrosivity classification in Thames Water compared with other companies

Hazard	%age difference between TW and other water companies in terms of area within hazardous soil		
	1	2	3
Corrosivity	-17.0	0.7	16.4

1= Unlikely to cause corrosion
2= May cause corrosion
3= Likely to cause corrosion

Note: Colours are scaled such that red indicates largest negative percentage change value and green indicates largest positive change value. Oranges indicate not much difference.
Source: Mott MacDonald analysis of BGS data for large urban areas (OS definition)

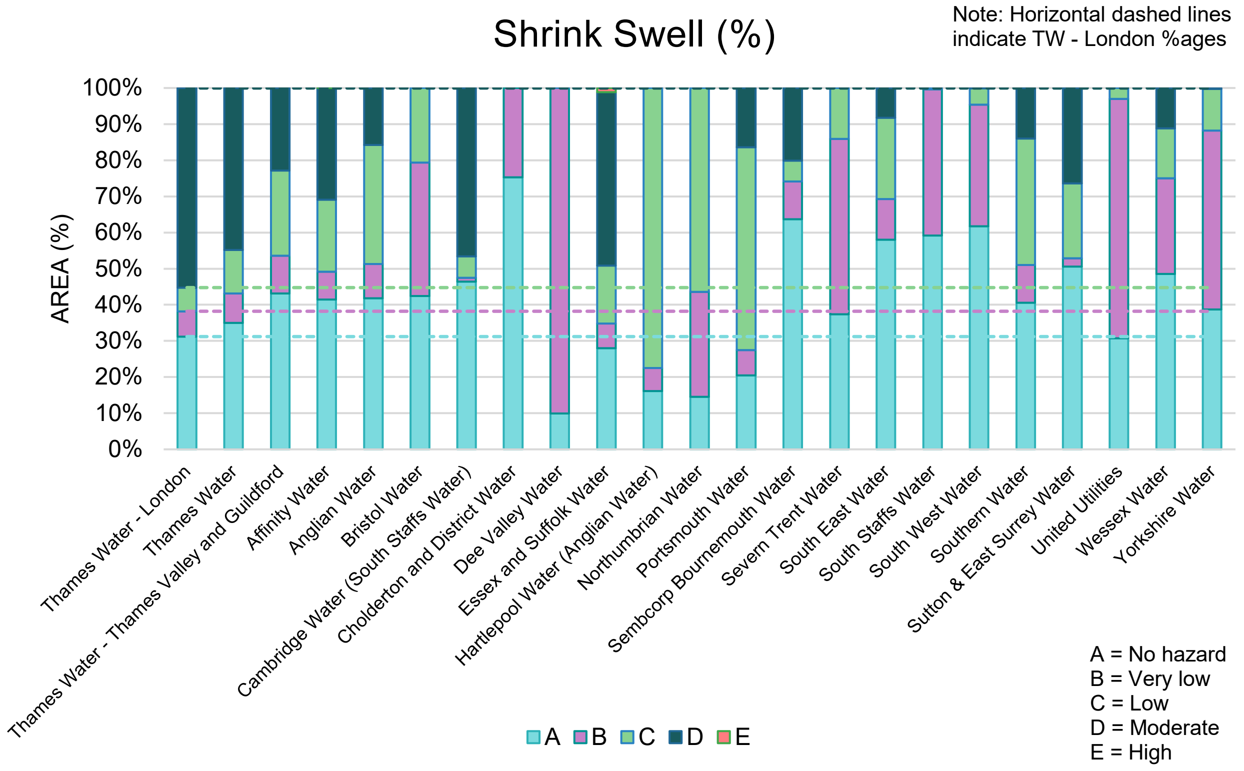
It is noticeable in the results that Corrosivity and Shrink Swell present the most significant differences between Thames Water and the other companies. Table 4.1 shows that TW has 36.2% more category D (moderate hazard) for the Shrink Swell hazard than the other water companies. Similarly, Table 4.2 shows that TW has 16.4% more category 3 (likely to cause corrosion) for the Corrosivity hazard than the other water companies. The remaining five hazards; Collapsible Deposits, Compressible Ground, Landslides, Running Sand and Soluble Rocks show much more consistency with the other water companies.

As a result of these findings, we have compared Shrink Swell and Corrosivity in more detail.

Figure 4.25 and Figure 4.26 show the Shrink Swell hazard distributions across the different water companies, Figure 4.25 showing the % distribution of soil hazards and Figure 4.26 the areas.

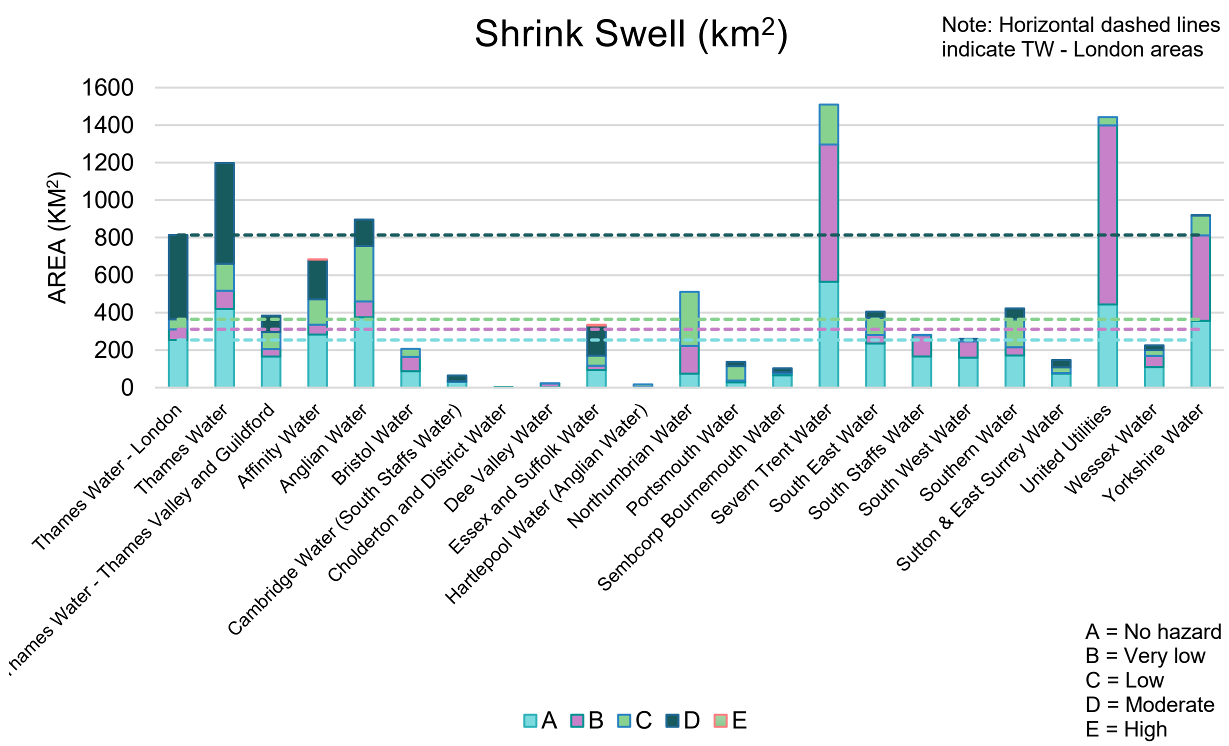
Figure 4.25 shows that there is very little ‘E’ “High” hazard anywhere in the country and so the distribution of ‘D’ “Moderate” is significant in presenting challenging ground conditions. 55% of TW’s London area is classified as ‘D’ “Moderate”, which is the highest out of any water company. Figure 4.26 shows that London and Thames Water have by far the greatest area of category D shrink-swell clays.

Figure 4.25: Shrink swell % hazard distribution across water companies



Source: Mott MacDonald analysis based on BGS data for large urban areas (OS definition)

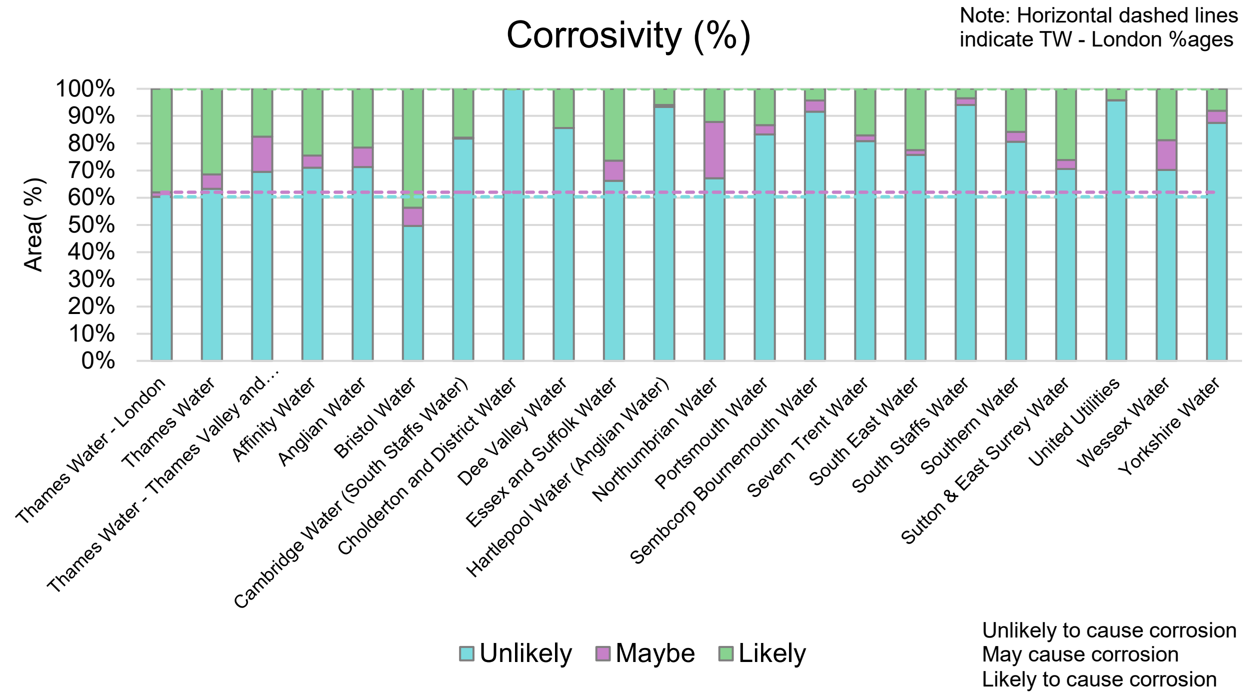
Figure 4.26: Shrink swell area hazard distribution across water companies



Source: Mott MacDonald analysis based on BGS data for large urban areas (OS definition)

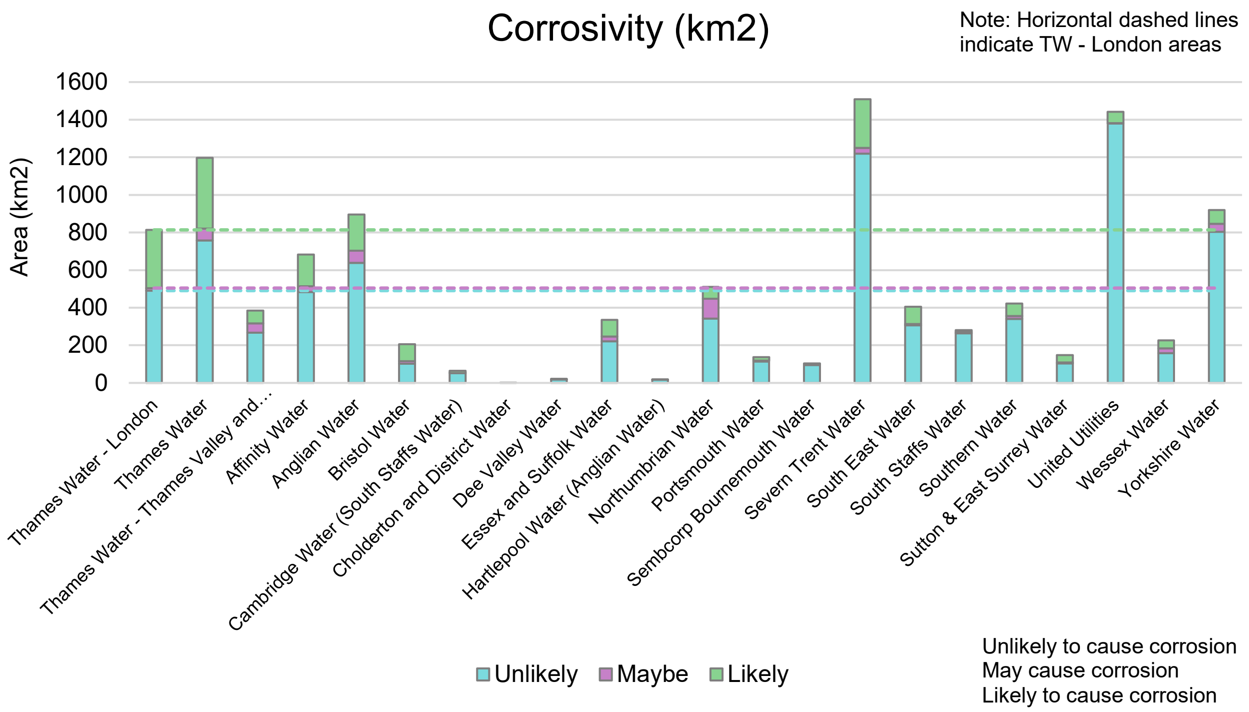
Figure 4.27 and Figure 4.28 show the Corrosivity hazard distributions across the different water companies; Figure 4.27 showing the % distribution of soil hazards and Figure 4.28 the areas.

Figure 4.27: Corrosivity % hazard distribution across water companies



Source: Mott MacDonald analysis based on BGS data for large urban areas (OS definition)

Figure 4.28: Corrosivity area hazard distribution across water companies



Source: Mott MacDonald analysis based on BGS data for large urban areas (OS definition)

As can be seen in Figure 4.27, 38% of the TW's London area is classified as '3' "Likely to cause corrosion". This is significantly higher than most other water companies. Only Bristol Water has a higher percentage at 44%. However, as seen in Figure 4.28, the Bristol Water company area is small in comparison to London, and its asset stock is younger which suggests a higher proportion of non-ferrous pipes which is not susceptible to corrosion. In total, TW's London area has 310km^2 of category '3' soil, which is 50km^2 more than any other water company.

To verify the correlation between the presence of aggressive soils in the TW London area and the propensity for pipes to corrode and fail, we have undertaken a GIS analysis of TW bursts and BGS hazardous categories. To do this we used the polygons from BGS Landmark, the data points from the Mains Repairs database, and the TW GIS CW asset data.

The mains repair database and TW GIS CW asset data were intersected against the BGS geohazard polygons for shrink swell and corrosivity, categorised by their hazard ratings. We limited the analysis to just ferrous pipe materials in the GIS CW asset data and mains repair database. From the output of the intersection, it was possible to calculate the total quantity of repairs and total length of pipe within the areas with different hazardous categorisations. This was used to calculate the repair density in the different regions to understand how repair densities correlated with increasing risk from the hazardous areas.

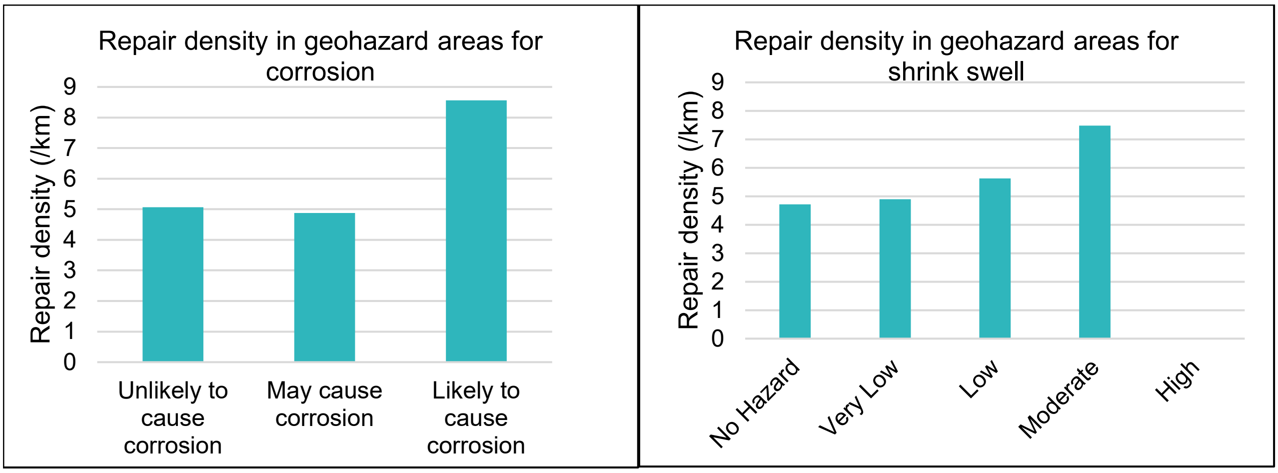
The output from the analysis is shown in Table 4.3 and Figure 4.29.

Table 4.3: GIS analysis of repair density in corrosive and shrink swell hazardous areas

	Corrosion				Shrink Swell		
	Repair count	Pipe length (km)	Repair density (/km)		Repair count	Pipe length (km)	Repair density (/km)
Unlikely to cause corrosion	58,301	11,495.7	5.07	No Hazard	29,631	6,282.4	4.72
May cause corrosion	3,485	713.7	4.88	Very Low	6,571	1,341.4	4.90
Likely to cause corrosion	42,381	4,947.6	8.57	Low	10,065	1,790.1	5.62
				Moderate	57,899	7,743.1	7.48
				High	0	0	0

Source: Mott MacDonald analysis of BGS data for large urban areas (OS definition), TW asset record GIS and TW mains repair database

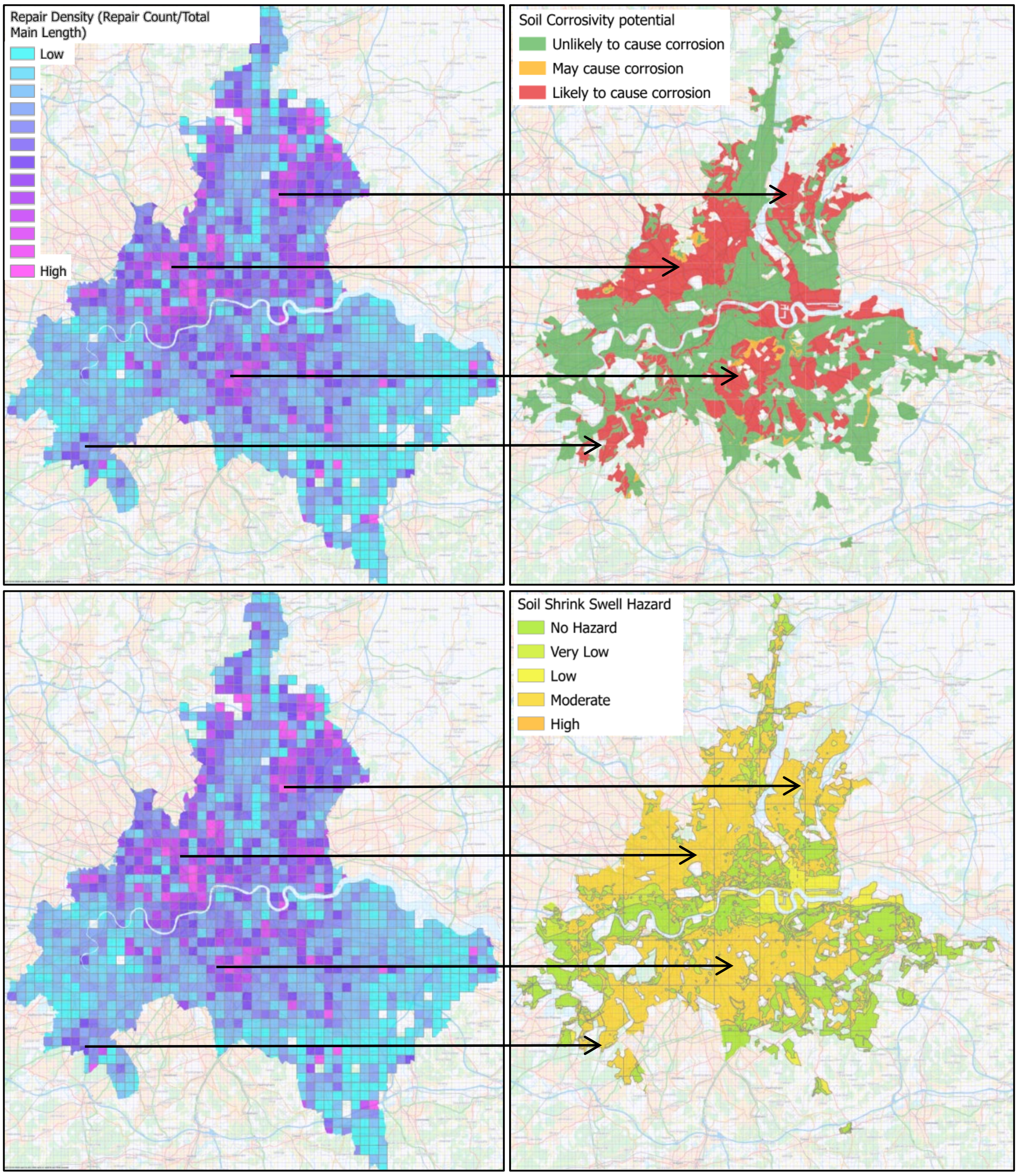
Figure 4.29: Repair density in corrosive (left) and shrink swell (right) hazardous areas



Source: Mott MacDonald analysis of BGS data for large urban areas (OS definition), TW asset record GIS and TW mains repair database

The results show clearly that TW are repairing more mains in soils which are more corrosive and in areas which are more susceptible to shrink swell. The assessment above demonstrates that there is a correlation between repair density and areas with higher risk from geo-hazards. It is reasonable to infer that areas with higher risk from geo-hazardous soils are more likely to have higher rates of leakage. This is shown visually in Figure 4.30 which shows a map of the corrosive soils in London compared with a map of repair densities across London. One can see the high correlation between the two, especially in North London.

Figure 4.30: Map of Geo-hazardous soils in London and repair densities



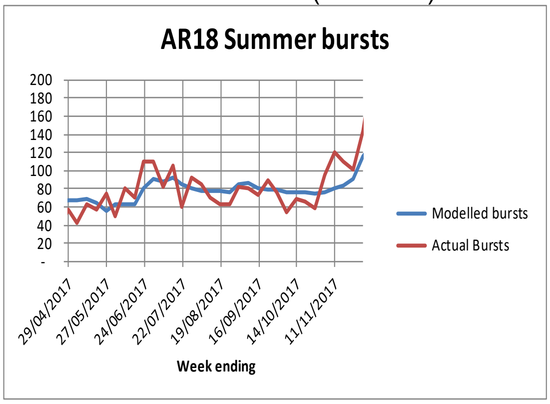
Source: Mott MacDonald analysis of BGS data for large urban areas (OS definition), TW asset record GIS and TW mains repair database

Confirming the presence and impact of shrink-swell soils, there is a clear relationship between changes in soil-moisture deficit and burst numbers in the London area as shown by comparing bursts in average and dry summer periods.

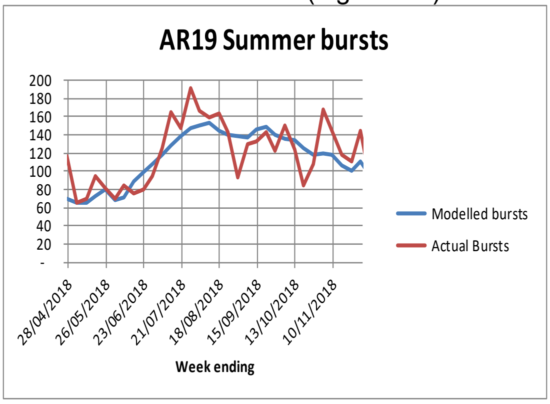
TW's short-term burst forecasting tool, which is used to forecast the effect of seasonal changes in weather on the network to inform leakage control activities, models the effect of changes in soil moisture deficit (SMD) on visible pipe bursts. This shows a clear relationship between SMD and burst numbers, which can be seen in Figure 4.31 which compares modelled and actual burst numbers for 2017, a relatively wet summer with low SMD effects and 2018, a dry summer with high SMD effects. Burst numbers are considerably higher in the summer of 2018 than those for 2017 owing to the effect of shrinking clay soils on the pipe network.

Figure 4.31: Impact of Soil-Moisture Deficit (SMD) on visible pipe bursts

Summer 2017 (low SMD)



Summer 2018 (high SMD)



Source: TW: summer bursts forecasting model v3, September 2018

4.4 Joint density and joint health

London is a densely urbanised area, and the pipe network is complex with many joints, fittings, and property connections. We have explored the hypothesis that the age of TW's network and the fact that older pipes were manufactured in shorter lengths means that London's water network has more joints than other water company networks and that these create more opportunities for leaks to occur in the network. We have used the kilo-joint concept, which was introduced by UKWIR in the 2018 report *'The Impact of Burst-Driven Mains Renewals on Network Leakage Performance'* as a measure for quantifying the number of joints within a DMA. The formula for this concept is:

$$kj = \frac{\left(7 \cdot N + \frac{L}{3}\right)}{1000}$$

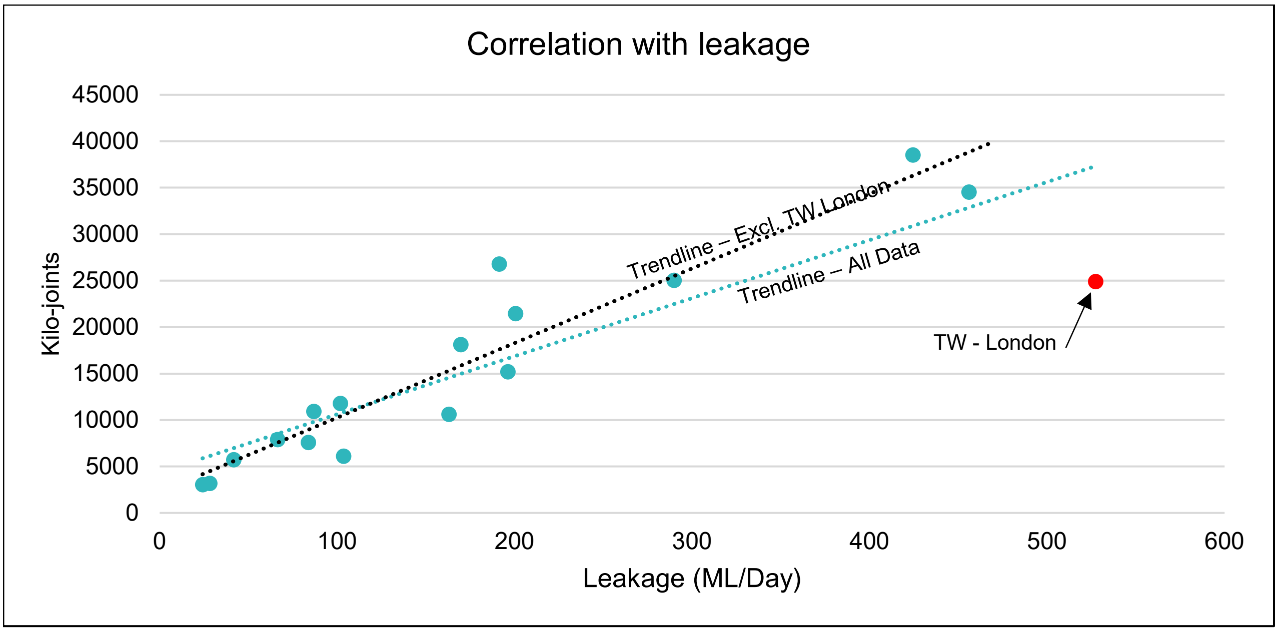
$kj = Kilo - joints\ (000s\ of\ joints)$

$N = Number\ of\ properties\ within\ the\ DMA$

$L = DMA\ mains\ length\ (m)$

The rationale for the formula is not explained in the UKWIR report, but it is clear that the number of pipe joints will relate to the length of pipe (in this case a joint every 3 metres) and the number of connections and service pipe joints will relate to the number of connected properties. Extending application of the concept from DMAs to whole companies, we have compared the total number of joints derived from this formula with total leakage in Figure 4.32.

Figure 4.32: Kilo-joint and leakage comparison by UK water company

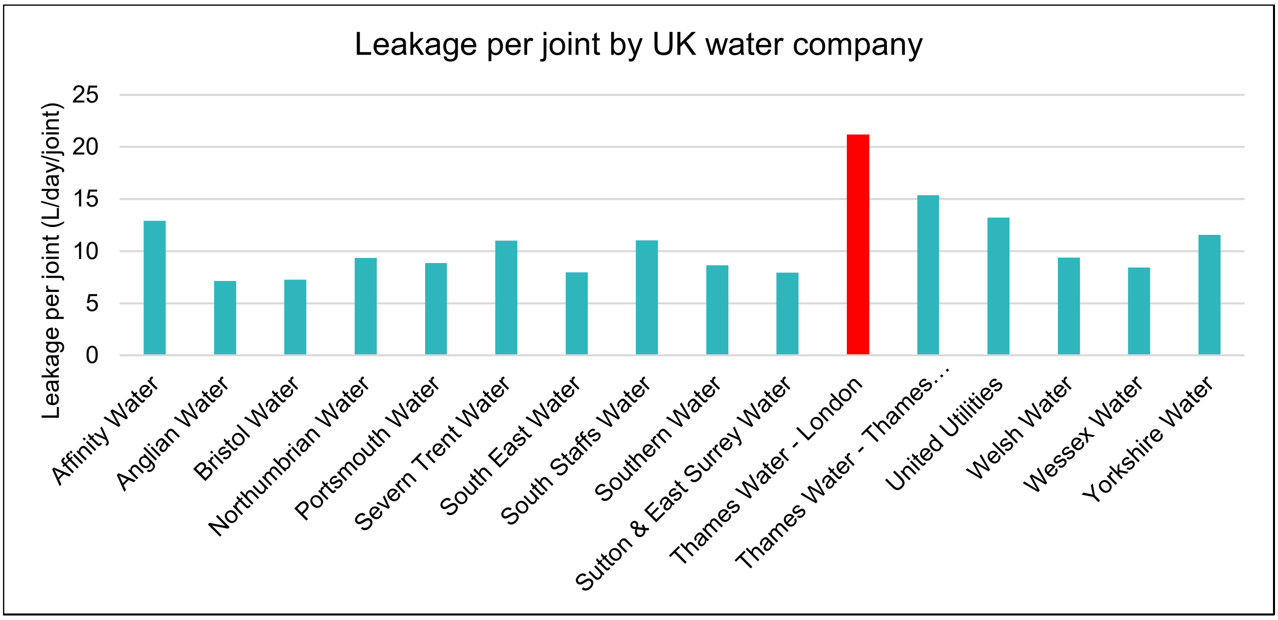


Source: Mott MacDonald analysis: Based on annual return data for 2019

Figure 4.32 shows that there is a strong correlation (r=0.88 for all data and r=0.95 when London is excluded) between total leakage in 2019 and the number of kilo-joints calculated using the formula above. Despite the strong correlation, however, London sits off the trendline with a higher leakage value than expected for the quantity of kilo-joints.

The leakage per joint has also been calculated for each water company as shown in Figure 4.33. This shows that the London region has the highest leakage per joint than any of the other water companies.

Figure 4.33: Leakage per joint comparison by UK water company



Source: Mott MacDonald analysis: Based on annual return data for 2019

The simple kilo-joint formula used to estimate joint numbers fails to account for some key factors that will vary between companies such as:

- Pipe age – older pipes are more likely to have more joints and branch connections during their lifetime than new ones and the joints may have deteriorated through corrosion, soil movements and third-party activity.
- Pipe material – older cast iron pipes have more joints than newer pipe materials because of their shorter manufacturing length, limited by the available technology at the time.
- Road junctions – networks in urban areas with high numbers of road junctions will have higher quantities of joints at those junctions where there are a lot of fittings and valves where services connect and cross each other.
- Property type – connection density varies by property type from one connection per dwelling for houses to many dwellings per connection for flats. Older pipes may have capped off connections where property type has changed from (e.g.) terraced houses to blocks of flats.

To account for some of these factors, we have modified the kilo-joint formula to account for pipe age by modifying the factor used to convert pipe-length into numbers of joints. As a high-level assessment, the factors which have been applied are shown in Table 4.4. The factors have been split into four classes as outlined below:

- Class 1: pre-1920 pipes. Most pipes within this class will be cast iron manufactured using horizontal or vertical casting methods. Research undertaken by the Cast Iron Pipe Research Association (CIPRA) into the history of manufacturing methods describes how horizontal cast pipes were often manufactured in lengths of 4-5ft. These pipes were pre-standardisation, so the manufacturing companies did not have a recognised British Standard to follow for manufacture. For this assessment, the length of pipe for this class has been set to 4.5ft (1.4m).
- Class 2: 1921 to 1960. Most pipes within this class will be cast iron manufactured with improved centrifugal casting methods. These pipes will have followed the specification set out in BS78 which was introduced in 1917 and specified lengths of 9-12ft for manufacture. For this assessment, the length of pipe for this class has been set to 10.5ft (3.2m) assumes a 50:50 split between pipes manufactured in 9ft and 12ft lengths.
- Class 3: 1961 to 1980. These may be cast iron or ductile iron pipes but with a growing preference towards ductile iron. Ductile iron pipes will have followed the specification set out in BS 4772 from 1971 (later superseded by BS EN 545 in 1995) with a standardised length of manufacture of 5.5m.
- Class 4: 1980 onwards. Whilst ductile iron pipes will still have been used, there has been a growing preference towards the use of polyethylene plastic pipes. These flexible pipes can be delivered on site in sticks, or in rolled coils up to 100m. This makes it difficult to determine exactly what the average length would have been between joints. An assumption of 15m has been made.

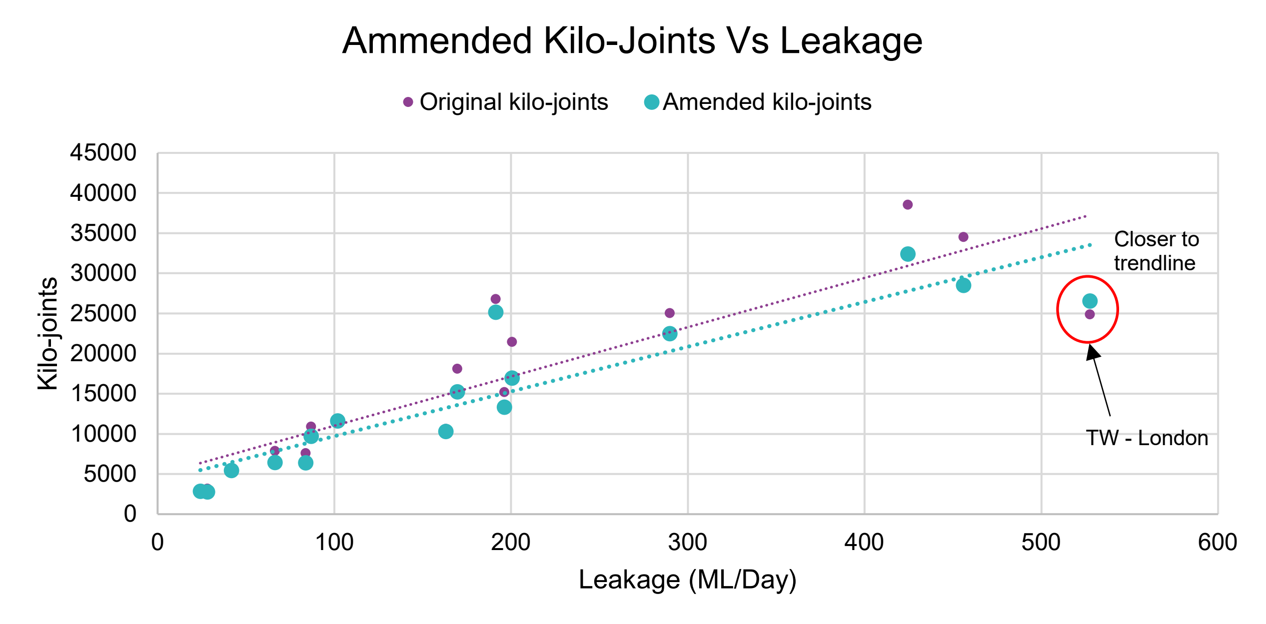
Table 4.4: Estimated manufactured pipe lengths by age band

pre-1880	1881-1900	1901-1920	1921-1940	1941-1960	1961-1980	1981-2000	2001-2020
1.4	1.4	1.4	3.2	3.2	5.5	15	15

Source: Mott MacDonald

The effect of the amended kilo-joint calculation on the water industry leakage comparison is shown in Figure 4.34. The correlation is improved for all data points including TW (r=0.91), and TW is noticeably closer to the trendline which has been set. This indicates the importance of accounting for pipe age and the effect of older manufacturing techniques (and newer ones) in estimating numbers of joints and justifies changes to UKWIR’s kilo-joint method.

Figure 4.34: Kilo-joint and leakage comparison with amended kilo-joint method



Source: Mott MacDonald analysis: Based on annual return data for 2019

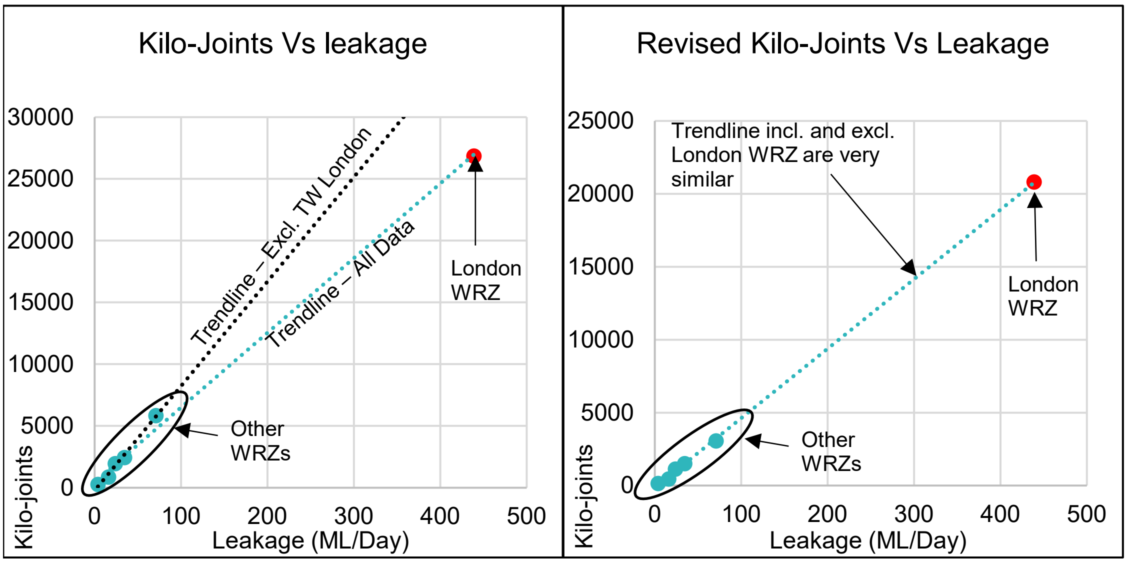
Returning to the original hypothesis, we have shown that:

- Using UKWIR's kilo-joint concept, there is a reasonable correlation between 'kilo-joints' and total leakage at a water company level, but the London network does not fit the trend-line using the original UKWIR formula
- A modified formula that accounts for the age profile of company networks and allows for more joints for older pipes to reflect the shorter lengths of pipe that could be manufactured, results in a better correlation and the London network is closer to the trend line.
- On this basis, we conclude that the revised kilo-joint is a good high-level leakage indicator.
- The London network has a higher number of revised 'kilo-joints' than the rest of the industry, creating more opportunities for leaks to occur. This partly explains TW's poorer leakage performance; the old parts of the network have higher numbers of joints and connections.
- An analysis of leakage per kilo-joint using the revised formula shows that TW's joints leak more than other companies, but not by as much.

Figure 4.34 shows that the relationship between higher numbers of joints and more leakage holds true for the whole industry, not just TW. The corollary is that if the industry wishes to reduce leakage, it should aim to reduce the number of joints in its networks. This perhaps explains the high performance of PE as a pipe material. Not only does it resist London's aggressive clay soils, but its installation method results in fewer joints.

We have used the revised kilo-joint formula to assess leakage performance within TW's region at WRZ level (see Figure 4.35). Positive results have been achieved whereby the trendline fits the datapoints more accurately.

Figure 4.35: Mapping kilo-joints at WRZ level



Source: Mott MacDonald analysis: Based on annual return data for 2020

We have not tried to use the revised kilo-joint formula to correlate leakage at a more granular level, for example FMZ level. We recommend exploring this and if it holds promise to perhaps track it as a high-level indicator which should fall as 'jointy' cast iron pipes are replaced with more continuous PE pipes.

We know that older cast iron pipes are vulnerable to fracture from changes in cold water temperature owing to corroded and 'locked' lead-pack joints. Studies by the University of Surrey have proved the failure mechanisms in the laboratory (see section 4.1). Given this, it would be good to know the location and health of all pipe joints in order to target interventions more appropriately.

In this context, we define a healthy joint as one that ensures the leak-tight connection of two pipes or fittings while allowing flexibility so that soil movement does not induce undue stresses in the pipe leading to fracture.

Unfortunately, there is very little information available on joints or joint health:

- No information is available in the mains repair database on joint condition or health. Comments are collected from field staff but often these do not include any information on the condition of the joints.
- No information is stored in TW's GIS database on joint location or health. Locational data is available on fittings, valves, washouts and other jointed apparatus, but no information is kept on the health of these. It may be possible to infer joint type from the date of installation (for example cast-iron pipes pre-1950s will not have rubber gasket push-fit joints), but this will not provide any information on their health.
- The trunk mains inspection database is the only data source which captures joint health information, but the information is limited and cumbersome to use. It is captured as a text-entry, meaning that each record is often unique as it is filled in by a field staff member. Of the 1556 records in the trunk mains inspection database, there are 480 unique entries.

The trunk main dataset is naturally biased towards pipes which have failed, otherwise they would not have been inspected and the dataset only considers trunk mains, so any lessons to be taken from the data may not be transferable to distribution mains. Nevertheless, the following observations have been made from the text entries in the database:

- Of the 1556 records, 45% of the entries do not explicitly mention if leakage is or is not occurring at the joints.
- Of the text entries which do explicitly mention if leakage is or is not occurring, 66% observed leakage at the joints.
- Lead protrusion was observed at 74% of joints where leakage was observed, albeit that only 1% observed no lead protrusion and 25% did not explicitly mention anything about lead protrusion.
- 69% of leaking joints were socket and spigot, 11% double socket, 7% did not mention joint type and the rest were couplings, previous repair fittings and bolted flanges.

In April 2021, TW updated its specification for the undertaking of pipeline condition assessment surveys by Hydrosave (the framework service provider). The updates to the asset standard include improved capture of visible joint data, with drop-down lists to collect standardised data which is better to use for statistical analysis. The new specification will require the capture of better information on joint type, lead protrusion, joint condition and joint deflection, which will provide greater insight in the future on the health of trunk main joints. We nevertheless make the following recommendations:

- Increase the number of mandatory fields to be completed during an inspection under the new specification, and review completion rates with Hydrosave to ensure that the data is being captured.
- Increase the number of visual fields for joint health to capture information on leak locations and volumes, external corrosion and any signs of stress fracture.
- Create a field in GIS to record the location of pipe joints on trunk mains and distribution mains and populate the type and location of joints initially based on pipe age, material and estimated type of manufacture. These can be steadily updated through observational data from the field.
- Consider assigning a condition grade to pipe joints to reflect their health. This could be based on a mix of observational data from inspections and other data on joint-type, age, leakage, and recurrence (see next section).

Capturing information to confirm joint locations and their health is challenging. In-pipe inspection techniques can identify joint locations and the presence of leaks, but we are not aware of current technologies that can determine the health of joints from the inside. A review of condition assessment technologies by United States Environmental Protection Agency (USEPA) in March 2012 identified this as a technology gap which the industry needs to fill. A follow-on report from USEPA in 2013 following a field demonstration assessment of different inspection tools indicated that the Australian company “Rock Solid Group’s” Broadband Electro-Magnetic (BEM) technology may offer a solution to inspect joints, although it was not specifically tested in any of the field tests.

In-pipe inspection technologies are developing at a rapid pace and therefore we recommend that technologies that claim joint health assessment capability are tested at TW’s new test-rig at Kempton Park. It is understood that TW will be trialling the technologies offered by Pure Technologies, Breivoll Inspection Technologies, and Acquaint at the test-rig, and it is recommended that TW take this opportunity to evaluate the effectiveness of these technologies to assess joint health. In the short term, we expect these technologies to be only viable for selected trunk main diameters, but in time it might be viable to use them on distribution mains.

4.5 Pipe health, leakage recurrence

The pipe health information that TW has available on its distribution mains consists of:

- Pipe burst and repair data, including date and location and since April 2021, type of failure (longitudinal or circumferential)
- Database of pipe samples taken in AMPs 3, 4 and 5 and associated pit-depth analyses and assessments (see section 4.1).

For its trunk main network, TW has:

- A trunk main inspection database containing pipeline condition surveys reports and assessments undertaken by Hydrosave (reported on above).
- Sahara leakage surveys and online pressure monitoring and acoustic logging.

TW uses this information, together with other datasets on age, material and pipe environment to forecast the likelihood of failure statistically.

4.5.1 Distribution mains health

In 2003 and 2004, to assess the variability of pipe condition in a localised area and within DMAs, TW commissioned whole street exhumations to help them understand how factors affect pipeline deterioration in metropolitan London[9]. These works are often referred to as the “two street exhumation”, but two separate studies were undertaken providing a dataset of four London streets. These streets include Elm Tree Road, Nugent Terrace, Cambridge Crescent and Navarre Street. In total, 289m of pipe was exhumed across the four streets, and the pipes were analysed using conventional pit-depth analysis to determine the extent of corrosion and whether remaining wall thickness was sufficient to sustain operating pressures.

Some of the key findings, which are still relevant today, were:

- Soil conditions are highly corrosive London clay and the impermeable nature makes it difficult for any leakage to pass through the soil. This affected acoustic leakage detection techniques, which were unable to locate the leaks pre-exhumation.
- On the streets, there was evidence of highly localised pockets of corrosive soil, with factors such as moisture content, presence of gas mains and tree roots causing localised hotspots.
- Bedding conditions were often poor, introducing potential stress hotspots. This was sometimes poorly constructed bedding but was also sometimes caused by direct contact with other utilities, or uneven support beneath the pipe. Localised stress hotspots often related directly with pipe performance.
- Repair clamps had sometimes been fitted but were not always operating as they should be.
- Several leaks were attributed to ferrule connections, where some had caused fractures, and others were simply missing.

Some of the concluding remarks include:

- Age is a key factor in pipe condition with pre-1900 cast iron pipes being particularly vulnerable due to length of service and absence of corrosion protective coating, and there is a general relationship between condition and performance.
- Pipe renewal rather than spot repair was more effective for pre-1900 cast iron pipes.
- Spot leakage determinations may not target all vulnerable assets in a DMA. The absence of leakage in one street with a severely corroded pipe was explained by the amount of (unrecorded) repairs/renewal along the street.

[9] Two streets Phase 1 – Final report and appendices 2003, + Two streets Phase 2 – Final report and appendices 2003

- The four streets showed differences in condition and performance demonstrating the variable nature of pipeline conditions within localised areas. Pipe fracture was observed to result from a combination of pipe condition and pipe stress with pipe stress resulting from localised factors such as soil-moisture deficit caused by the presence of tree roots.
- The best approach for assessing asset condition across a DMA is to measure pipe condition directly, and not infer conditions from surrogate data sets. It was found that the statistical relationship between age, soil and extent of corrosion was insufficient to predict pit depths.
- The best data set to invest in to improve asset condition information is surveys sampling actual condition (pipe samples or inspection pig) and surveys to assess the loading environment.
- Street works activity, (by all utilities) involving substantial removal of soil from along or near a water main, can affect pipe performance.

The findings are synchronous with our analysis. While we can use datasets and statistics to understand the risk of failure, the network is variable in its nature and localised hotspots can be particularly problematic due to a host of factors which are not always easy to explain until they are investigated. This emphasises the importance of having good asset health information at a local level. If the extent of corrosion is known to be extensive, (as in the case of Cambridge Crescent) than local conditions would dictate renewal to be the optimum intervention and prevent continuous repair of pipes at increased cost and disruption.

The ‘two-street exhumation’ work obtained valuable information on TW’s distribution system and helped to justify the VMR programme in AMP4. Whereas the need for localised asset health information is clear to confirm the extent of corrosion and identify hotspots, we would not recommend exhuming whole streets of pipes to obtain it. Statistical modelling undertaken since the two-streets investigations were completed has proven quite reliable in identifying vulnerable parts of the network and targeted sampling in these areas together with other performance and environmental information should be sufficient to confirm need and identify optimum solutions.

4.5.2 Trunk main monitoring

Understanding asset health on trunk mains systems is notoriously difficult and expensive but TW are arguably one of the leaders in this field.

TW has a limited number of ways in which it monitors trunk mains for the purposes of early warning and associated failures. There are primarily two ways in which this is undertaken, fixed monitoring and targeted surveys. Fixed monitoring has been adopted in areas of the network through the use of Syrinix and Hydroguard units. Both devices rely on acoustic monitoring of the network to identify noise variations and hence bursts in the localised network. Targeted surveys are also undertaken through the use of Sahara surveys on high-risk mains. As with the other units this is an acoustic monitoring system to identify active leaks on the trunk main system, from which repairs can be carried out.

Limitations exist with both systems, primarily a failure needs to occur for the acoustic monitoring to record that a failure has occurred. The fixed locations will only record data across a limited coverage area of the network, and while the Sahara surveys allows mobility, it will only identify leaks that have already occurred in the network at the location of the survey. We are aware that new Syrinix units are being used for monitoring pressure transients.

Leaks identified through the use of Sahara surveys are assessed on the basis of cost benefit for repair and scheduled accordingly or monitored further over a period of time.

TW has available to it other sources of data. Pressure reducing valves (PRV’s), Critical Pressure Points (CPP’s), Zonal meters, and district meters are all equipped with pressure transducers. This information used to exist in separate systems, however a new tool called

System Risk Visualisation(SRV) has been developed which begins to pull this information together (this is discussed more in chapter 6.7).

Non-Destructive Testing (NDT) is generally undertaken by the framework supplier Hydrosave. TW has recently made changes to the requirements and quality of the data collection when undertaking an NDT on a trunk main. More detailed assessments are now required that will provide additional data on joint health of the main.

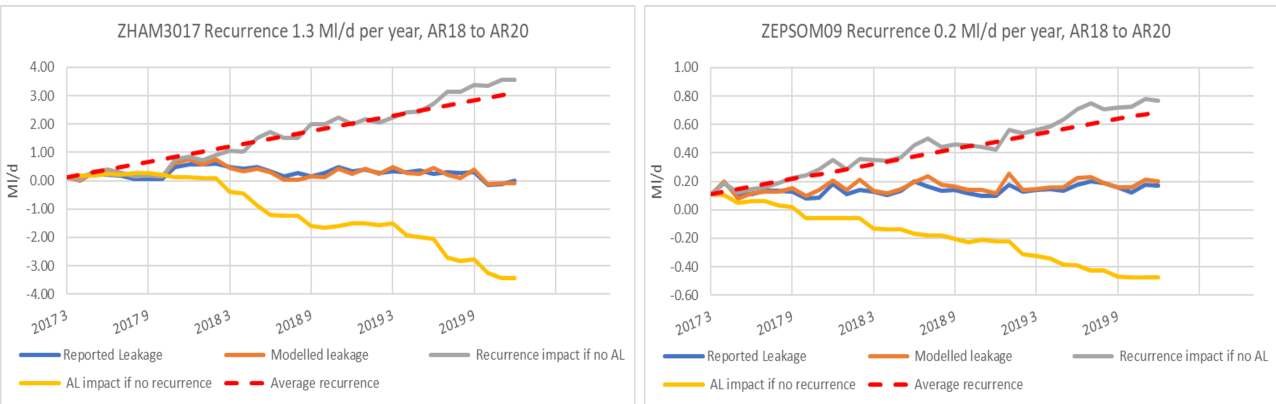
While there is an aspiration to capture NDTs on every main exposed during an excavation, coordination of this is not always feasible, due to third party influences like available traffic management restrictions, and other buried assets adjacent to the mains. Where NDT data is collected, it is provided to asset management to assess the data and feed into the trunk main assessment tools.

4.5.3 Leakage recurrence

For distribution mains, apart from recording pipe repairs and taking and testing pipe samples to determine the health of pipes, TW has been exploring recurrence as a measure of asset health. Leakage recurrence (otherwise called net rate of rise NRR) is the rate at which leakage increases in a DMA when no detection or repair work takes place. DMAs with high recurrence rates need more frequent active leakage control to maintain a given level of leakage than zones with low recurrence rates. High recurrence rates occur when the pipes within a DMA are in poor health and start to fail and leak again quite quickly after repair gangs have finished repairing leaks from previous leak detection work. This is because pipes are corroded with limited wall thickness and cracks open and leak under normal operating pressures. DMAs with low recurrence rates are generally in better condition resulting in the beneficial effects of repair being felt for longer before pipes deteriorate and start leaking again. This makes recurrence a good measure of asset health.

This is good in theory, but the challenge with recurrence is having sufficiently complete data to estimate it reliably. TW has achieved this at a company and regional level and is starting to have some success at DMA level as shown in Figure 4.36.

Figure 4.36: Estimating DMA recurrence rates



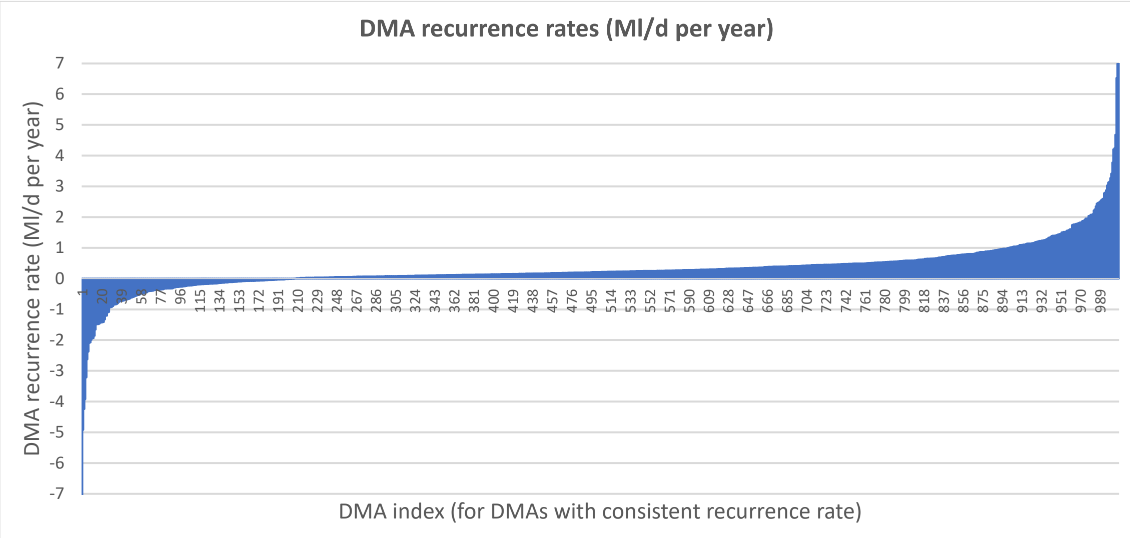
(a) DMA with high recurrence rate (b) DMA with low recurrence rate

Source: Thames Water, 'Estimating DMA recurrence', August 2020

In each of the charts in Figure 4.36, recurrence (the grey lines) has been estimated from changes in minimum night flows when no leak repair work was taking place over the AR18 to AR20 period. The amount of leakage saved from leak repairs on mains, communication pipes and fittings was also estimated (the yellow lines) and subtracted from recurrence to estimate net leakage (the orange lines). This was compared with measured leakage (the blue lines) to confirm that estimated recurrence is correct and aligned with leakage control activities and measurements.

This has been repeated for all TW's DMAs for data from AR18 to AR20 (data from previous years were too unreliable) and where recurrence rates were consistent across the three years, these have been averaged (the red-dotted lines on the charts in Figure 4.36). It was found that for 40% of the DMAs, the data were too inconsistent to derive a reliable estimate of recurrence. For the 60% where recurrence could be estimated, the range of values is shown in Figure 4.37.

Figure 4.37: Range of DMA recurrence rates



Source: Mott MacDonald analysis of TW DMA recurrence data

Figure 4.37 shows that some DMAs apparently have negative recurrence rates, which is not feasible. The likely reason for this is incorrect recording of the flow direction of the meters on the boundaries of these DMAs. For the DMAs with positive recurrence rates, 35% have low recurrence rates (<0.2 Ml/d per year), 35% have medium recurrence rates (0.2 to 0.5 Ml/d per year), 17% have high recurrence rates (0.5 to 1.0 Ml/d per year) and 13% have very high recurrence rates (>1.0 Ml/d per year). Table 4.5 shows the correlation of leakage recurrence rate with repair rates for these DMAs.

Table 4.5: Correlation of leakage recurrence rates with repair rates

Recurrence category	Nr. DMAs	% DMAs	Recurrence rate (Ml/d per year)	Average repairs/km[1]
Low	276	35	<0.2	0.177
Medium	279	35	0.2 to 0.5	0.266
High	138	17	0.5 to 1.0	0.352
Very high	107	13	>1.0	0.368

[1] Average for same period used for recurrence calculations (2018 to 2020)

Source: Mott MacDonald analysis of TW DMA recurrence and repair data

Table 4.5 shows that there is a strong correlation between recurrence rate and repair density, showing that it is a good measure of asset health. We recommend therefore that recurrence is developed and captured as an asset health metric at a DMA level and then aggregated up to regional and company level for reporting. One would expect recurrence rates to fall as mains are renewed in a DMA and thus it can be captured as an asset health benefit and as it relates directly to leakage control costs, the long-term benefits to opex reduction can also be captured. Recurrence could also be used as an additional means for targeting DMAs for investment as those with the highest recurrence rates have the greatest potential for opex reduction through mains renewal in addition to other benefits to leakage and service provision. TW plans to include recurrence rates in its DMA fingerprinting (see Chapter 6).

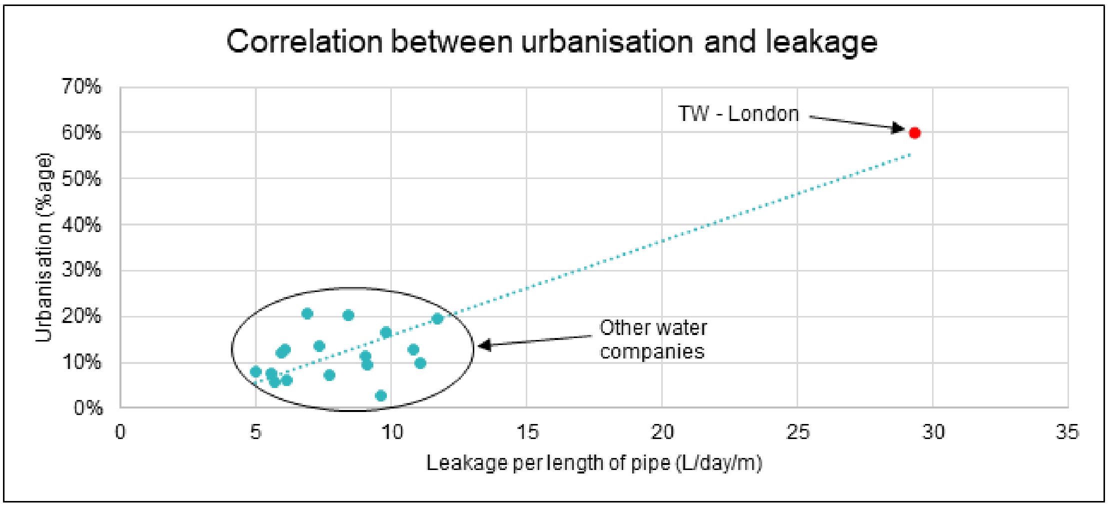
Further work is required, however, to review the data for those DMAs with negative recurrence rates and to increase the number and percentage of DMAs for which consistent estimates of recurrence can be derived. The work that TW has already done, however, has identified which DMAs require investigation.

4.6 Failures at road junctions

There is evidence that London experiences higher traffic flows and has a higher concentration of major roads than elsewhere in the country and high traffic flows may cause pipe failures, particularly at road junctions. There is evidence that more bursts occur at road junctions, where pipes may experience acceleration and braking forces from vehicles and there is also commonly a concentration of pipe fittings and joints at road junctions. This section examines the evidence that London has high numbers of road junctions and this leads to higher bursts and leakage.

London has a higher level of urbanisation than the areas covered by other water companies and this impacts leakage. Highly urbanised networks have more joints and connections and section 4.4 has shown that there is a good correlation between joint density and leakage. To show this, we have charted leakage against water companies' urbanisation percentage (measured as total urban area within the water company boundary divided by the total area of the water company boundary). The result in Figure 4.38 shows that while leakage in London is higher than other companies, there is a strong correlation (r=0.89) with urbanisation.

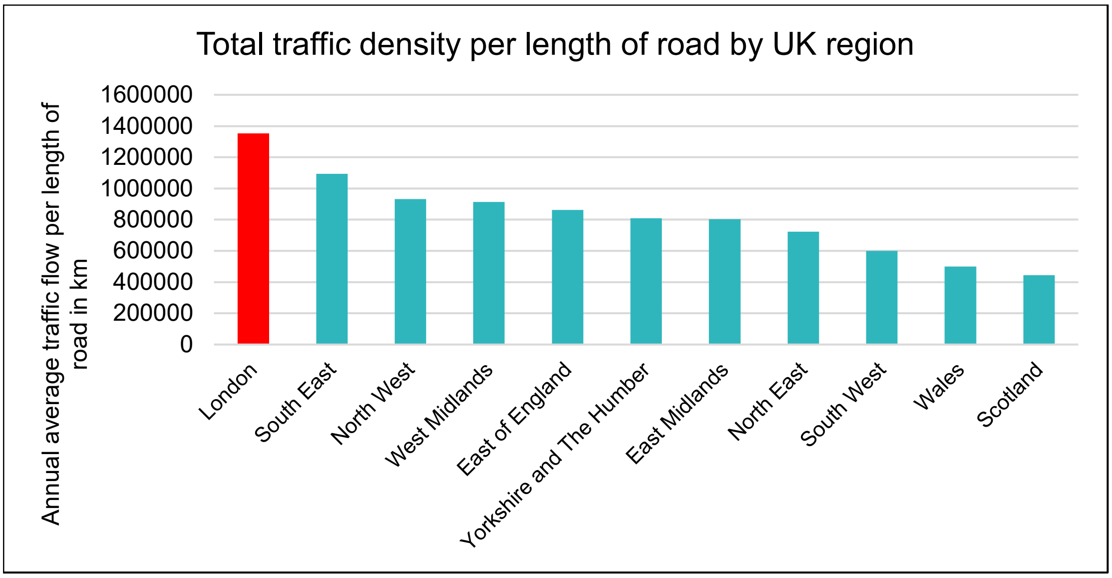
Figure 4.38: Correlation between urbanisation and leakage



Source: Mott MacDonald analysis based on OS urban regions (strategic) and annual return data for 2019

Data from the Department for Transport indicates that London receives higher traffic flows than other UK regions (see Figure 4.39).

Figure 4.39: Traffic flow per length of road by UK region

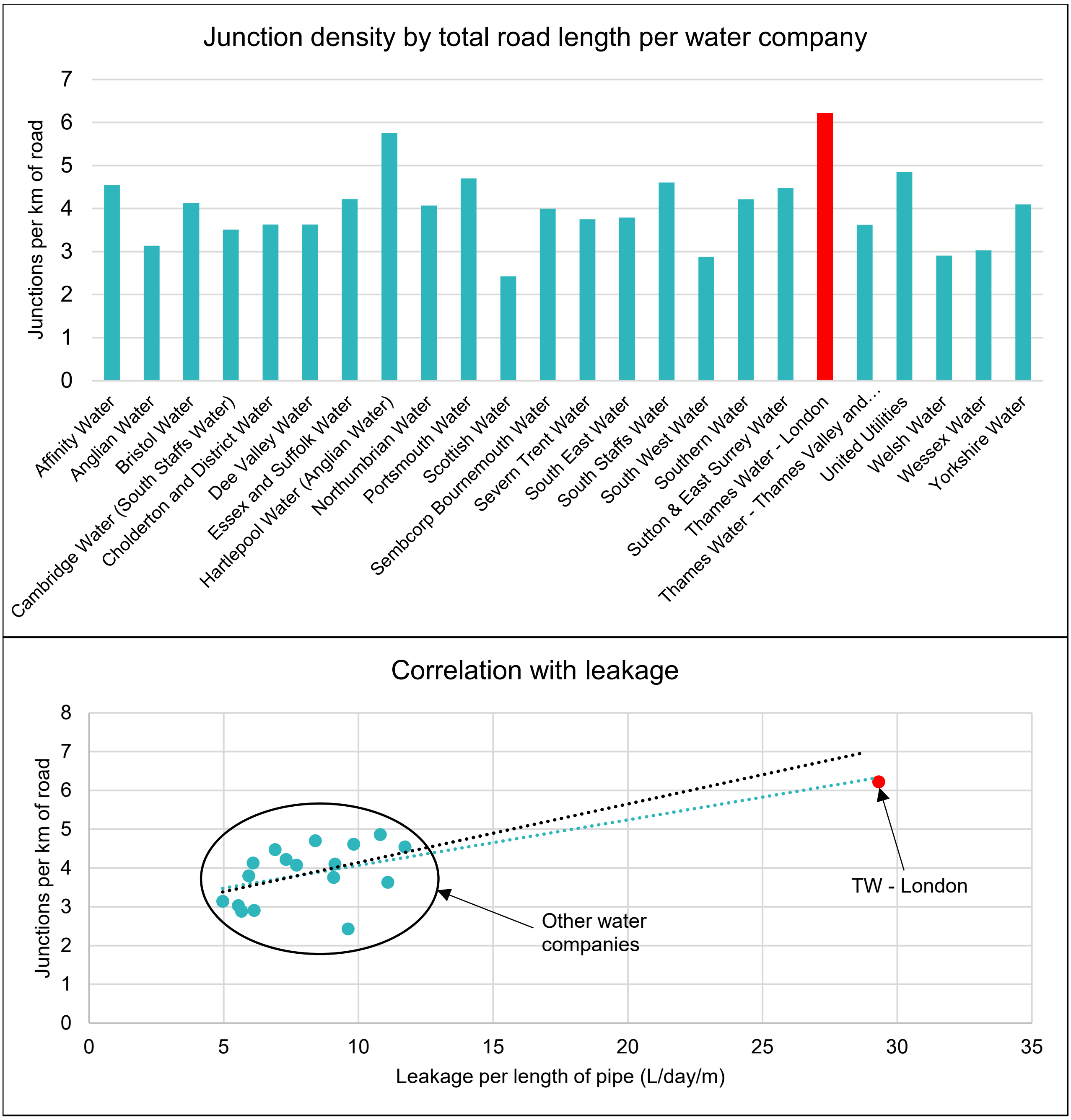


Source: Data from Department for Transport

We have analysed junction density and road lengths per water company using intersected GIS data and compared this with leakage. The analysis indicates that TW has a higher road junction density per length of road than any other water company as shown in Figure 4.40. In some cases, the junction density is more than double that of other water companies.

The chart at the bottom of Figure 4.40 shows the correlation of road junction density with leakage. The chart shows that water companies with higher junction densities will have higher leakage values. Two linear trendlines have been included in the analysis. The first trendline includes all data points and the leakage performance of TW London fits well on this trend line with a moderate/strong correlation (r=0.70). The second trendline excludes the TW London data point as an ‘outlier’, and while there is a reduced correlation between those points (r=0.44) the data still indicates that higher road density equates to higher leakage values.

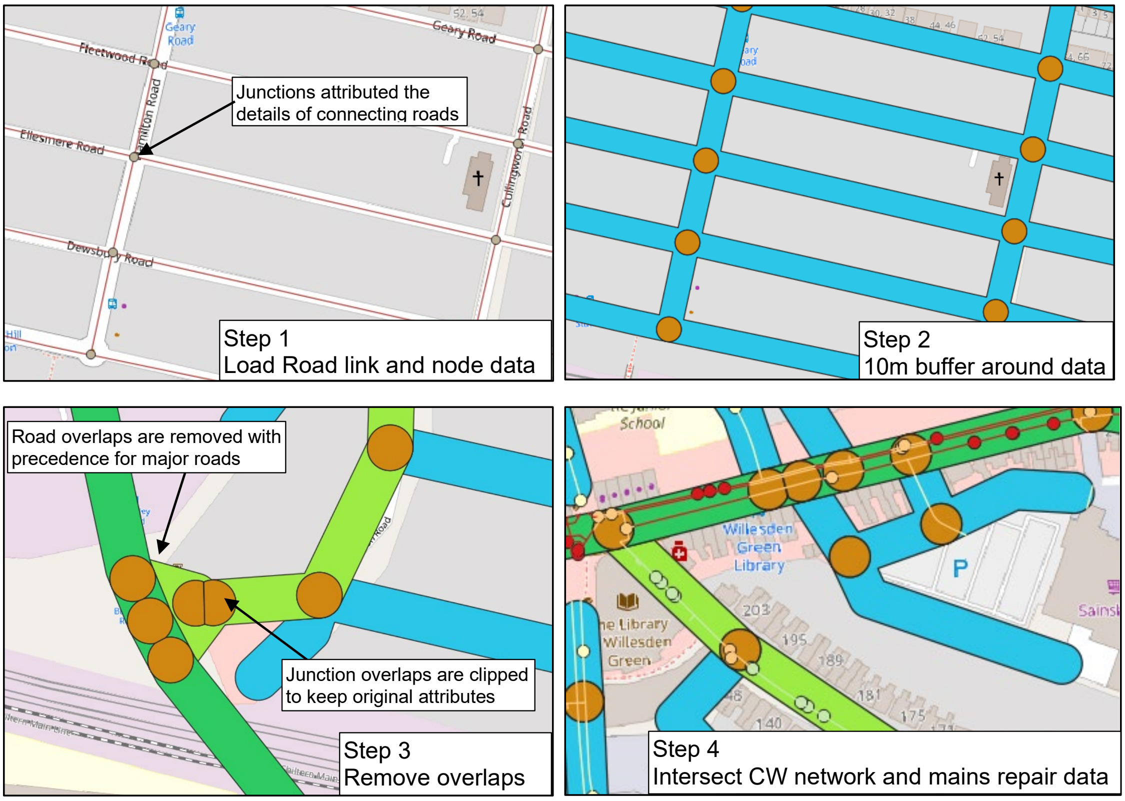
Figure 4.40: Junction density by road length (top) and correlation with leakage (bottom)



Source: Mott MacDonald analysis based on OS Open Roads and annual return data for 2019

To estimate the prevalence of pipe failures at road junctions we followed the steps described in Figure 4.41.

Figure 4.41: Processing road junction data to analyse prevalence of repairs at junctions



Source: Mott MacDonald analysis based on OS Open Roads and TW mains repair database

The output from this process is presented in Table 4.6 as a repair density per kilometre of pipe. The analysis indicates that a length of pipework located within a junction/roundabout is 53% more likely to be repaired than a comparative length of pipework located within a road (away from any junctions). It can therefore be inferred that more leakage is occurring at junctions as more repairs have been undertaken. This supports the previous analysis that junction density correlates with leakage.

Table 4.6: Repair density comparison between roads and junctions

	Repair count	Main length (km)	Repair density (/km)
Road	99,784	22,946	4.35
Junction/Roundabout	28,944	4,362	6.64

Source: Mott MacDonald analysis based on OS Open Roads and TW mains repair database

As no repair data is available for other water companies, the only comparison which can be undertaken on a regional level is between TW's London region and the Thames Valley and Guilford region. The difference in repair density is shown in Table 4.7. The data presented shows that more repairs per kilometre of main are undertaken in London than in Thames Valley and Guildford, both at junctions and roads. For both regions the data shows higher densities of repairs in junctions. In the London region, junctions are 40% more likely to have received a repair in comparison to roads, and in the Thames Valley and Guildford area this is higher at 54%. This data shows that the finding that bursts and leakage are higher at road junctions than the roads between junctions is not limited to the densely urbanised area of London.

Table 4.7: Repair density (by length of pipe) between TW regions

	Repair density in roads (/km)	Repair density in junctions (/km)	Total repair density (/km)
TW – London	5.49	7.66	5.89
TW – Thames Valley and Guildford	2.87	4.41	3.06

Source: Mott MacDonald analysis based on OS Open Roads, TW asset record GIS and TW mains repair database

Another important variable to consider with roads, is the road classification and how that effects performance. The repair densities per kilometre of pipe for different road types are presented in Table 4.8. There is no difference in the repair density between A-Roads and B-Roads, and the difference with minor roads is also minimal. However, local and access roads do receive slightly higher repairs. This may indicate higher leakage on these roads, although it may also be a result of easier access to undertake repairs on these smaller residential roads.

Table 4.8: Repair density (by length of pipe) by road classification

Road classification	Road repair density (/km)
A Road	4.04
B Road	4.04
Minor Road	3.90
Local/Access Road	4.63

Source: Mott MacDonald analysis based on OS Open Roads, TW asset record GIS and TW mains repair database

There are many factors to consider when trying to understand why leakage may be more prevalent at junctions in comparison to roads. Some of the potential factors include:

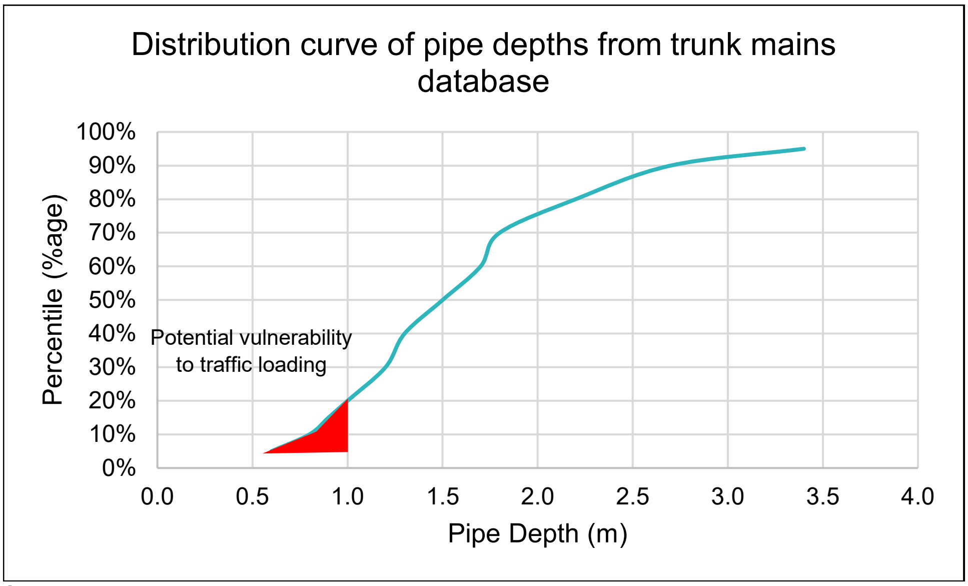
- More joints at junctions for all the necessary fittings (tees, washouts, air-valves, gate valves etc.).
- Bends and tee fittings at junctions which will exert hydraulic forces on the pipeline which could lead to joint displacement if not adequately restrained.
- Junctions may have received non-preferential treatment for mains replacement schemes due to complexities with traffic management, which means there is a higher proportion of older cast iron mains at junction locations (67% of pipe length in junctions are CI, compared to 63% in roads).
- More third-party services at junctions such as high voltage electricity cables which can cause corrosion.
- More works by other third parties inducing ground movements around the water mains.
- Increased traffic loading through braking, acceleration, and cornering forces.

All of these factors will contribute in some way to explain why pipes fail more at junctions in comparison to roads, and some of these factors will have a greater influence than others.

For the case of traffic loading, there is an argument that the horizontal forces imposed by vehicles on the ground from accelerating, braking, and cornering may increase the loading on pipes. BS 9295 is used as the standard for the structural design of buried pipes and their bedding design, and this indicates that at shallow depths of 1m to 1.5m, traffic loading is the dominant load on buried pipes, whereas at depths greater than this, the weight of the backfill is the dominant load. Shallow-buried, large diameter, flexible pipes may be more vulnerable than small diameter pipes owing to the risk of asymmetrical deformation from horizontal forces.

Unfortunately, TW does not currently keep a record of the depth of its clean water assets so we have been unable to assess which pipes might be vulnerable to traffic loading owing to their shallow depth beneath the road surface. Today's TW asset standards require clean water pipes to be installed at a depth of cover of at least 0.9m so that the pipe is less prone to effects of traffic loading. Despite this, depth data from TW's trunk main inspection database (the only source of data for pipe depth) indicates that 15% of its pipe stock is less than this, with 5% less than 0.6m deep (see Figure 4.42). Given that this is a trunk main database, distribution mains could be even shallower, particularly at junctions where the mains may rise and fall to accommodate other third-party utilities. It is also uncertain how bedding design and construction in the past was controlled in pipe laying installations. The understanding of bedding design has improved over time as well as improved construction methods and quality assurance practices. This means that TW may be disadvantaged by its older pipe stock that has not benefited from these improvements.

Figure 4.42: Distribution curve of pipe depths from trunk mains inspection database



Source: Trunk mains inspection data

In summary:

The analysis which has been undertaken shows how the London region is significantly more urbanised than any of the other water companies and how it also experiences larger traffic volumes. The analysis also shows that the London region has the highest density of road junctions in comparison to other water companies, and that this measure has a proven correlation with leakage.

The geospatial analysis which has been undertaken shows that repairs are 53% more likely to occur within 10m of the centre of a junction in comparison to a road. It can be inferred from this measure that more leakage is likely to occur at junctions as a result.

While TW does have the highest traffic volumes, traffic loading dissipates quickly with depth, and it is only shallow pipes (<1m) which are likely to experience significant traffic loads. Unfortunately, pipe depths are not recorded across the TW region. However, there is some pipe depth data in the trunk main inspection database which indicates that approximately 15% of the pipe stock is laid at a shallower depth than the 0.9m limit set in the asset standards.

There is a correlation between junctions and leakage, but traffic loadings will not be the only factor to consider. Naturally there will be more joints at junctions which are a source of leakage, there will be more third-party utilities at junctions including high voltage cables which may cause corrosion, and there will be a transfer of forces at bends and fittings etc. The relative importance of these factors has not been evaluated in this assessment.

It has been possible to locate the junctions with the highest rates of failures, and some analysis of these sites has been undertaken. The outcome from this assessment indicates that there are a range of location-specific factors at play at the worst performing locations which affects leakage performance.

Many of these sites have a high frequency of repairs within relatively short distances of each other and it is likely that a whole-life cost-benefit analysis at these sites would favour pipe replacement over continued repair. We recommend that TW applies repair triggers (automatic monitoring of repair workorders in the same location) to flag such cases to asset planners to consider the case for replacement instead of continued repair.

Other recommendations we make arising from our analysis of failures at road junctions are:

- Use the analysis to inform targeting of mains replacement by identifying high risk mains at junction locations and spend-to-save opportunities.
- Continue investigations into the causes of higher numbers of mains failures at road junctions, focusing on the higher burst frequency sites. The purpose of understanding the causes better would be to a) improve forecasting of bursts and leakage at these locations and b) ensure that any asset renewal work accounts for them. Like for like replacement, for example, may leave the new pipe vulnerable if the causes are not fully understood.
- Improve the recording of pipe depth, especially at road junctions where vehicle loading may be important. Identify road junctions where pipe depths are shallow (below TW's asset standard) to inform plans for the replacement and/or protection of these assets.
- Enhance the analysis of road junctions presented here by refining the 10m buffer used to define road junctions to improve insight into the causes of failure.
- Consider field studies to improve understanding of the impact of acceleration and braking forces from vehicles on buried pipelines.

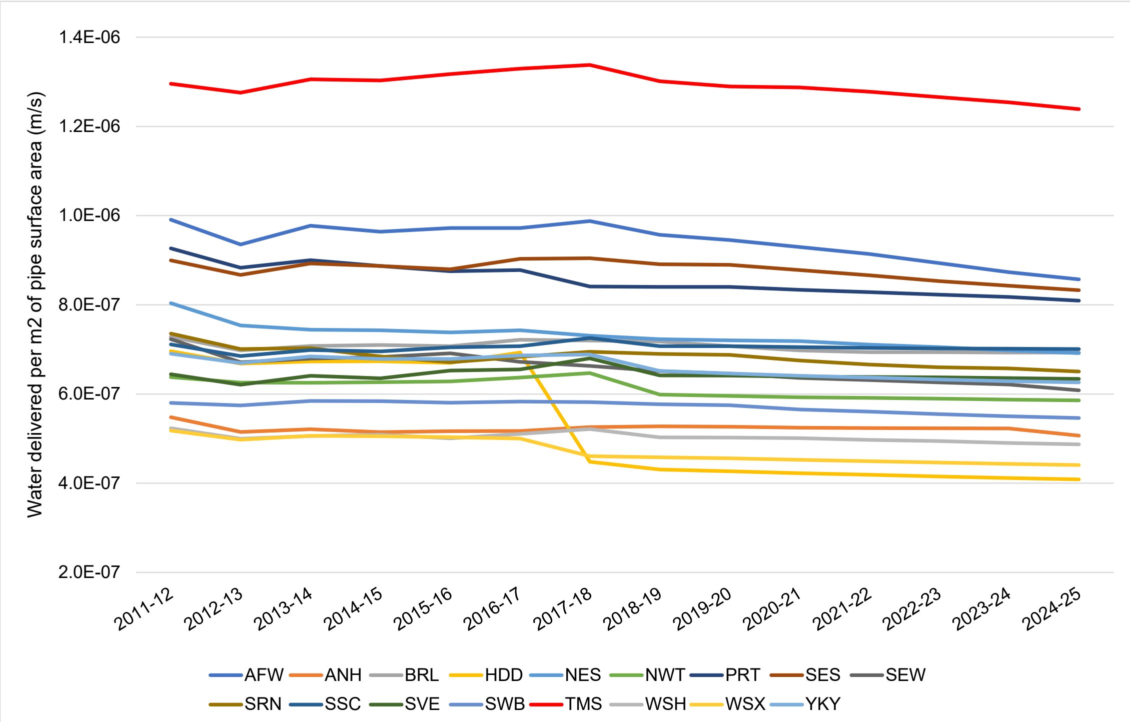
4.7 Impact of hydraulic stresses on pipe failure

4.7.1 Hydraulic loading

There is top-down evidence that TW's network incurs greater hydraulic stress than that of other companies by virtue of the larger volumes of water pumped into it, the concentrated nature of the network around London and the historic growth in demand served by a network which was designed for a smaller population. The population in London is now 30% higher than it was 20 years ago and is projected to grow further.

Based on industry data, we have calculated the surface area (m^2) of the water mains for each of the water companies for the years 2011/12 to 2024/25 and related this to water delivered (in m^3/s) to derive hydraulic loadings in m/s. The results are shown in Figure 4.43.

Figure 4.43: Comparative hydraulic loading of water networks



Source: Mott MacDonald analysis: Data from 2017 cost assessment data share and 2018 BP data tables

The overall hydraulic loading on TW's water network is considerably higher than for other water companies, nearly twice as much on average. Interestingly, the nearest company to TW is Affinity Water, another company that operates in the London area. Note that all companies are projecting a fall in hydraulic loadings in AMP7, reflecting ambitious leakage targets.

The flat topography of London also means that most of the water must be pumped, either via transmission mains or boosters in the distribution system, creating a greater chance of transients, whereas some other networks operate by gravity, creating calmer conditions. The impact of higher hydraulic stress on the network is to increase the likelihood of pipe failures, especially in older parts of the network that are known to be vulnerable from corrosion.

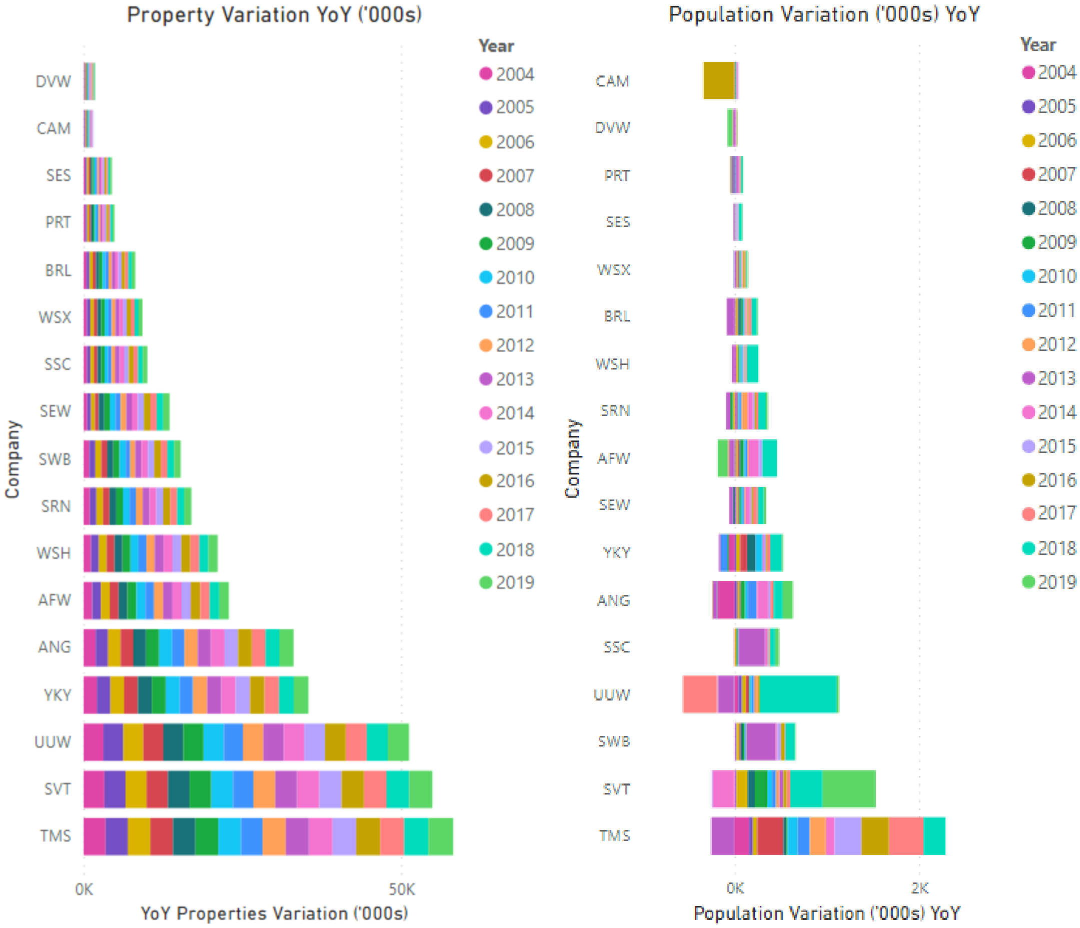
Apart from this top-down analysis, evidence that TW's network suffers higher hydraulic stresses than other companies because of higher hydraulic loading is limited. This section explores bottom-up evidence of the impact of hydraulic stresses on network performance and seeks to evidence what TW has done to mitigate the effects through 'calm network' policies and controls.

4.7.2 Hydraulic features

First, we examine growth and compare the hydraulic features of the London network. Growth in demand can gradually increase flows in a network and take the operating parameters outside historical design assumptions for any aspect of the hydraulics. Pipeline additions to service new demand areas will be well designed with headroom for the future, but velocities in existing pipes suppling them may increase, pumps may operate away from optimum efficiency and other hydraulic controls and surge protection may be near their limits, even if maintained well. It is the cumulative effect of these changes that causes hydraulic stress on the system.

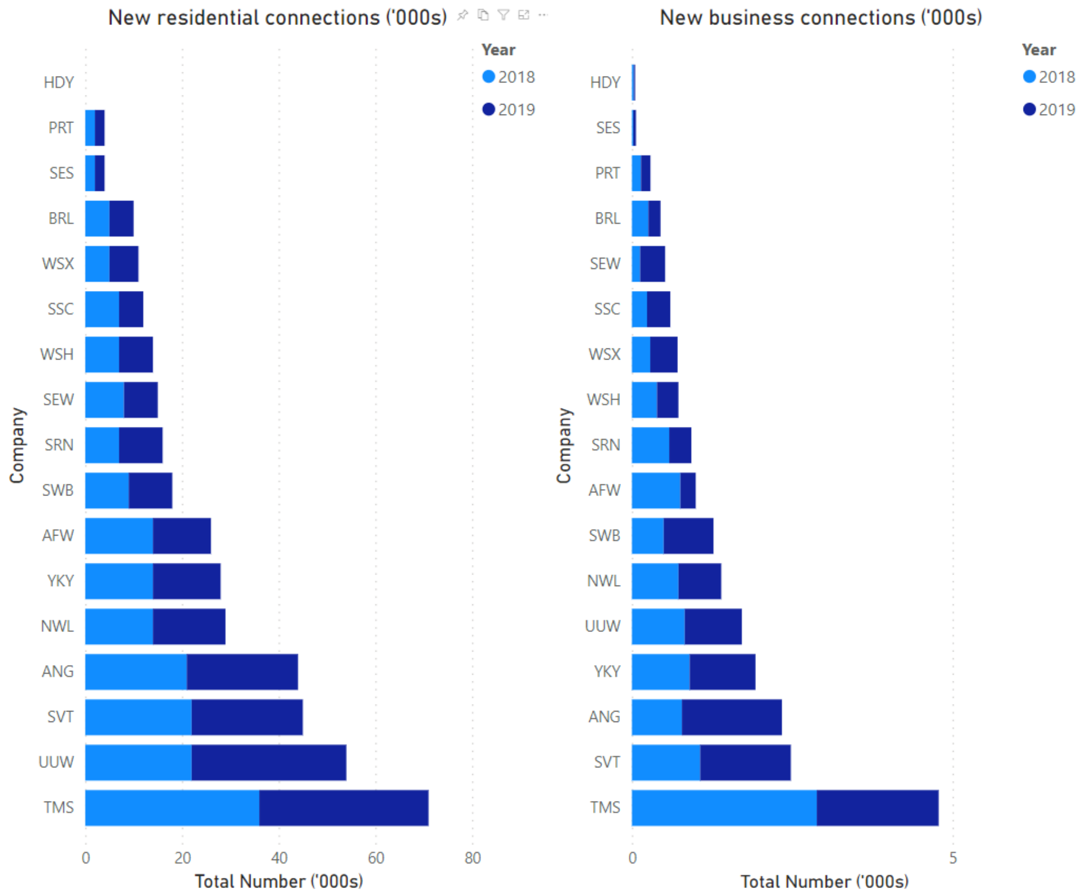
Figure 4.44 and Figure 4.45 show that TW has had a higher growth rate than other companies (both in terms of property variation and population variation) and therefore has a higher risk of being impacted by these cumulative effects.

Figure 4.44: Comparative analysis of Growth in England and Wales



Source: Annual return data from 2004 to 2019

Figure 4.45: New Business and Residential Connections (2018/2019)

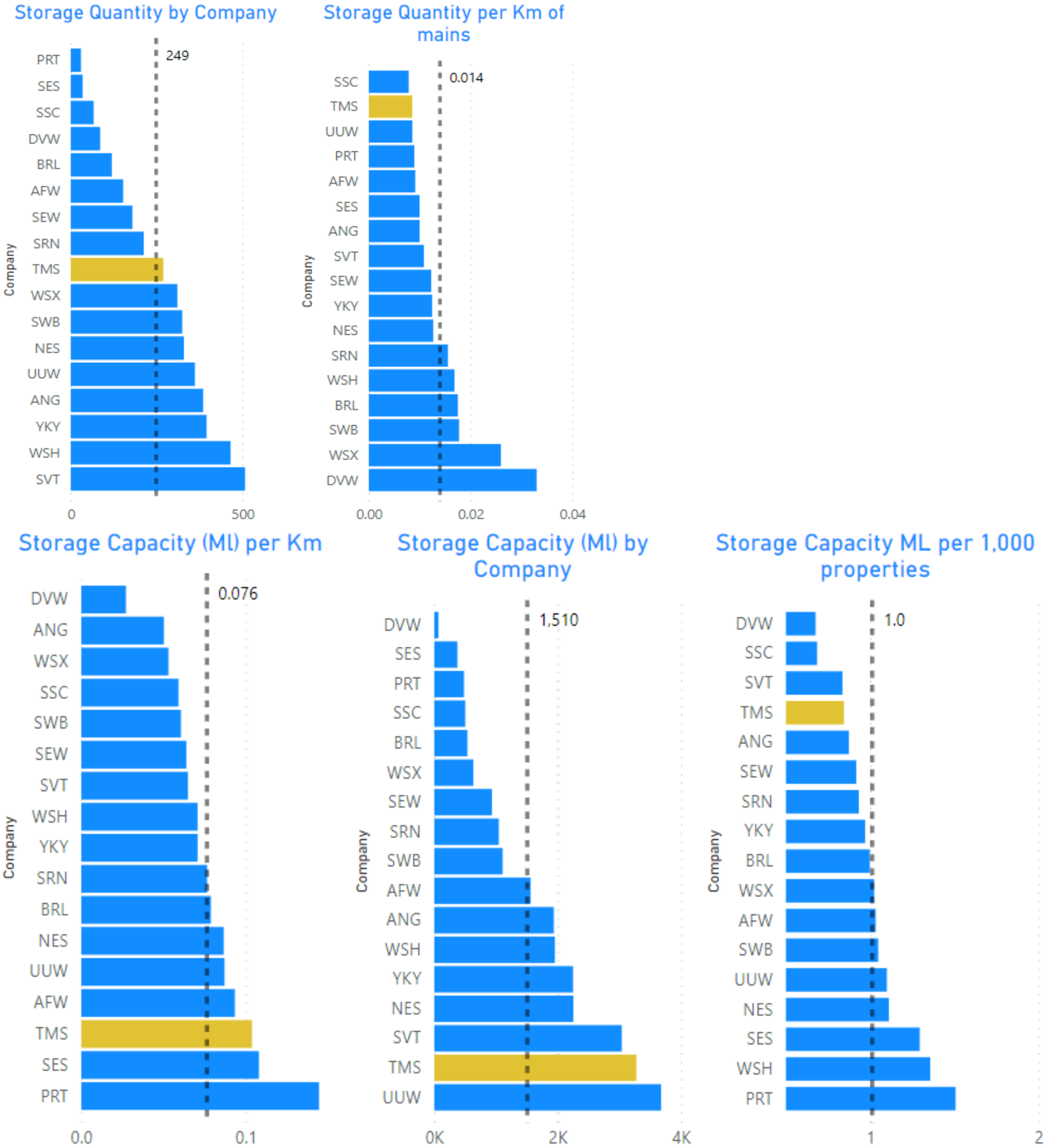


Source: Annual return data for 2018 and 2019

In the context of growth in demand, TW has inherited a network which is not conducive to calm operations. It has comparatively few service reservoirs for its size, one of the lowest in terms of reservoirs per kilometre, but it has the second highest reservoir storage volume. The smaller number of larger reservoirs means that TW's customers may be further away from a service reservoir than those in other companies and many customers are not supplied by gravity from a service reservoir but have a pumped supply which can create turbulence.

Figure 4.46 also shows that TW has below-average storage capacity per property. This is not an indicator of hydraulic stress but does show that Operations have less time to respond to events and less flexibility for managing outages which could affect interruption to supply performance and/or water quality if reservoirs are drawn down toward bottom water level.

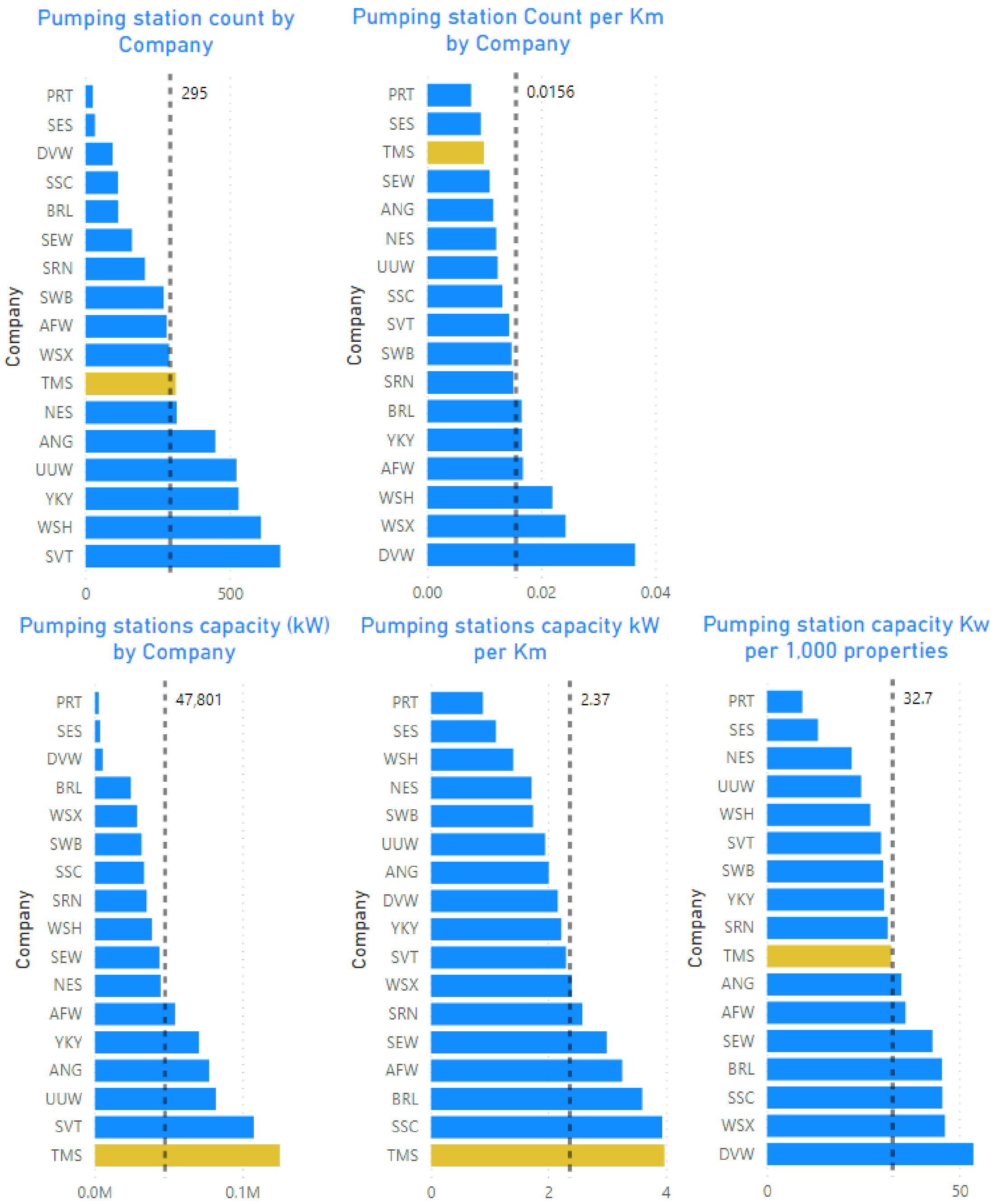
Figure 4.46: Comparative reservoir storage



Source: Annual return data 2020

Figure 4.47 compares pumping facilities. Like storage reservoirs, TW has comparatively few pumping stations, but they are much larger than those of other companies. In fact, TW has the highest installed capacity in kW per Km of watermain than any company. This reflects the high level of pumping in the network, increasing the risk of transients and other hydraulic stresses.

Figure 4.47: Comparative pumping capacity



Source: Annual return data 2020

4.7.3 Hydraulic stress – diurnal pressure variance

In investigating evidence of hydraulic stresses, we considered two possible pipeline failure mechanisms resulting from hydraulic stresses:

- Cyclic loadings over extended periods caused by diurnal pressure variations
- Instantaneous pressure spikes caused by surge events

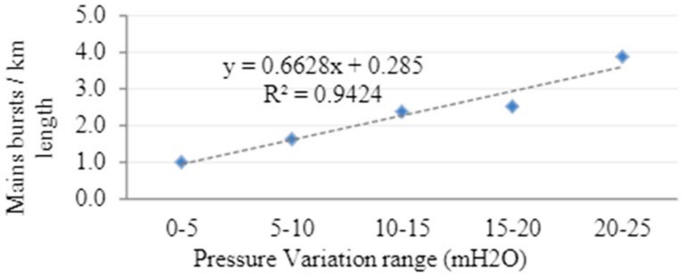
These failure mechanisms can be accelerated by factors such as:

- Pipeline degradation (e.g. corrosion).
- Changes to system operation (e.g. increased pump switching and demand variations)

We would not expect a new, well designed network to be vulnerable to normal diurnal pressure variations. The pressure variations normally experienced are well within the fatigue limit of ferrous materials. However, TW operates an ageing and corroded infrastructure with diminishing pipe pressure ratings, and diurnal pressure variations may be sufficient to open pre-existing cracks or defects and promote leakage and bursts.

Our point of reference for believing that diurnal pressure variation might affect leakage and numbers of bursts is a 2015 paper by Imperial College[10] which found a correlation between pressure variance and burst numbers using data from Severn Trent Water. This is shown in Figure 4.48. In addition, an UKWIR report[11] on the impacts of mains renewal on leakage found that the benefits from mains renewal for leakage and mains repair are reduced in DMAs with high pressure variance compared with those with low pressure variance.

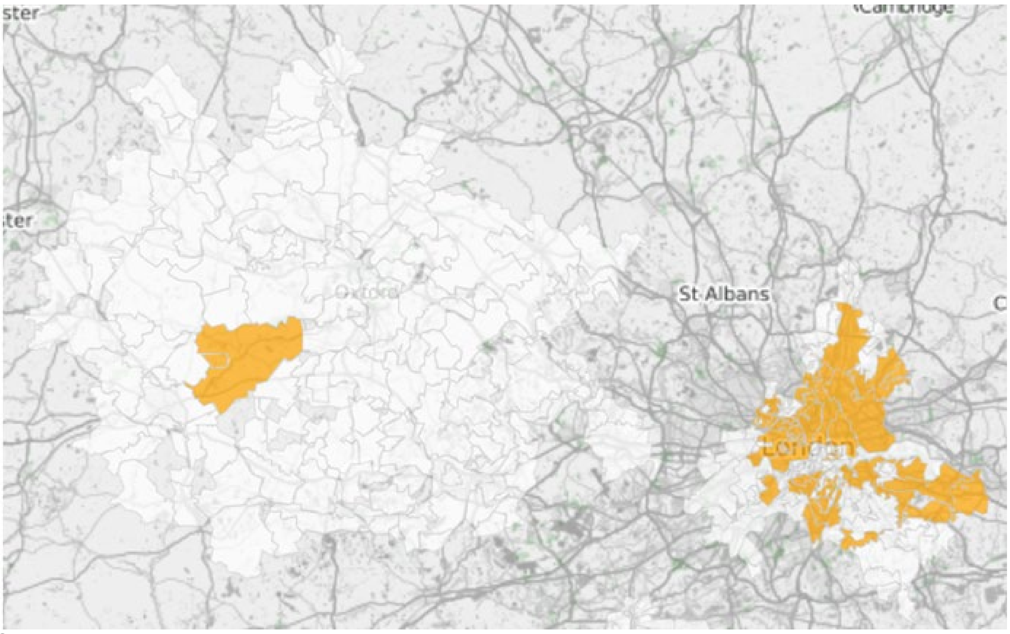
Figure 4.48: Positive correlation between pressure variance and bursts



Source: Extract from 'Pipe failure analysis and impact of dynamic hydraulic conditions in water supply networks' 2015

To test the hypothesis, we used DMA level data from 28 zonal performance assessment reports (ZPAs) and pipe level data from the Barrow Hill and Shootup Hill FMZ hydraulic model. it's the ZPAs covered approximately 35% of the TW network, but these are concentrated in London as shown in Figure 4.49.

Figure 4.49: Zonal performance assessment report coverage



Source: Thames Water

[10] Pipe failure analysis and impact of dynamic hydraulic conditions in water supply networks, proceedings of Computer Control for Water Industry Conference, 2015

[11] UKWIR, The impact of burst-driven mains renewals on network leakage performance, report ref 18/WM/08/67, 2018

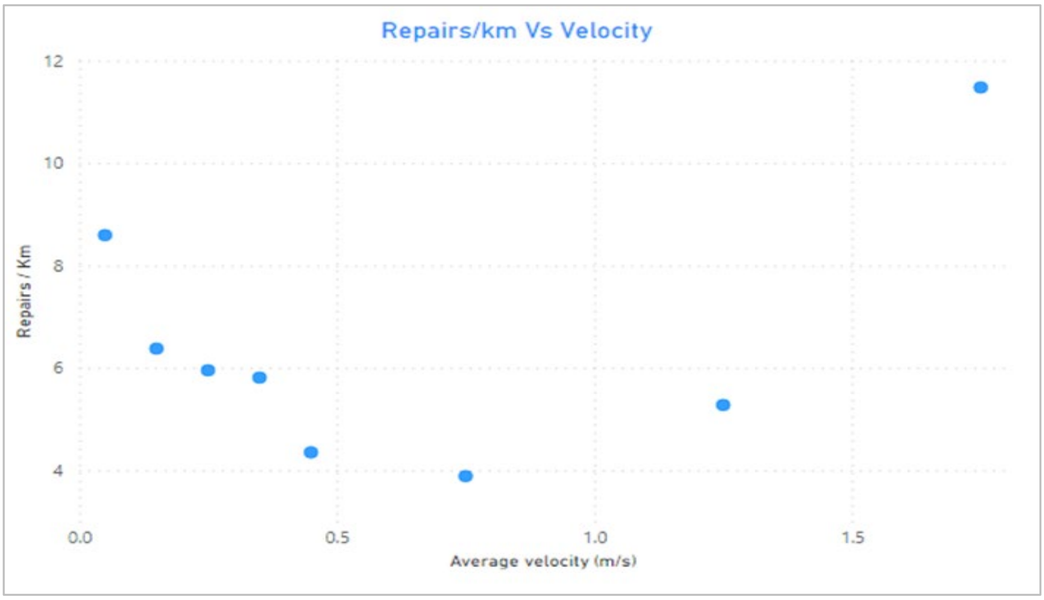
The calibrated Barrow Hill and Shootup Hill FMZ hydraulic model was used to test the potential relationship between various hydraulic parameters and repair frequency. The model results were extracted at 15-minute intervals for the 24-hour period on the day of calibration.

The attributes analysed were:

- Pipe repair rate and velocity
- Pipe repair rate and pressure regime exposure
- Pipe repair rate and diameter / wall thickness

Figure 4.50 shows a strong relationship between velocity and repair rate, indicating high repair rates at low and high velocities respectively. We believe that at low velocities in old cast iron pipes, increased tuberculation / corrosion may be an issue leading to increased failure rates, while high velocities result in turbulence, damage to internal linings and joint movement. The relationship in Figure 4.50 supports the design practice of maintaining average pipe velocities at around 1 m/s.

Figure 4.50: Comparison of repair rate and velocity



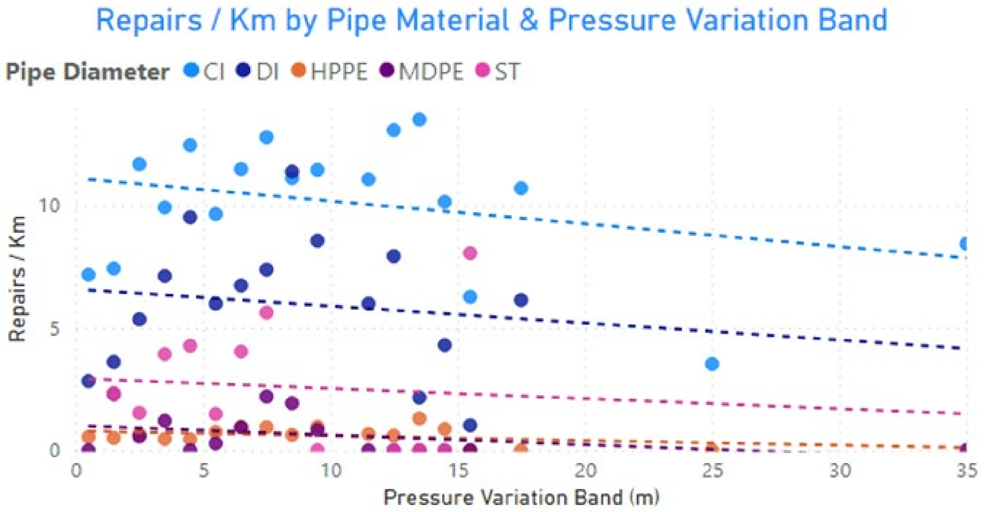
Source: Mott MacDonald analysis: data extracted from Barrow Hill and Shootup Hill FMZ hydraulic model

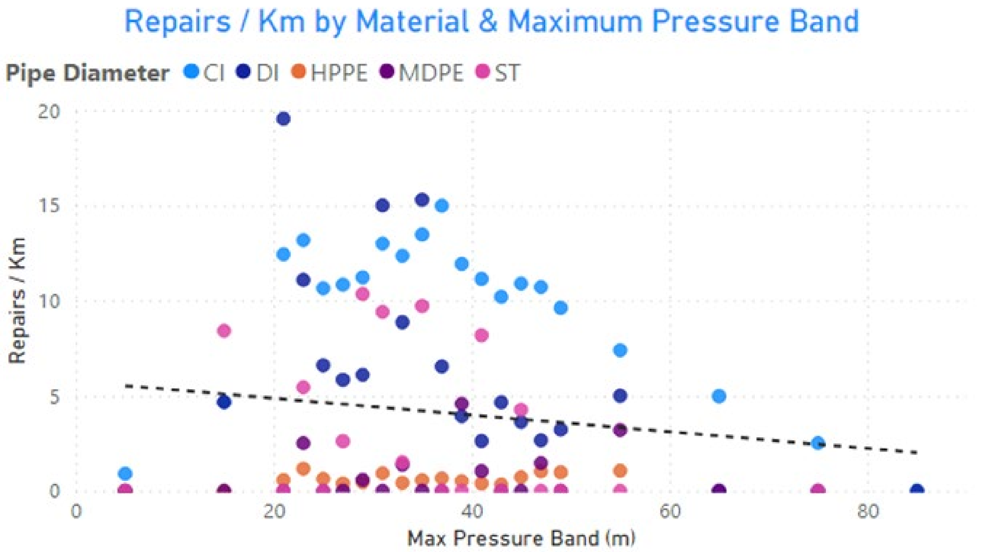
This analysis identifies velocity to be an important parameter in understanding the likelihood of failure. Unfortunately, as TW does not have full coverage of its network with up-to-date hydraulic models, it does not know the velocity in all of its pipes. The velocities that we have used in this analysis reflect those on the day that the model was calibrated, which may not represent today’s situation. Quantifying hydraulic effects on the network such as velocities will be easier when the whole system is modelled, which TW intends to have completed by the end of AMP7. This analysis shows, however, that insights can be gained using current models in the interim.

In Figure 4.51 we tested the correlation between repair frequency and cyclic loading from the diurnal pressure variation in pipes. Both the diurnal pressure variation banding and maximum pressure were considered. The resulting trends indicate, counterintuitively, that increases in diurnal pressure variation results in decreasing pipe repair rates.

The data set used in Figure 4.51 is a mix of results from large and small diameter pipes and we know that large diameter pipes fail less frequently as they have thicker pipe walls and thus are more resistant to corrosion. The explanation for the downward trend is that dots on the right of the charts represent larger diameter pipes and thus fail less frequently. It may be that pipes exposed to higher pressure variations have been designed to have a thicker pipe wall thickness owing to their pressure rating. This is particularly evident for the maximum pressure band chart.

Figure 4.51: Comparison of rate of repair to Pressure variation and maximum band

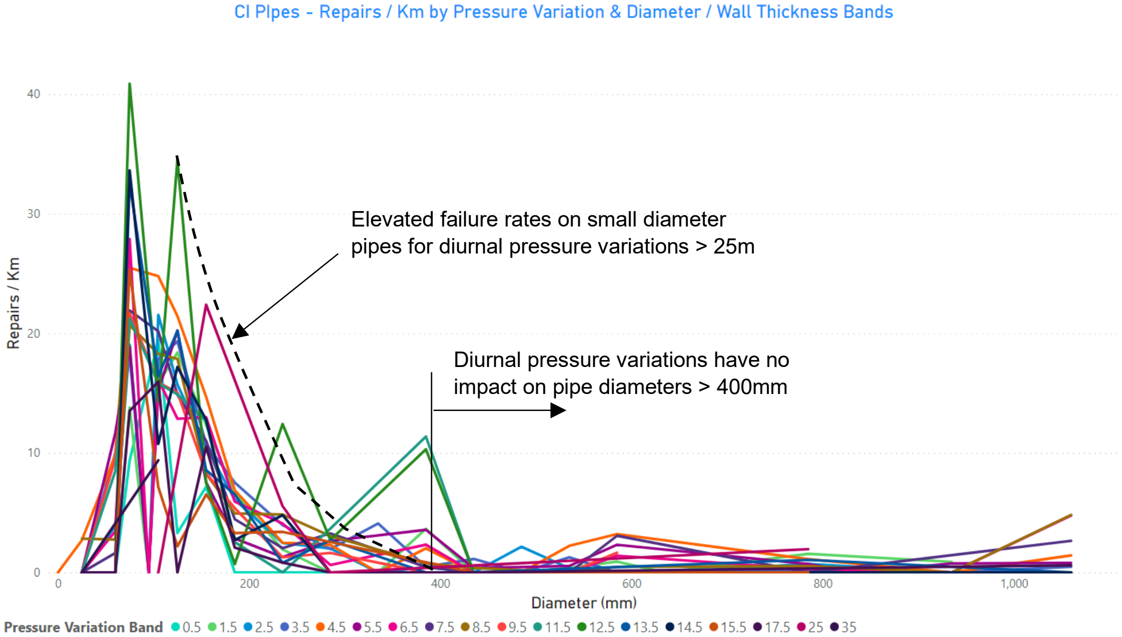




Source: Mott MacDonald analysis: data extracted from Barrow Hill and Shootup Hill FMZ hydraulic model

Accepting that the correlation of diurnal pressure variation with repair rates must account for pipe diameters, in Figure 4.52 we have compared diameter with repair rate for different diurnal pressure bands for cast iron pipes only (to remove the variance between pipe materials).

Figure 4.52: Comparison of rate of repair to pressure variation and diameter (CI only)



Source: Mott MacDonald analysis: data extracted from Barrow Hill and Shootup Hill FMZ hydraulic model

Figure 4.52 shows that for modest diurnal pressure variations (<15m) the relationships between repair frequency and diameter are very similar and overlay each other, although there is some variance in the numbers. For higher diurnal pressure variations, however (>25m) it appears that repair numbers are higher, but only for diameters <400mm. For larger pipe sizes than this, there is no discernible relationship between repair frequency and diurnal pressure variations.

There is a plausible explanation for this. We would not expect even corroded cast iron pipes to be affected by modest diurnal pressure variations (<15m), but at higher pressure variations we might expect a few hydraulically driven failures through cyclic loading. However, we would only expect this to affect smaller pipe diameters as larger diameter pipes would have too much resistance.

Although plausible, these are provisional findings as we have only extracted data from one calibrated model. Ideally, we should repeat the exercise for other modelled areas to confirm the findings which support those reported in the 2015 Imperial College paper[12].

One point to note about the Imperial College paper is that it reported a positive correlation with diurnal pressure variations for longitudinal pipe failures associated with hoop stresses but reported no correlation with circumferential failures. In our analysis we have included all repairs as the type of failure has not historically been recorded in the mains repair database. This changed in April 2021 and TW is now capturing the type of failure in its repair records.

In conclusion, although analysis of more modelled areas is required to confirm these findings, it is clear that hydraulic stresses are impacting performance and that indicators such as pipe velocity (v < 0.3 m/s and v > 1.2m/s) and diurnal pressure variance (for ΔP > 25m) could aid understanding and targeting.

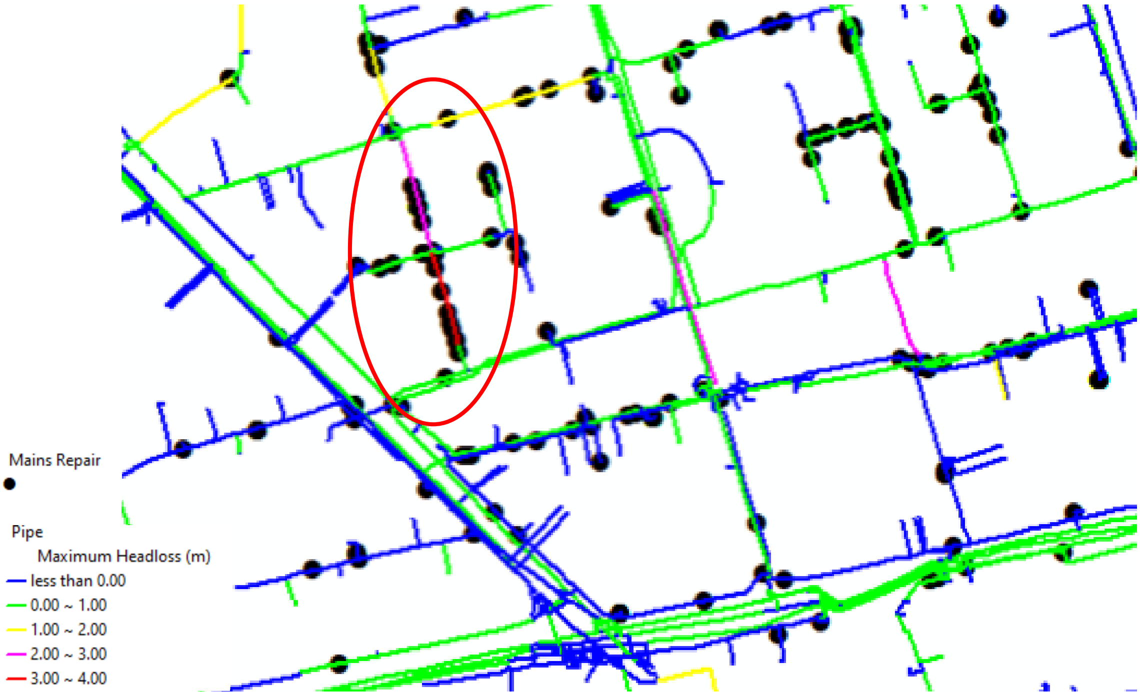
[12] Pipe failure analysis and impact of dynamic hydraulic conditions in water supply networks, proceedings of Computer Control for Water Industry Conference, 2015

4.7.4 Hydraulic stress – head-loss induced

Given the age of the network and prevalence of cast iron pipes, one would expect tuberculation to occur inside the pipes and for the resulting head losses to cause localised hydraulic stresses, possibly in extreme cases inducing fracture and leakage in pipes that are also externally corroded. Pipes with high head losses experience higher diurnal pressure variations compared with low head loss pipes and as we have shown above, there is some evidence that such pipes fail more frequently.

We examined evidence of this by overlaying pipe repair data on hydraulic model output colour-coded to show maximum head loss (the head loss experienced at peak daily demand). An example output for one area of network is shown in Figure 4.53.

Figure 4.53: Comparing head losses and repair frequency in the network



Source: Mott MacDonald analysis based on Barrow Hill and Shootup Hill FMZ hydraulic model and TW mains repair database

It can be seen from Figure 4.53 that the street highlighted has both high head losses compared with neighbouring pipes and a high incidence of repairs, suggesting a relationship between the two. In other areas of the same network, we quickly found other examples where this was the case, although in general it was found to be localised. There are also examples of pipes with low head losses and high incidence of repairs, so it is only in specific circumstances that hydraulic stress is a significant factor in inducing failure. Nevertheless, there is sufficient evidence that the hydraulic performance of the network and the deterioration and integrity of the network are linked to give value to this type of analysis and support the inclusion of hydraulic characteristics in the targeting of investment needs.

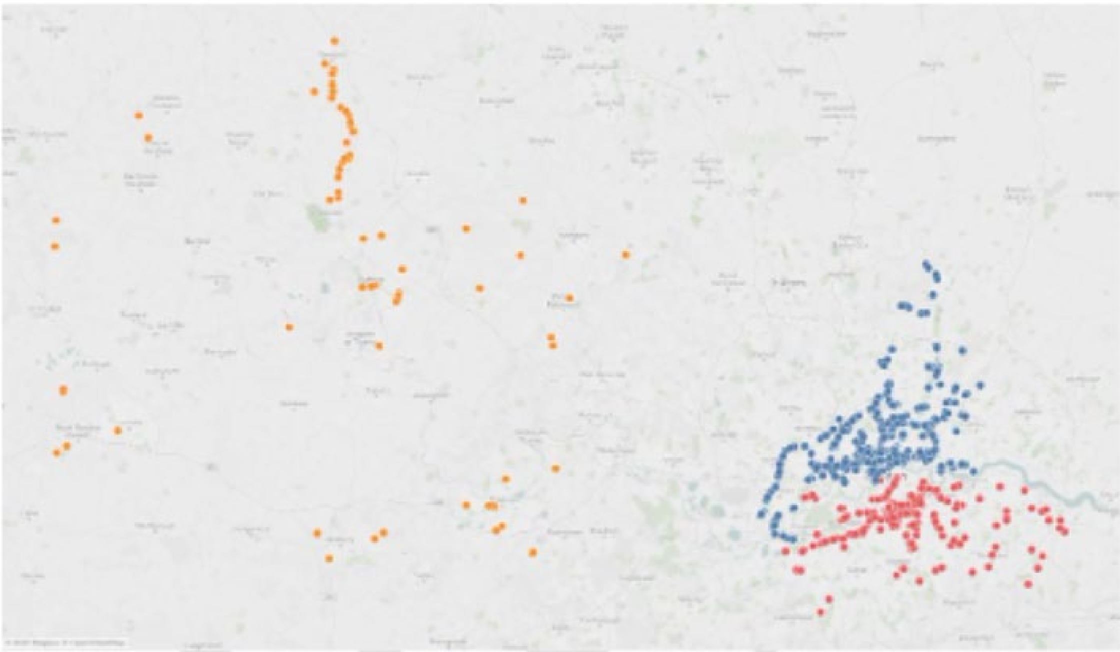
Another observation from this is that high head losses from tuberculated pipes is a source of hydraulic inefficiency. Given that much of the network is also pumped, this is also a source of cost inefficiency. We have not explored this enough to quantify it, but if the network is to be replumbed in the coming AMPs, then it is an opportunity to improve hydraulic efficiency and reduce power costs. This will require well calibrated hydraulic models to quantify potential cost savings with confidence.

4.7.5 Hydraulic stress – transients

Another area of hydraulic stress that we have investigated is the occurrence and impact of transients in the network.

Firstly, TW commissioned ICS to assess whether there is statistical evidence that transients in the network result in more bursts. In their report, ICS[13] used the existing pipe-level burst model to predict the number of expected bursts on distribution mains, communication pipes and supply pipes and compared the results with the number of observed bursts in areas experiencing transient pressure events to answer the question 'do transient pressure events cause excess bursts?' Transient alarm data was used from 2014 to 2019 from monitoring as shown in Figure 4.54, which is where TW experiences many of its transient issues owing to the high level of pumping in this part of the network.

Figure 4.54: Transient monitoring sites used for ICS study



Source: ICS report on Transient Pressure Analysis, June 2020

The number of monitoring sites and available transient alarm data was limited in 2014 but gradually increased and information in the ICS report shows that it was only by 2018 and 2019 that sufficient transient alarm data were available to try to correlate with burst data.

The study found that transient pressure alarms were not a significant predictor of increased excess bursts in the vicinity of monitoring sites, i.e. the inclusion of transient event data did not significantly improve the goodness of fit of predicted with observed burst numbers. The report concluded that '*there is an underlying burst rate and deterioration process that is largely independent of transient pressure events. One potential effect might be that transient pressure events compress the expected number of bursts in a shorter time period but have little effect on the long term*.'

The report also concluded that the weather is likely to be a bigger explanator of variations between modelled and observed bursts on a monthly basis where seasonal effects are seen

[13] ICS, Report for TW on Transient Pressure Analysis, June 2020

and recommends the inclusion of weather data in the model. It also recommends the capture of more transient data, provided it is on a non-biased basis.

In contrast to this statistical analysis, a temporal analysis of pressure and leakage data for the Farnborough FMZ in 2019 found a strong correlation between a zonal hydraulic stress measure (incorporating transients) and leakage[14].

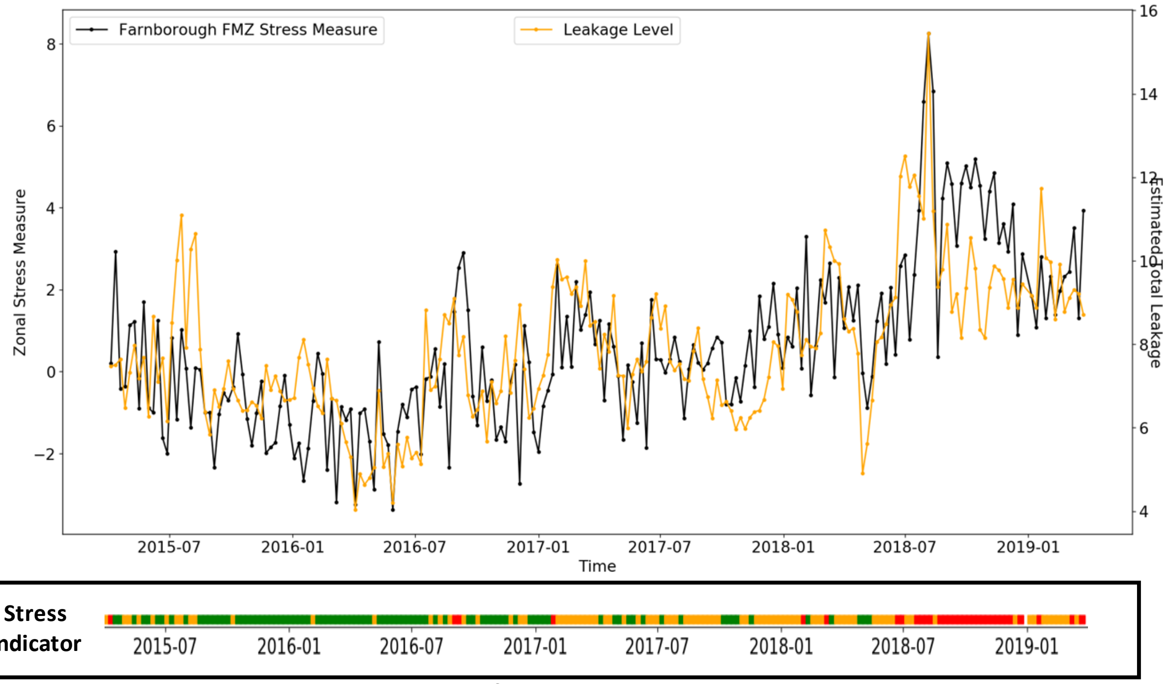
Using time-series 15-minute pressure data at pumping stations serving the Farnborough FMZ, a stress measure was created based on a weighted combination of:

- The count of excessive pressure readings
- The size of excessive pressure readings
- The count of significant pressure jumps
- The size of significant pressure jumps

Pressure jumps using 15-minute pressure data were shown to correlate reasonably well with transient events so 'pressure jumps' were used as surrogates for transients in the absence of directly logged transient data.

The variation in the resulting stress measure with changing operating conditions in the network was then compared with the variation in leakage over a period from 2015 to 2019. Leakage was estimated from district meters supplying Farnborough FMZ. The result is shown in Figure 4.55.

Figure 4.55: Comparison of zonal stress measure with leakage for Farnborough FMZ



Source: TW presentation, Network breakage and DMA fingerprinting, July 2019

Figure 4.55 shows that there is a strong correlation between the hydraulic stress measure and leakage over the period which included periods of relatively calm conditions (green in 2016) and uncalm conditions (red in 2018/19). In addition, analysis shows that there is a 30% difference in leakage in Farnborough between calm periods of operation and high stress periods. The causes of the high stress could be traced to particular pumping stations at treatment works supplying

[14] Reported in TW presentation on Network breakage and DMA fingerprinting, July 2019

the zone (Orpington and Shortlands WTWs) where there was a high count and size of pressure jumps as well as excessive pressure readings.

The analysis clearly shows that hydraulic stress caused by transients and high pressures from pumping is strongly correlated with leakage and it also shows the potential value of calming measures such as variable speed drives to reduce hydraulic stress and therefore also leakage (in this case by up to 30%, though in practice may be less). It was recommended that the analysis be extended to other zones and that in future data from transient loggers be included in the hydraulic stress measure (renamed 'calmness index'). It was also recommended that the calmness index be operationalised and incorporated into DMA fingerprinting.

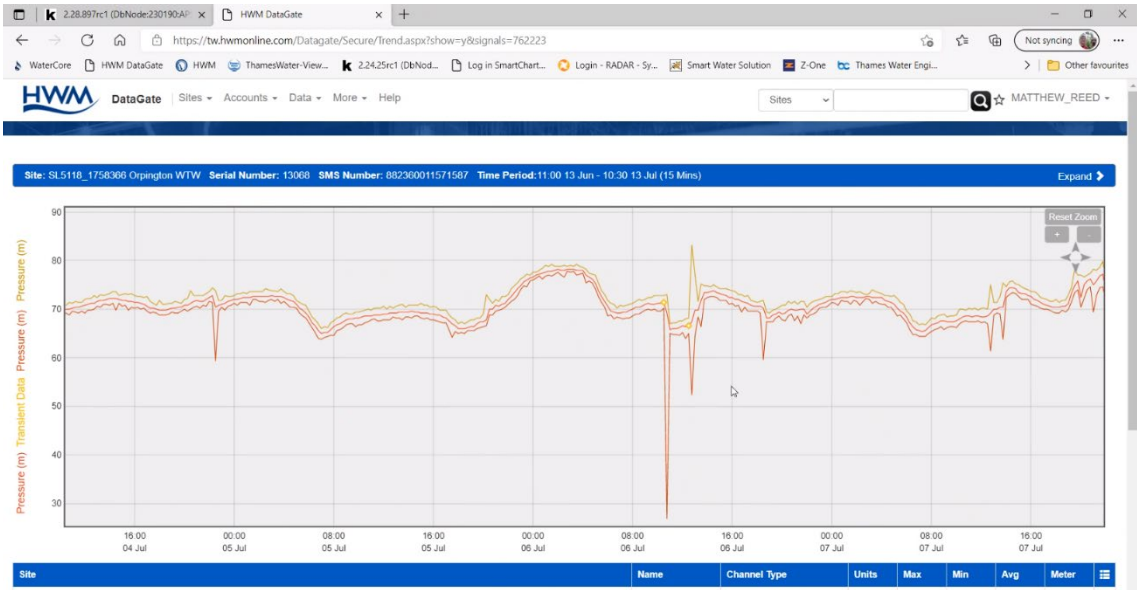
There is potentially a conflict between the results of the Farnborough study and those of the ICS statistical study, though the former compared hydraulic stress with leakage and the latter with the occurrence of excessive bursts. It is possible that transients affect leakage but not bursts (for example by increasing background leakage only) but any increase in leakage would normally be followed by detection and repair effort which would be reflected in burst numbers eventually. We feel therefore that the ICS study was either hampered by a lack of monitoring data, and/or that transient alarm data are not fully reflective of the hydraulic stresses in the network, and/or that the base model already incorporates some hydraulic stress effects in the derivation of other factors such as deterioration, so any increase in burst numbers associated with transient alarms is therefore marginal.

TW has nevertheless recognised the importance of understanding and controlling transients to prevent bursts and service impacts, focusing on its trunk-main network where consequences of failure are greatest. Transient monitoring started relatively recently in 2019 in South London and has been extended out to the rest of London and Thames Valley in 2020. TW has a dedicated team of hydraulic engineers and analysts examining the data as it comes in, assessing system performance and the severity of transient effects, determining what measures are required to mitigate them and assessing the benefits of the mitigations measures once they are installed.

TW deploys HWM transient loggers on its network in hot spots with high leakage. Some loggers are installed permanently, and others are moved if they detect little transient activity. TW is now using Syrinix loggers in place of HWM loggers. Approximately 400 loggers are deployed currently, most installed on trunk mains and battery life is approximately 5 years. An example of surge monitoring is shown in Figure 4.56, showing transient spikes from pump operations at Orpington WTW, one of the sites included in the Farnborough study.

TW's team examines surge data such as that in Figure 4.56 and compares it with other time-series data on leakage and bursts. Where there appears to be clear cause and effect, measures are considered to control the transients and reduce leakage and bursts. TW is finding localised problems, especially in SE London where there are many booster pumping stations. Many of these sites already have surge vessels, but the team has found that they are designed to mitigate complete failure (for example from power failure) and have no effect in controlling smaller transients caused by every-day pump switching. In these circumstances, TW has had good experience with replacing fixed-speed motors with variable speed drives and installing anti-slam devices on non-return valves.

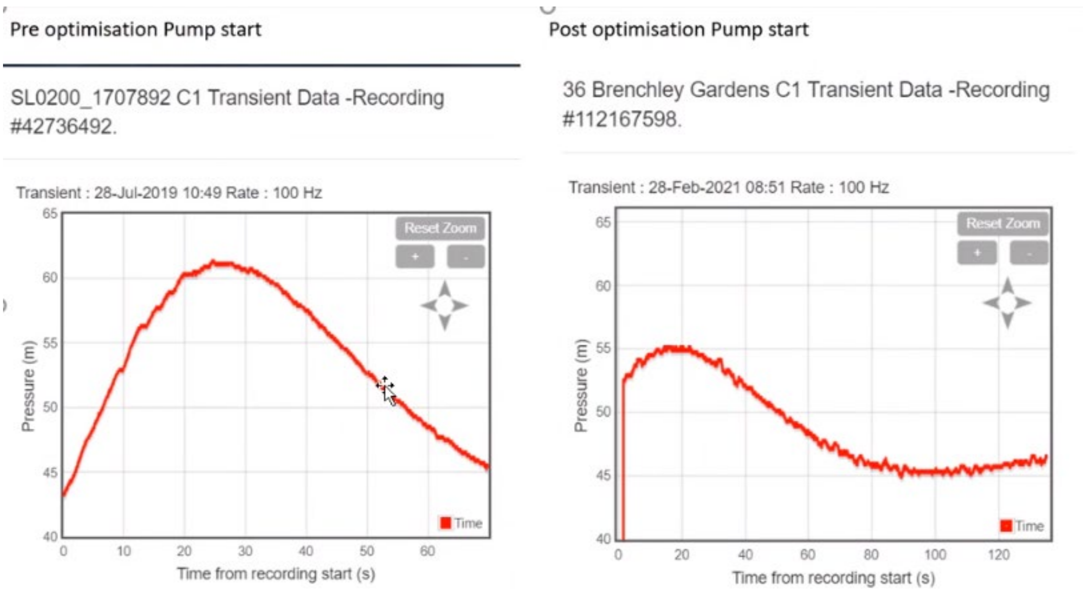
Figure 4.56: Example of surge monitoring



Source: Thames Water

For those areas where mitigation measures have been put in place, TW is in the process of assessing the benefits to leakage and bursts. Pre and post transient logging have shown the benefit of surge mitigation measures in controlling pressures (see Figure 4.57) and in the areas that the team has worked in, TW estimate a 20% reduction in the number of bursts. However, further monitoring is required to confirm these benefits to leakage and bursts, both in the short term and on a sustained basis.

Figure 4.57: Impact of mitigation on transient pressures (example)



Source: Thames Water

TW has an ongoing programme to investigate transients in the London network and to plan mitigation where they have a detrimental impact on bursts and leakage. Table 4.9 lists the number of schemes planned for the AMP7 period. The schemes mainly target operational sites, such as water treatment works, pumping stations, booster stations, service reservoirs, and involve the following types of interventions:

- Reconfiguration of control systems of operational sites
- Installation of variable speed drives
- Upgrade to non-return valves
- Installation of surge vessels and pressure safety valves
- Reconfiguration of existing pressure managed areas and setting up new pressure managed areas.

Table 4.9: TW's programme of transient mitigation measures – number of schemes planned for AMP7

	Benefit		
Region	Leakage reduction	Mains repairs reduction	Both
North London	12	12	7
South London	9	30	5
Thames Valley	3	27	11

Source: Thames Water

As part of the programme, TW will continue to monitor the benefits of transient mitigation measures to leakage and burst reduction to confirm the findings of the Farnborough study.

There is clearly a lot more to do to understand and manage transients in the London water network and to monitor the benefits to leakage and burst numbers, but TW has a dedicated team and a programme of work to achieve it as part of its calm network strategy.

Clearly the control of transients relies on surge protection assets such as surge vessels, air valves, VSDs, flywheels, actuated valves etc, but TW has no central register of these assets with information on their status and condition. Information is held locally in site operating manuals (SOMs) but these do not always detail surge assets and TW's transient team report that they often suffer a lack of information.

Surge protection assets are not defined as a separate asset group for planning purposes and as such do not receive a specific focus for investment. The condition and maintenance of air valves, for example, is not managed centrally and these are important for transient control, especially on pipe bridges. As TW focuses more attention on transient control and calming measures, the importance of having a central register of information will grow and we recommend that TW creates a separate asset group to provide a focus for investment planning.

4.7.6 Pressure management

TW has a long history of implementing pressure management throughout its area, which involves the reduction of excess pressure within the network to reduce leakage, and minimising pressure fluctuations to reduce burst frequency.

Pressure management is usually achieved through the installation of Pressure Reducing Valves (PRVs) in an area termed a Pressure Managed Area (PMA), which is a discrete area established within a DMA by closing existing or installing new valves so that the area receives water via one or two PRVs. Each PRV in a PMA is set to deliver water at a certain pressure. The pressure being delivered by each PRV is monitored by the Critical Pressure Point (CPP) located at the highest point in the PMA. The CPP regularly feeds back to the PRV through telemetry systems so that any change in pressure is rectified and the pressure throughout the PMA is minimised and remains constant.

TW uses a data management system called Water-Net that holds data for the existing PMAs whereby the average pressure reduction and resulting leakage reduction has been recorded for the life of the PMA. Water-Net is used for forecasting, calculating, reporting and monitoring leakage savings and PMA maintenance.

TW has over 1,000 pressure management schemes across its water supply area. As a standard, Thames Water now install remotely controlled, “closed loop” systems, which ensures that the outlet pressures at the PRVs are continuously adjusted to address changing customer demands (night and day, winter and summer) and to keep pressures at their optimum level.

The schemes implemented vary in size and complexity; simple schemes involved the creation of a new PMA within an existing DMA; the more complex schemes were undertaken on the trunk mains that feed DMAs and often included zonal reconfiguration, feeding systems with over 400,000 customers. Tall buildings are accounted for in all the schemes to identify any risk of low pressure – where this is the case, a booster pump or another solution is implemented to maintain the level of service.

Comparative performance

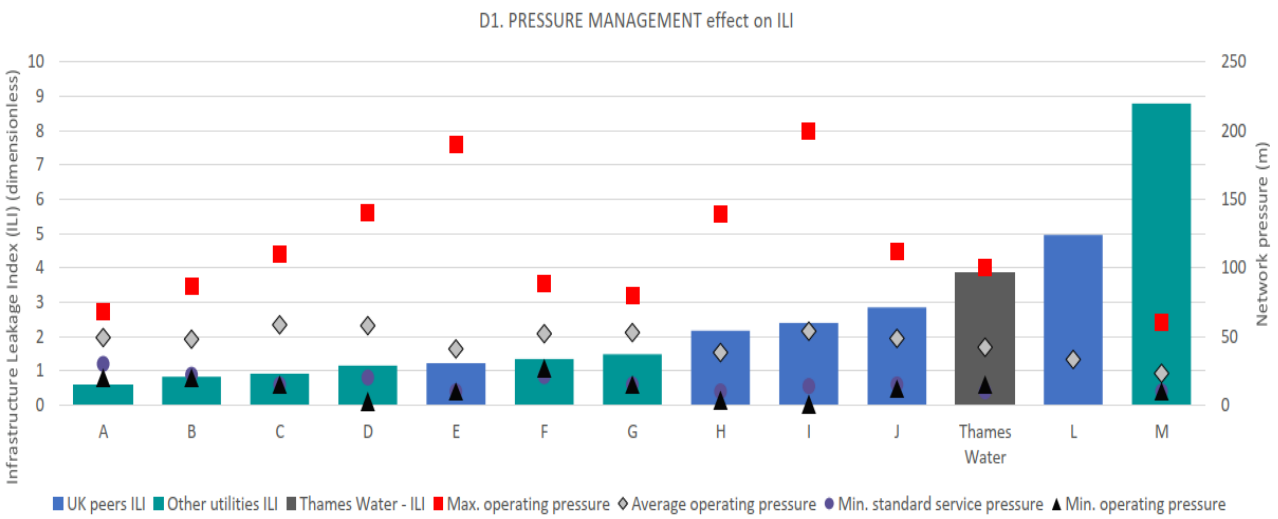
A leakage management benchmarking programme was undertaken by Isle in October 2020 which included a summary of how TW is performing in terms of pressure management against a peer group of water companies (seven UK companies, eight Australian companies and one Brazilian company). Its findings were as follows:

Pressure management as a leakage indicator – TW performs well when compared with the peer group for pressure management. Its relatively low average operating pressure and PRV density are positioned in the third quartile and the proportion of remote controlled PRVs is positioned in the top quartile of the peer group.

Investment – TW has the highest expenditure on pressure management in comparison to the peer group (normalised by number of properties), both in terms of Totex and capex.

System pressure differential – TW has a focus on moderating and stabilising supply pressure for customers using remote-controlled PRVs, as reflected by the relatively low difference in maximum and minimum pressures when compared with other utilities in the peer group.

Figure 4.58: Isle leakage benchmarking programme – System pressure differentials (the difference between maximum and minimum system pressure)

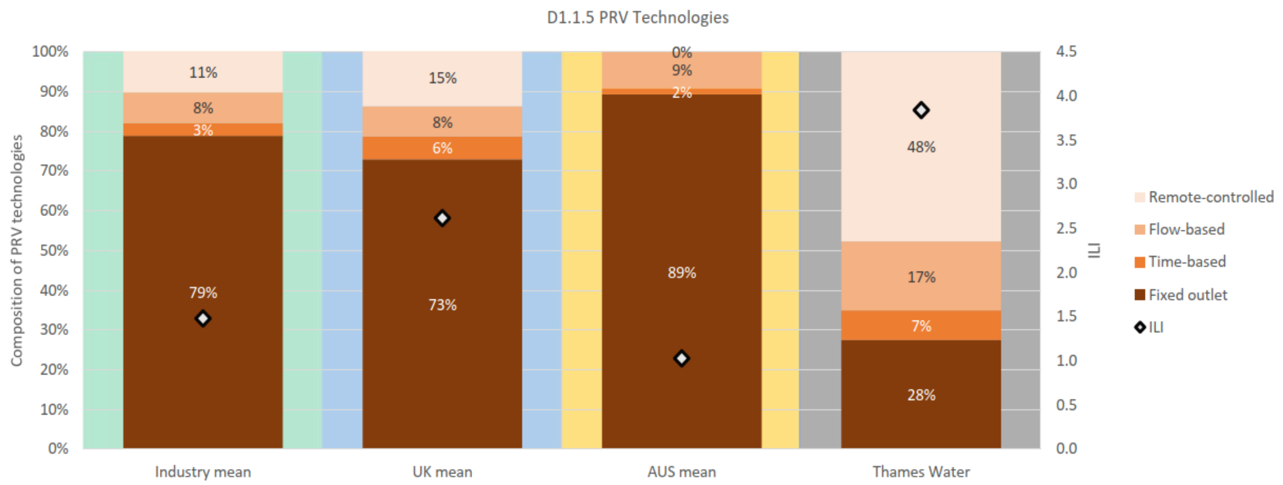


Source: Isle Leakage Management Benchmarking. Utility Report – Thames Water. 16th October 2020

PRV and DMA Density – Thames Water has the lowest density of PRVs, and one of the lowest DMA density figures, in the UK peer group. We discuss DMA density in Chapter 6, but PRV density may merely reflect relative opportunities for pressure management given the difference in topographical circumstances. However, TW staff feel they do not have a strong understanding of pressure throughout the network. This is partly due to the lack of calibrated models for all areas of the system.

PRV Technology – Thames Water has the highest proportion of remote-controlled PRVs in the UK peer group, which has been cited to improve performance in responding to emergency requirements and in managing fire flows (see Figure 4.59).

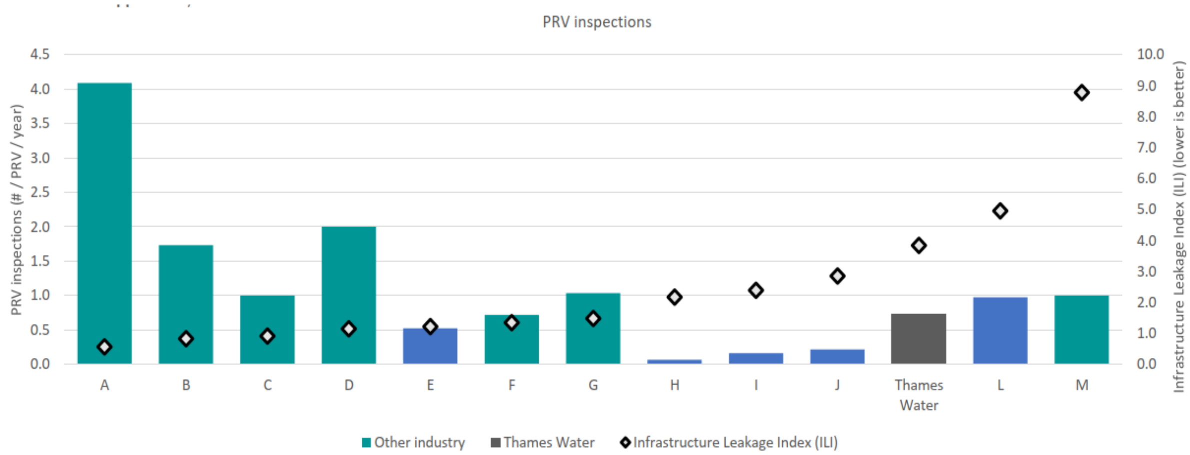
Figure 4.59: Isle leakage benchmarking programme – composition of PRV technologies used



Source: Isle Leakage Management Benchmarking. Utility Report – Thames Water. 16th October 2020

PRV Maintenance – TW has one of the lowest levels of PRV maintenance within the peer group. However, this is due in part to having higher levels of remote-controlled technology that requires fewer inspections and/or maintenance (i.e. the PRV operational data is captured remotely and used to log the performance and condition status of the PRV). The chart below does not show a strong correlation between PRV maintenance and Infrastructure Leakage Index (ILI).

Figure 4.60: Isle leakage benchmarking programme – PRV inspections



Source: Isle Leakage Management Benchmarking. Utility Report – Thames Water. 16th October 2020

The Isle benchmarking study found it difficult to fully understand how effective TW's pressure management program had been to date. It found that leakage losses throughout the network were high relative to the peer group, PRV and DMA densities were the lowest in the UK peer group, and there was a scarcity of data on network pressures. However, the study noted the work done to date and the high penetration of remote-controlled PRVs provided a great foundation for further leakage improvement by expanding the pressure management programme.

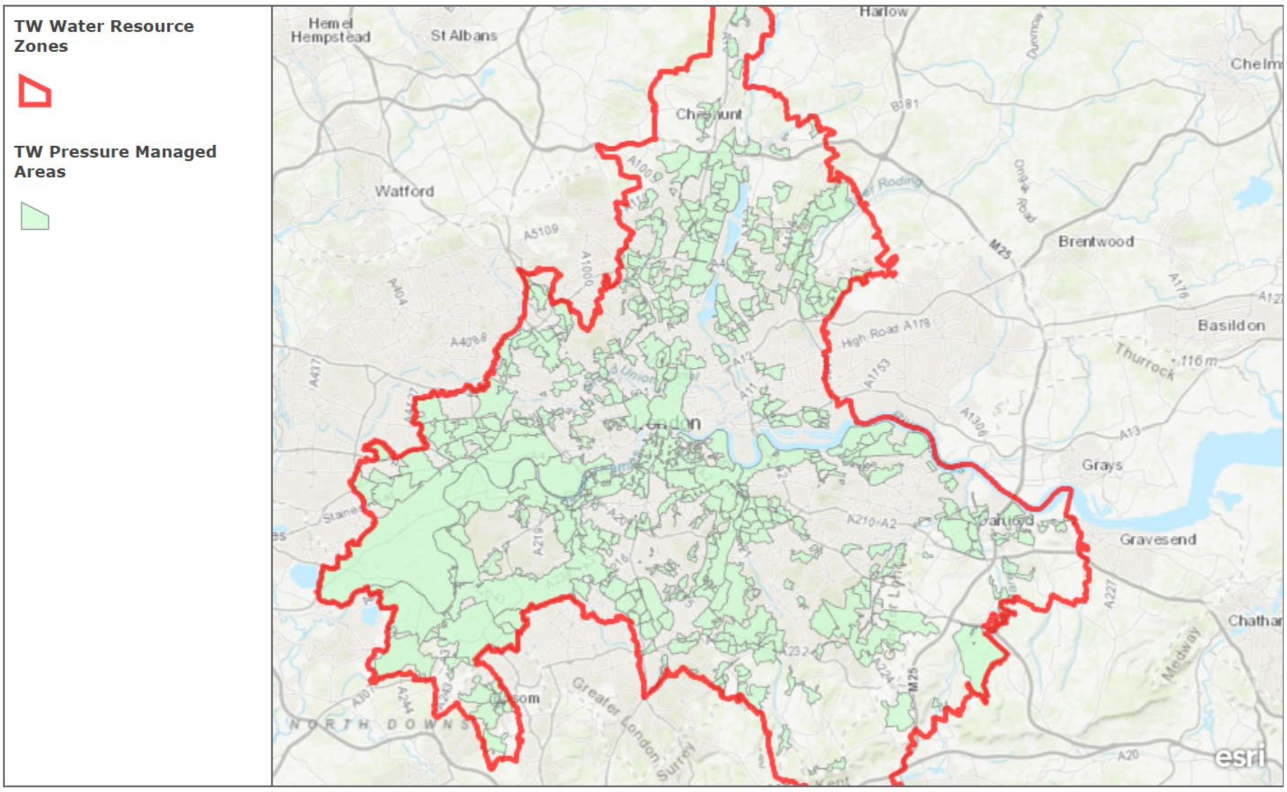
Limitations to expanding the pressure management programme

In WRMP19, the total volume of pressure management available was considered based on the following assumptions:

- Greater than 5% of the DMA must have pressures higher than 35m head before a DMA was eligible for pressure management.
- DMAs with a current pressure below 30m were not considered as there are minimal leakage savings that can be achieved by dropping pressure 1-3m head.
- DMAs are also required to have an average minimum pressure of 25m before they are considered for pressure management, to meet the required service levels (i.e. 10m pressure and 9l/s flow at the property boundary).
- DMAs with current pressure above 40m were also not considered due to network restrictions, potential additional costs to new developments and customer complaints.

Given these criteria and as pressure management coverage has been increasing since AMP4, the available opportunities for new schemes have gradually reduced.

Figure 4.61: Pressure managed areas within the London WRZ



Source: TW GIS asset data

A summary of pressure management programmes undertaken by TW throughout the AMPs:

- In AMP4 (2005-2010) TW implemented a programme of new pressure management schemes in support of the VMR programme to achieve its leakage reduction target.
- In AMP5 (2010-2015), TW only delivered smaller PMA schemes as the larger schemes had already been delivered in AMP4, and TW did not plan to significantly reduce leakage in this period further.
- In AMP6 (2015-2020) TW committed to reduce leakage by 59Ml/d through a combination of mains replacement, pressure management, repair of customer side leakage from newly metered properties and enhanced find and fix activity.
- In AMP7 (2020-2025) TW is planning to reduce its investment in delivering new pressure management schemes. This is due to the limited areas remaining that are available for pressure management. TW anticipates that a portion of the available pressure management schemes across its area will contribute to offsetting water network deterioration; whilst the remaining volume of pressure management available has been assumed to achieve a leakage reduction for WRMP19.
- AMP8 and beyond – Based on current technology, TW anticipates that opportunities for additional large scale pressure management (i.e. in excess of activity for asset management) will have been exhausted in London by the end of AMP7, and it has no current plans for continuing to implement new PM schemes beyond AMP7. From AMP8 onwards, all pressure management activity will be to maintain the benefits achieved from pressure management schemes previously installed.

Figure 4.62: WRMP19 – London preferred plan – Overall plan for demand management

Table 11-1: London preferred plan – Overall plan (DYAA) for demand management

	London	Delivery date and ongoing supply demand benefit (Ml/d)							
		AMP7	AMP8	AMP9	AMP10	AMP11	AMP12	AMP13	AMP14-AMP22
		2020-2024	2025-2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-2054	2055-2100
Total benefit from DMP		**177.2**	**93.7**	**49.4**	**84.8**	**29.8**	**15.0**	**7.5**	**Benefits maintained**
Leakage reduction	**Total leakage reduction**	**122.4**	**46.8**	**29.4**	**40.8**	**24.8**	**10.0**	**7.5**	**Benefits maintained**
	AMP6 Leakage reduction carry over	31.6							
	Household metering customer side leakage (CSL)	22.7	9.7						
	Bulk metering CSL								
	AMP7: 36,001 meters	3.0							
	AMP8: 122,081 meters		15.4						
	AMP9: 0 meters			0.0					
	AMP10: 87,505 meters				6.0				
	Replacement metering CSL	3.5	3.5	3.5					
	Mains replacement	6.1	0.9	21.1	30.0	20.0	10.0	7.5	
	Pressure management	6.2							
	Innovation			4.8	4.8	4.8			
	DMA enhancement	26.0	17.3						
	AMP6 activity deferral	23.3							
Usage reduction	**Total usage reduction**	**54.8**	**46.9**	**20.0**	**44.0**	**5.0**	**5.0**		**Benefits maintained**
	Household metering								
	AMP7: 365,007 meters	28.7							
	AMP8: 319,793 meters		28.1						
	AMP9: 0 meters			2.4					
	Water efficiency	24.8	18.1	16.9	5.0	5.0	5.0		
	Incentive scheme	0.8	0.2	0.2	0.2				
	Non-potable water	0.5	0.5	0.5	0.5				
	Innovative tariffs				38.3				

Source: Final Water Resources Management Plan 2019. Section 11: Preferred plan – April 2020.

4.7.7 Hydraulic summary

On the basis of the above analysis, we conclude that:

- The London water network has higher hydraulic loading and has experienced higher demand growth than any other company network.
- There is also a high level of pumping, driven by the flat topography, and collectively this creates the potential for hydraulic stresses in the network.
- Using a calibrated model for one of TW's areas, we have found clear evidence of a relationship between velocity and pipe failures, with elevated bursts occurring at velocities greater than 1.5m/s and at less than 0.5 m/s.
- For the same modelled area, an analysis of the relationship between diurnal pressure variation and bursts shows some evidence of elevated bursts in areas experiencing pressure variations greater than 25m, but only for small pipe diameters. There is no evidence that diurnal pressure variations affect trunk mains.
- There is evidence that some pipes in the network with high head losses also experience high incidence of repairs, indicating that the two are related. This only occurs in localised circumstances, but confirms that the hydraulic performance of the network and the deterioration and integrity of pipes are linked and should be considered together in identifying investment needs.
- The old tuberculated pipes that result in localised head losses are also a source of hydraulic inefficiency. Replacing them is an opportunity to improve hydraulic efficiency and in pumped networks, reduce power costs and carbon emissions.
- Monitoring has shown the presence of pressure transients in the network, especially in south-east London.
- Although the statistical evidence that transients cause excessive numbers of bursts compared with other drivers (e.g. deterioration) is inconclusive; the Farnborough study in 2019 showed a strong relationship with leakage and subsequent transient monitoring and calming measures have shown clear benefits in reducing pressure spikes and bursts.
- In areas experiencing transients, TW estimates the benefits of transient control measures to be a 20% reduction in bursts. These are early results and further monitoring is required to confirm them.
- TW has a programme of transient control schemes that it is implementing in AMP7 to reduce the impact of transients on the network, but there is scope to do more in subsequent periods and to better understand the long-term benefits to bursts and leakage.
- TW has no central register of surge protection and network calming assets with information on their status and condition. Surge protection assets are also not defined as a separate asset group for planning purposes.
- TW has long applied pressure management to control leakage (starting in AMP4) and has over 1000 pressure managed areas across its network.
- Benchmarking shows that TW compares well with its water industry peers, achieving relatively low average operating pressures with good use of remote-operated PRVs to modulate pressures by flow, limiting maximum to minimum pressure differentials.
- TW believes that there are increasingly limited opportunities for further pressure management in the London network owing to physical constraints and the benefits from marginal pressure reduction not matching the costs. TW is implementing some schemes in AMP7, but expects further opportunities to have been exhausted by the end of the AMP (based on current technology).
- TW is constrained in its understanding of its network by a lack of up-to-date calibrated hydraulic models (only 35% coverage). This has implications for understanding high and low velocities and localised diurnal pressure variations, (which we have shown to have a relationship with repair frequency), hydraulic efficiency, pressures, and other important hydraulic features. TW has plans to update and increase its model coverage in AMP7, covering the whole of the London network by the end of the AMP. This, together with

ongoing improvements to its DMA infrastructure, will enable it to better understand and control hydraulic stresses.

4.8 Previous reviews of asset capability

In the recent past, TW has undertaken several independent enquiry reviews to improve their understanding of asset capability. In 2012, following the Victorian Mains Renewal Programme, an independent third-party panel was commissioned to review the whole life cost and benefits of the mains renewal programme, to inform the 2013 Water Resources Management Plan. Later in 2017, following several highly disruptive bursts, TW commissioned an independent enquiry to review the root causes from when they occurred. Both of these reports are summarised in the sections below.

4.8.1 Mains replacement programme independent review (2012)

The mains replacement programme independent review from 2012 was commissioned to review the successes of the Victorian Mains Renewal programme to assist with the 2013 Water Resources Management Plan.

The report was split into three scope items. The first scope item was to review the process, performance and benefits derived up to March 2010 based on the whole life costs and benefits, of the mains replacement programme against expectations. The programme was successful in reducing leakage from more than 900ML/D in 2003/2004 to less than 700ML/D in 2009/2010 through replacement of 1,868 km of mains. The selection of DMAs followed a robust process, albeit the process was not always effective at predicting savings in individual DMAs or predicting the most beneficial DMAs for renewal. Schemes delivered in the latter half of the 2005-2010 period experienced a decline in the benefits delivered. From the dataset the construction cost of the benefit was 8% higher than estimated and the leakage saving was 9% lower than estimated. Part of this was due to previously unknown consumption and the overestimation of reductions in customer side leakage. Despite this, the mains replacement with pressure management and zonal reconfiguration was considered to be an appropriate course of action for resolving the issues. In the review it was also identified that 60% of mains were replaced using open cut construction methodologies (identified as the most expensive construction technique) although there was no evidence that other lower cost techniques would have been more appropriate.

The review also provided recommendations based on the findings. Some of the key recommendations included:

- Process to be reviewed, defined, and documented so that all parties understand their roles.
- TW to use actual costs and benefits from 2005-2010 period to improve their DMA targeting.
- Align the Trunk Main Leakage programme with mains replacement programme.
- Private mains are problematic for metering and should be metered before developing a policy to tackle private main leakage.
- TW should review alternative construction techniques as well as productivity to demonstrate cost effectiveness in delivery.
- A need for TW to work closely with contract partners to improve stakeholder relationships to assist in efficient delivery in highways.

The second scope item from the review was to identify learning points from performance to date and how these could inform planning for more effective and efficient delivery through AMP5 and beyond. It describes how TW took steps to improve the process in its 2010-2015 programme through a highly competitive tender process, and through well-defined contractor arrangements. It acknowledged TW's commitment to deliver the serviceability objectives from the Business

Plan and described how TW had expanded data capture on construction site productivity to improve understanding of which factors were affecting efficiency. At the time of writing the report in 2012, TW had surpassed the projections it had made in its business plan with fewer bursts and lower levels of leakage.

The recommendations from this scope item were as follows:

- TW should develop a common platform for understanding the benefits derived from different activities to assess future schemes and programmes of work.
- TW should undertake whole life cost and cost benefit analysis for all assessment processes.
- TW should quantify the wider benefits associated with the overall infrastructure programme to target the programme to meet serviceability and deterioration objectives of both burst rates and leakage.
- Comprehensive data analysis is required to understand deterioration and performance and where optimum benefits are being derived. This should include a more integrated investment approach to defining the right schemes to deliver the benefits for least cost.

The final scope item was to identify the incremental costs and benefits of a range of options of mains rehabilitation for improving the supply demand balance beyond maintaining base service in the water network. The review team was to propose options to integrate optimisation of leakage in the supply demand balance with optimisation of investments in water infrastructure.

The key recommendations from this scope item are outlined below:

- The WRMP should be updated following the recommendations from the review and TW should review its asset management policy and strategy to ensure alignment with corporate objectives.
- TW should map its asset and risk management approach to the specific detailed processes from this review including analysis of data, model verification, the integration of solutions for a set of assets, governance and benefits.
- The review recommended changes within the organisation to move from discrete scheme selection based on asset needs, to the identification of true business risk and clear understanding of the resultant business outcomes and benefits, including the impact on serviceability.
- TW should develop a better understanding of company specific factors affecting unit cost rates to inform decision making and future business cases.
- TW should establish a common platform and language for cost benefit analysis, related to a more integrated companywide common single process.
- TW should regularly update the assessment of Average Incremental Cost for renewal and for other demand reduction schemes.
- TW should undertake a sensitivity analysis on pipe deterioration rates. TW should also continue to evolve its deterioration models considering an UKWIR report on the topic (‘Distribution: Development of National Deterioration Models’), and any future deterioration models should consider a pipe level approach and incorporate background factors.
- TW should adopt a risk-based approach for targeting both individual pipes and groups of pipes with high impact risks of serviceability failure.
- TW should understand more about the how the benefits are split between the activities of mains replacement and length reduction through design rationalisation to improve targeting.
- It was recommended that TW carry out a systematic review of the following:-
  - The change in failure rates in the un-renewed areas of partly renewed District Metered Areas, where possible linking failures to incidents or construction events.

  - The change in leakage levels and failure rates in District Metered Areas neighbouring renewed District Metered Areas.
  - The change in leakage levels in Flow Monitoring Zones (FMZs) that are partly renewed.
- TW should review all of the potential benefits that Advanced Metering Infrastructure offers over Automated Meter Reading which was being trialled in six District Metered Areas.
- It was recommended that TW reviews the effects and benefits of pressure management with targeted mains replacement on the network in more detail.
- It was recommended that TW review rehabilitation methods (e.g. structural lining, spray applied lining, condition assessment) so that the most cost effective and appropriate techniques to minimise disruption to customers are adopted. Productivity, cost and other construction performance data should be captured and considered.

Following the evaluations which were undertaken, the independent review concludes that mains replacement in insolation could not be economically justified at the time. However, it noted that mains replacement should be considered as a component part of an overall investment programme necessary to address a Supply Demand deficit. Despite all of the recommendations above, the conclusion draws out a specific fundamental conclusion from the review, which is that TW needs to ensure that the asset management process is end-to-end and clearly defined. It summarises that without clearly defined policies, strategies, targets and objectives and a comprehensive understanding of the level of business risk, establishing programmes that ensure maximum benefits to customers and stakeholders is difficult to achieve.

4.8.2 Trunk mains forensic review (2017)

Following eight highly disruptive bursts in London between October and December 2016, Thames Water commissioned the Trunk Mains Forensic Review, an independent review of the bursts from 2016 and the root causes from when they occurred. The eight bursts were particularly high profile due to their scale, location, and customer impact (flooded homes, damage to business, risk to life, and road closures). The review involved interviews, workshops, and data reviews of 31 major events in 2016, but with particular focus on the eight high profile events. Reports from specialists on the failure modes were also considered.

The analysis indicated that there are no common causes for the bursts and no systematic failings that may have caused or enabled the burst. Age and condition were an underlying factor, but mostly there were singular reasons for the failures. There were no clear causal patterns about operating practice, age-related condition, material type or asset risk management and planning being the main drivers for failures. That being said, it is important to recognise that this analysis is based on a sample size of 31 events, and that this is not a substantial sample for this type of analysis.

A summary of the review is provided below:

- Many of the mains which burst were correctly identified as having a high-risk ranking. Some of the mains which were low risk burst due to human error. It was concluded that TW's risk model was valid for long term planning.
- Asset age was a factor, and it was confirmed that the burst mains were more predominant on older pipes. However, it was also noted that there were several bursts on recently installed mains (as late as 2000) which indicate other factors are at play.
- Burst dates indicated that events are often grouped (i.e. several bursts within a particular short-term timeframe). There was no statistical trend to suggest a marked change in the rate of trunk main bursts.
- The time at which the bursts occurred were reviewed as it was thought that there may be more bursts in the morning peak demand between 05:00 and 07:00. The analysis indicates

an even distribution of bursts throughout the day. Similarly, there was an even distribution throughout the days of the week.

- The failure modes identified on the eight high profile bursts are summarised below:
  - Camberwell New Road – Point loading due to 30” CI pipe bearing directly on a brick structure with elevated stresses from traffic loading above.
  - Crayford Road – A 12” CI main burst during the installation of a line stop due to oversized line stop. A separate linestop was then installed for the repair which caused the burst of an adjacent 18” CI main likely due to heavy vibrating equipment and pressure waves from valve operation.
  - Leigham Vale 1 – Heavy corrosion on a 21” CI main resulted in a circumferential and longitudinal fracture. Corrosion may have been accelerated by stray electrical currents from a nearby railway line.
  - Leigham Vale 2 – Linked to the previous burst, the heavily corroded pipe failed again when the main was being recharged, likely caused by lack of support and transient pressure waves from the recharging process.
  - Lee High Road – A 24” CI main failed at a bell and spigot joint after timber supports rotted from beneath. The burst was located under a bus stop which may have exaggerated the issue from repetitive loading from buses.
  - Upper Street – A 36” CI main failed due to heavy amount of external and through-wall corrosion.
  - Lee Road – The burst of a 12” CI main was due to excessive vibration from an excavator trying to break-up a concrete slab from 50mm above the main.
  - Northwold Road – Multiple factors may have contributed to the burst of this 30” CI main. These include: significant corrosions, stress concentration from arrangement at time of installation, leakage, and traffic loading causing additional displacement and stress. A pressure wave is thought to have caused the final fracture causing the joint to fail.

The findings and conclusions from the forensic review provide useful insight for comparative purposes with our assessment. In the review it summarises that there are no common causes for the trunk main failures, but that age was an underlying factor. It concluded that mostly there were singular reasons for the failures.

Whilst these conclusions may be true for the limited dataset that was reviewed, we believe that on a broader macro level, multiple external factors are often present which can be used to explain some of the contributing causes for main failures (age, material, pressure, installation method, traffic loading, soil conditions etc.). The factors are often variable in their nature, but there is also often a hierarchy. In many cases, the age, material and condition of the main in aggressive soils are the core factors driving a vulnerability to the other factors that may also be at play, such as traffic loading. It is significant, for example, that heavy corrosion is cited in several of the eight failure mechanisms.

Nevertheless, the variable nature of the conditions across the supply network in London emphasises that it is important to review and understand all the factors to assess the risk as well as possible, but that sometimes it is impossible to predict that a main is likely to fail as there may be a very specific and hidden locational issue (e.g. a point loading from a sharp object).

A summary of the recommendations from the review are as follows:

- Asset Planning

  - Current risk models (AIM) should be improved upon to develop a dynamic risk tool that can be updated with current asset data and knowledge (in particular feedback from operations teams).
  - Gaps in asset data should be improved on, especially where they can assist with operability (e.g. key valve locations). It was suggested that TW should develop their predictive analytics and infill analysis capability, as well as consider a programme of works to capture and confirm the location and position of all valves in GIS.
  - TW should establish a single end to end owner for Trunk Mains and set the asset group aside for a period of 'intensive care' in order to establish a deep and consistent focus across the lifecycle.
- Asset operations and maintenance
  - The pre and post-work controls of a permit to work (PTW) need to be improved to ensure the conditions or terms of the documents are fully adhered to, including oversight from the operations teams to mitigate risks and prevent avoidable mistakes.
  - Individual operations staff can be highly knowledgeable about their assets, but this knowledge is not accessible to all. The knowledge needs to be curated and codified where possible.
- Asset Monitoring
  - There is a programme in place to install more asset monitors and it would be beneficial to increase the scope and pace of this programme as part of this recommendation.
  - Syrinix and Hydroguard systems and data are not fully integrated into the SCADA system, which means that they are not monitored in 'real time'. The integration is recommended at the earliest opportunity, which will also require an update to processes and policies for prioritising alarms. The integration will also assist to statistically analyse the available monitoring data in order to improve burst predictability.
  - Understanding of the health of the Trunk Main network needs to improve, to better plan proactive works and more accurately predict bursts. Risk modelling addresses this in some way, but new ways of assessing Trunk Mains health should be trialled, with a focus on involving supply chain partners more in the identification of innovative solutions for asset condition assessment.
- Event Response and After Care
  - There was some inconsistency in the responses to the 8 high profile events, in particular the time taken for a Network Service Technician (NST) to arrive on site, and the time taken to isolate the burst main.
  - Event controllers should receive 'refresher' training for event management, and TW should develop a specific set of guidelines for Trunk Main-specific burst event response.
  - The communication with customers fell short of expectations, in particular the social media response. The implementation of a 24/7 social media team has since been undertaken along with a programme to improve multi-format stakeholder communication.
  - Thames Water should look to improve communications with customers, especially around the insurance claims process.
  - The capacity for staff to effectively deal with a burst main is dependent on the number of events occurring within a time period and the severity of the events. The capability to respond to an event is dependent on the knowledge of the event site and the availability of contingency plans and /or Control Room knowledge to identify network activities required to close the burst main. Thames Water should look to review the use of overtime and standby staffing with a view to establishing 'night teams' for each region.
  - The Thames Water Business Resilience and Security team should work with the wider business to review the existing event learning processes to ensure they are fit for

purpose. In addition, regular event response practice exercises should be conducted to generate insight that can be used to inform the training, processes and information provided during an actual event to improve the response.

4.9 Comparative analysis of factors impacting the health of London's water network

The preceding sections have established that the health of London's water network assets is significantly worse than that of other companies' networks and have identified the factors that impact performance to explain why London's assets are in poor health. Chapter 5 discusses the investment decisions that TW has taken to mitigate the impact of these factors.

As well as identifying the factors impacting performance, in many cases we have been able to compare the scale and severity of the impacts with the rest of the industry to get a sense of the extent to which London and TW as a whole is an outlier. These are listed in Table 4.10.

Table 4.10: Factors impacting network performance

Factor	Report Figure	How it affects network performance	Comparative assessment?
Corroded locked joints on old cast iron pipes	4.8	Prevents joint movement creating stress fractures under temperature shocks or soil movement	N
High proportion of network is cast iron	4.9	Cast iron is brittle and susceptible to corrosion in corrosive soils leading to bursts and leakage	Y
Network is the oldest in the country	4.10	Very old pipes are susceptible to corrosion in corrosive soils leading to bursts and leakage	Y
High proportion of shrink-swell clay under London	4.25	Soils shrink and swell when dried or wetted creating movement that fractures pipes or opens joints	Y
High proportion of corrosive clay soils	4.27	Corrosive soils corrode ferrous pipe leading to through-wall metal loss, bursts and leakage	Y
Changes in soil-moisture deficit affecting leakage	4.31	Changes in SMD in conjunction with shrink-swell soils leads to soil movement and increased leakage	N
High density of pipe joints and connections	4.34	There is a proven correlation between numbers of joints/connections and leakage.	Y
Higher traffic flows in London	4.39	Traffic loading can be transferred to buried pipes leading to bursts and leakage	Y*
High density of road junctions in London	4.40	Road junctions are where traffic loading is worst leading to bursts and leakage	Y
High hydraulic loading on the London network	4.43	High hydraulic loading (water delivered/surface area of pipes) increases hydraulic stresses on network	Y
High demand growth in London	4.44	High growth in demand can lead to increased velocities and hydraulic stresses in the network	Y
High proportion of network is pumped (Kw/km)	4.47	Pumped supplies, as opposed to gravity supplies, are more turbulent with higher risk of transients	Y

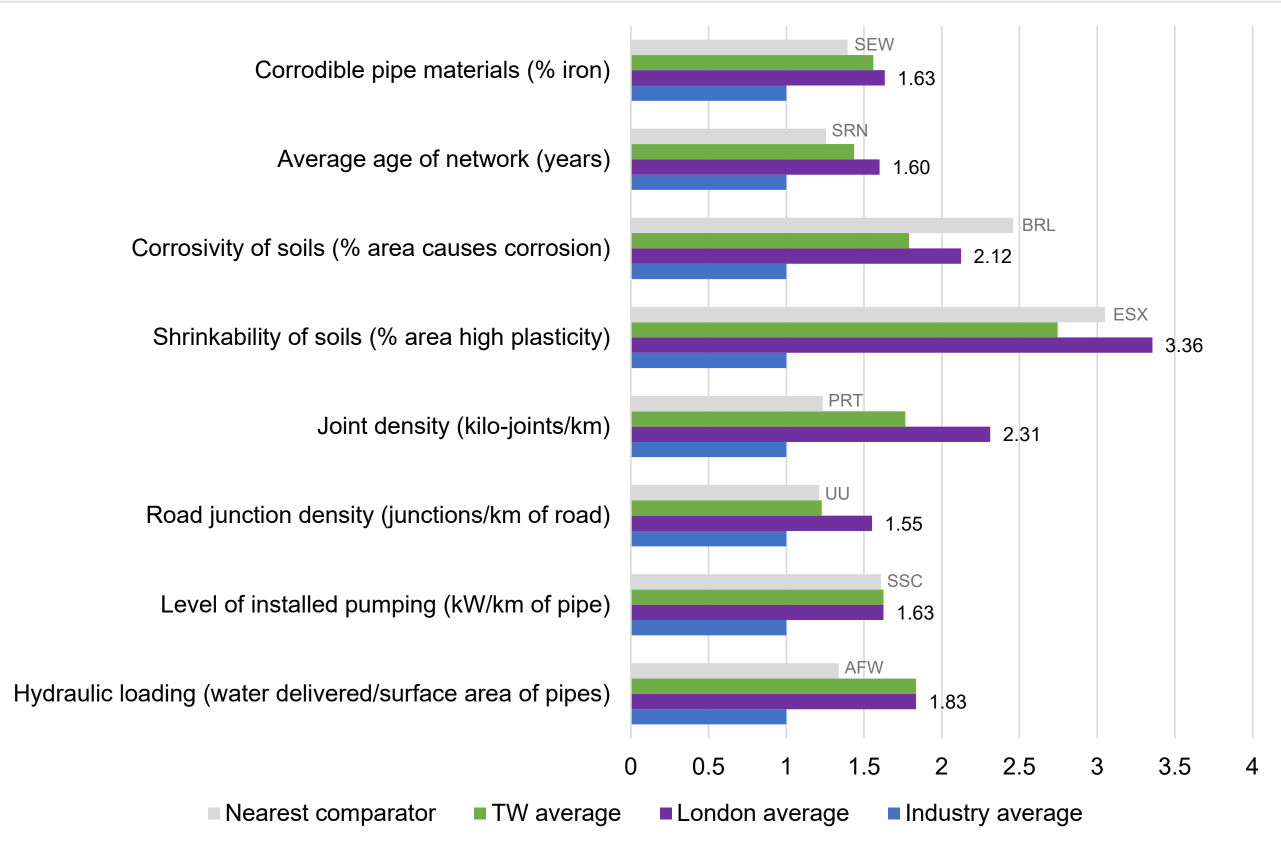
Source: Mott MacDonald
* Comparative analysis of traffic flows only available at a regional not a company level.

Figure 4.63 compares London and Thames Water with the industry average and nearest comparator values for a selection of the factors listed in Table 4.10. It shows that all the factors impacting the performance of TW's network are more severe for London, but also for TW as a whole, than the average for England and Wales and that in all but one case the factors for London are more severe than the nearest comparator.

For ownership of corrodible pipe materials and age of network, London is an outlier and for percentage of area covered by shrink-swellable clays, it is also an outlier and only one company has a higher percentage of corrosive soils. . It is not surprising that the combination of corrodible materials sitting for over 100 years in corrosive clays has resulted in a poor condition network subject to high burst and leakage rates, despite TW's best efforts to replace it at an affordable rate. Note that the nearest comparator company is different for each factor, so there is no other company facing a similar combination of challenges.

London has the highest joint density using the kilo-joint measure and this has been shown to correlate well with leakage. London also has the highest density of road junctions per km of road and our analysis shows that 40% more repairs take place at road junctions than in the roads between junctions, suggesting that the concentration of traffic loading and pipe fittings at junctions is having a detrimental effect.

Figure 4.63: Comparison of factors impacting performance



Source: Mott MacDonald analysis, data based on various data sources listed in Table 4.10

London's relatively flat topography also means that its network is predominantly pumped. As a result, TW has the highest installed pumping capacity per km of main than any other water company, increasing turbulence in the system compared with gravity networks and the risk of transients. In addition, the concentrated population in TW's supply area means that the demand is high relative to the size of the network meaning that it has a hydraulic loading that is twice that of other companies. This increases the hydraulic stress on the system.

TW has worked hard to mitigate these hydraulic factors, including pressure management and surge suppression to create calm network conditions. More work is needed to better understand pressure variances and velocities in the network and control transients, and TW has established a transient monitoring and analysis team to drive a programme of improvements.

In considering all the factors impacting performance in Table 4.10 and Figure 4.63, it is important to note that it is not one factor that is responsible for driving the poor condition and performance of the London water network. It is the action of all of them in combination that marks London out.

To prioritise investment, TW needs to understand the combination of factors that best explain localised performance. TW's AIM model for water distribution mains does this statistically for some of the key factors driving performance such as pipe material, diameter, age and soil conditions but not for all the factors analysed in this chapter. It would be valuable to undertake some follow-on statistical analysis to examine the compounding effect of the full basket of factors identified in this report. This could be done through multi-regression analysis and machine learning.

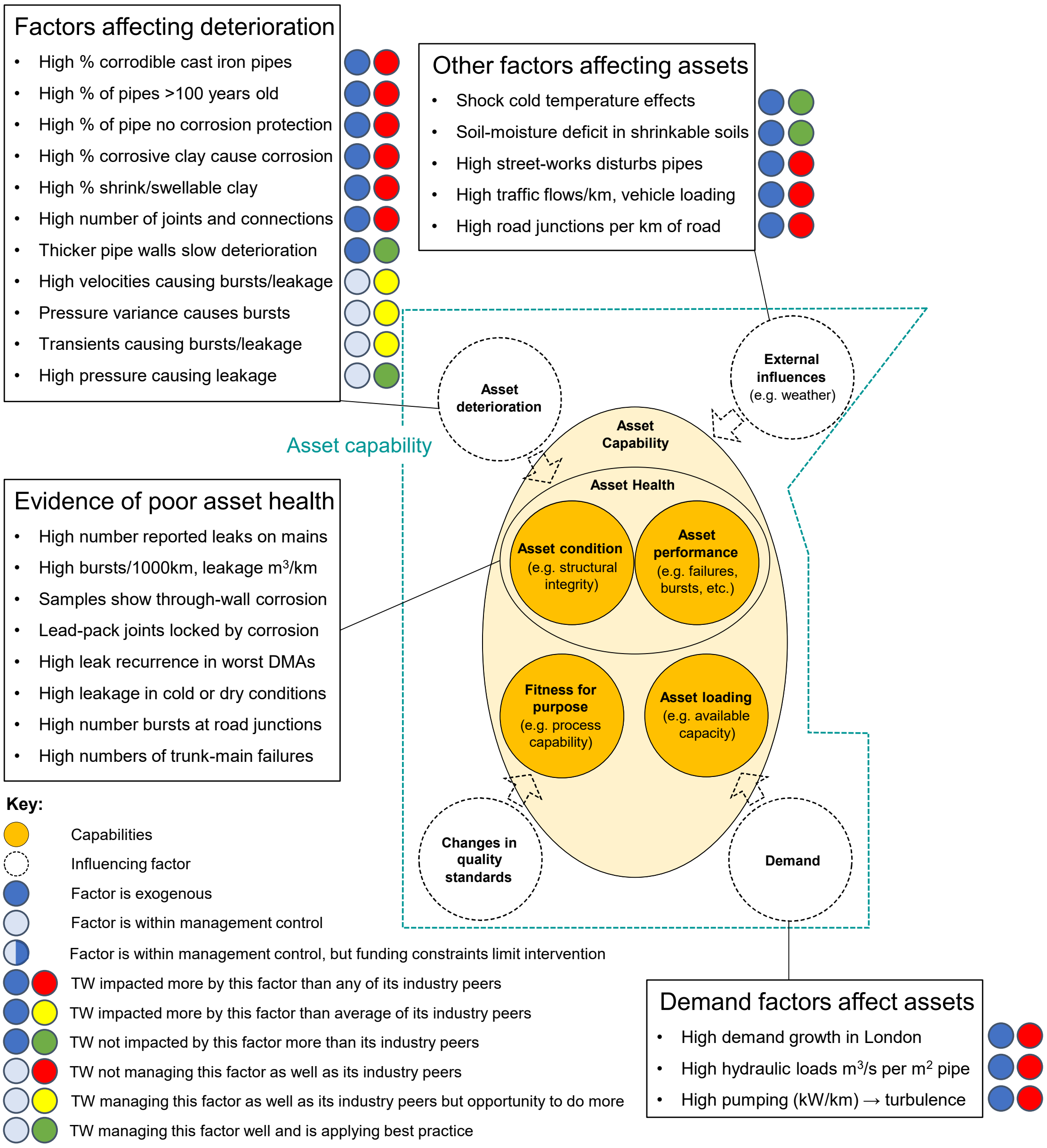
4.10 Conclusions on Asset Capability

In this section, we draw some conclusions on the capability of the assets in London's water network, the factors impacting performance and their causes and the extent to which TW is able to control them. We also compare the factors impacting London's water network with those affecting other networks in the country and consider ways to mitigate them. Finally, we draw some conclusions on the priority actions to mitigate the factors to enable TW to achieve a sustained improvement in performance that is comparable with its peers.

1. Factors impacting performance

Figure 4.64 summarises the key factors impacting the capability of London's water network, the extent to which they are exogenous or within management control and the severity of their impact compared with water industry peers or TW's success in managing them.

Figure 4.64: Key factors impacting asset capability



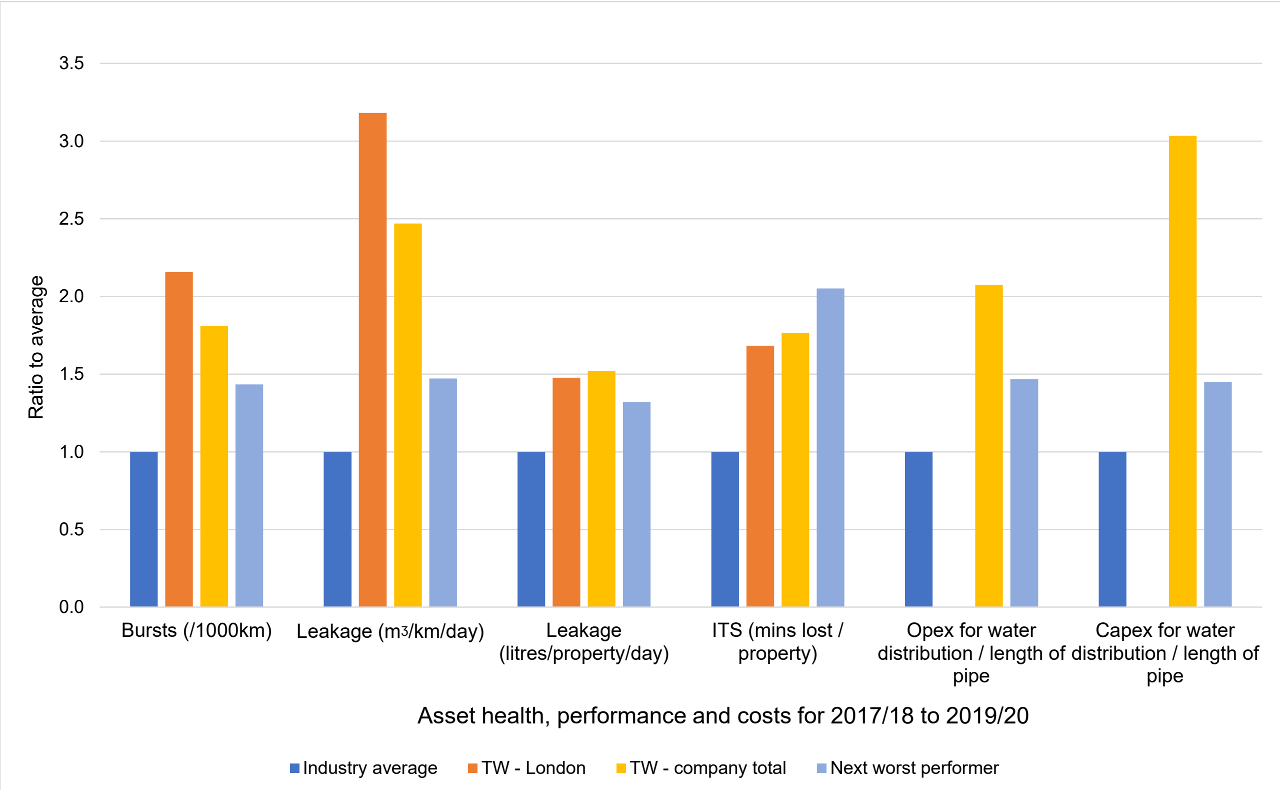
Source: Mott MacDonald

Firstly, many of the factors impacting the capability of London's water network are exogenous, but some, mainly to do with the hydraulics of the system, are within management control.

a. Evidence of poor asset health

In Figure 4.64 we have listed the evidence of poor asset health and to show the extent to which London is an outlier in this respect; we have compared performance and costs against industry averages in Figure 4.65.

Figure 4.65: Comparative asset health (AMP6)



Source: Mott MacDonald, based on annual return data

Figure 4.65 shows that London's water network is a performance outlier for bursts and leakage but not interruptions to supply, (though performance is worse than average). The poor asset performance is partly responsible for high levels of expenditure, both operationally in repairing the asset base and in capital maintenance (costs are discussed in Chapter 7: Cost of managing the network).

Other bottom-up evidence that London's water mains are in poor health, as described in this chapter, are that:

- There is a high number of reported (visible) leaks on mains compared with other companies
- Pipe samples show heavy corrosion with through-wall corrosion in many cases
- The lead-pack joints on many older cast iron pipes have become locked with corrosion, making them vulnerable to fracture when water temperatures drop in winter
- There is high leakage recurrence in the worst performing DMAs, indicating that the pipes are in very poor condition
- The network responds poorly to periods of cold or dry conditions, with leakage outbreaks
- There are high numbers of repairs at road junctions, suggesting vulnerability to traffic loading

- There were a high number of high-profile trunk-main failures in AMP6.

The following sections explain why London's water network is in poor health.

b. Factors affecting deterioration

One of the reasons for the poor health of London's water network is the high rate of deterioration of TW's ferrous pipes and the large number of exogenous factors driving it, as listed in Figure 4.64. The core factors are listed at the top:

- A high percentage of TW's pipes are made of cast iron, a corrodible material
- A high percentage of them are over 100 years old, predate the first British standard (BS 78) in 1917 and are of variable manufacturing and construction quality
- A high percentage of pipes have no corrosion protection and/or the original coal-tar lining has been lost
- Many of these pipes sit in corrosive clay soils and have become heavily corroded
- Many of the clay soils are also plastic and shrink and swell with changing moisture content. Soil movement then leads to breakage of brittle cast-iron pipes.

These are the core factors impacting the performance of London's water mains. The combined effect of corrodible materials and very old pipes of variable manufacture with no corrosion protection in contact with corrosive and plastic clay soils for so long has resulted in through-wall corrosion and propensity to burst and leak. Other factors, as listed below, also impact deterioration and likelihood of failure, but many of these are secondary factors that are significant because of the age profile and corroded state of the pipes. They are important, however, as they help identify the pipes that are the most vulnerable to failure.

Not all pipes are so affected as some are younger and have useful life left in them and others are located in less onerous conditions and have not deteriorated as much. What marks London out as different to other networks though is the scale and extent to which these factors apply (which we show below).

Other factors affecting deterioration listed in Figure 4.64 include:

- The high number of pipe joints and connections in London's dense urban environment, all of which are potential points of weakness for leaks to occur (there is a strong correlation between joint and connection numbers and leakage). The age profile of the network and the short length of pipe that could be manufactured in the 1800s means that London has proportionally more pipe joints than other networks.
- Pipe wall thickness, which determines how long it takes for corrosion to penetrate the pipe wall and cause failure. This generally marks the difference between thin-walled distribution mains and thick-walled trunk mains, resulting in very different deterioration rates and potential intervention strategies.
- High and low pipe velocities in some water mains which model data show are associated with higher failure rates.
- Diurnal pressure variance exceeding 25m which model data shows to cause higher failure rates in distribution mains (not trunk mains).
- The occurrence of transients in the network during normal operation, such as pump switching, has been shown to cause pipe bursts and leakage.
- Pressure, which has a direct effect on leakage. Uncontrolled, this could have a negative impact on leakage but in practice, TW manages pressure in the network well to reduce it as far as it can without impacting service. While this is a factor, it is one that TW manages daily.

The number of joints and connections and pipe wall thickness are exogenous, but the other factors listed above are within management control. We have designated three of these, all hydraulic factors, as ‘yellow’, meaning that there is more that TW could do to understand and manage these. TW’s limited coverage of the network with calibrated hydraulic models means that it does not have contemporaneous information on pipe velocities and diurnal pressure variance at a pipe level, though it is extending its model coverage and it may be able to do more with the models it has. Although TW is monitoring transients and has a programme of work in AMP7 to implement calming measures, there is more to do to cover all areas of the network.

c. Other exogenous factors affecting asset capability

In Figure 6.64 we have listed other exogenous factors affecting London’s water network. Many of these are secondary factors that we have shown impact the failure rates of pipes that we know to be in poor condition. We would not expect pipes in good condition to be so affected.

- Sudden drops in water temperature during cold weather cause temperature stresses in pipes with joints that are locked with corrosion deposits resulting in pipe fracture or joint rupture which leads to outbreaks of leaks. Most of London’s water comes from surface water sources, so the temperature can change quickly which shocks the pipe network. This failure mechanism makes the network vulnerable to freeze-thaw events such as that seen in 2018.
- Changes in soil-moisture deficit in clay soils lead to soil movement through shrink or swell effects, resulting in pipe rupture if there is no flexibility in the pipe or joints. Like freeze-thaw effects, this can lead to outbreaks of leakage during dry weather as TW experienced in 2018.
- The high density of utilities in London’s streets to serve the high population density results in a high level of street-works activity which can disturb water mains through nearby excavation. This was one of the findings of the two streets report (see section 4.5).
- London’s streets experience the highest traffic flows in the country, and this may result in high vehicle loads to water mains, depending how deep they are. Pipes within 1m of the surface are more vulnerable than deeper pipes.
- London has the highest number of road junctions per km of road in the UK and this is where vehicle loading is most acute through acceleration and braking forces. Analysis shows that pipes are 40% more likely to fail at road junctions than in the road between junctions.

London does not experience cold or dry weather more than other parts of the country, but they have a higher impact on TW’s fragile network. The high level of street works activity, traffic flows and density of road junctions are more significant in London than other parts of the country.

d. Demand-related factors affecting asset capability

London is a growing city and demand growth has an impact on the performance of pipe networks. We have listed some demand-related factors impacting the performance of London’s network:

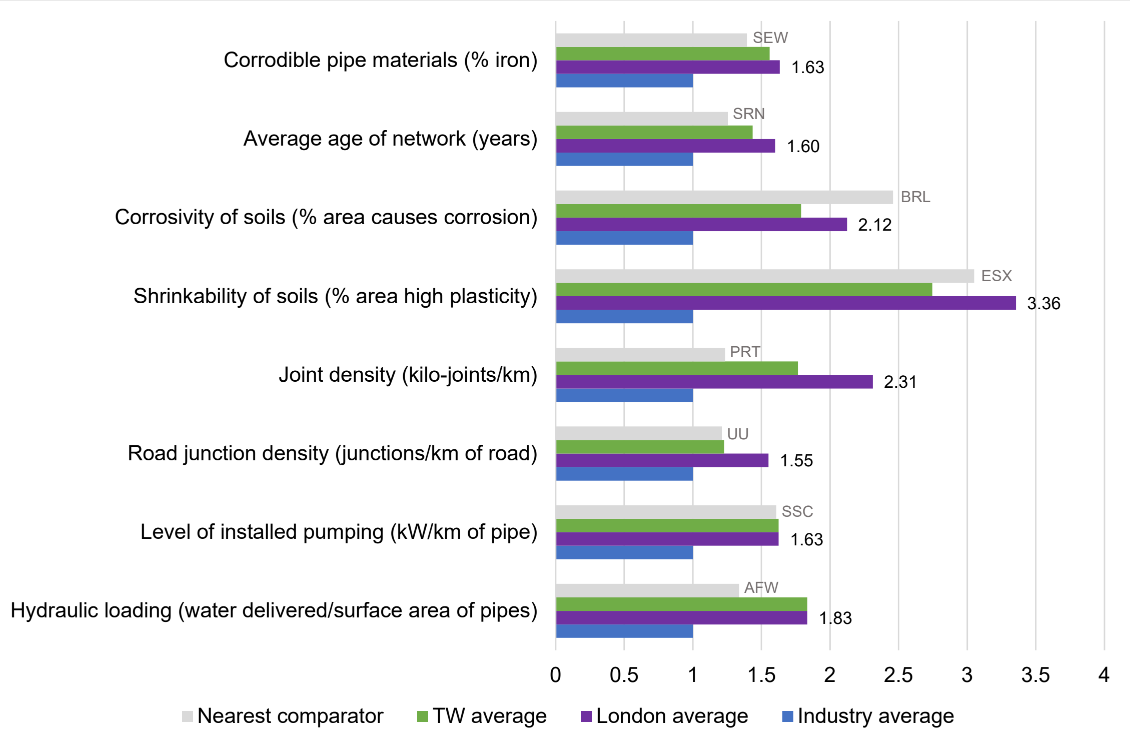
- London has experienced higher demand growth than anywhere else in the country, leading to higher velocities and hydraulic stresses in existing water mains.
- TW experiences nearly twice the hydraulic load (expressed in m^3/s per m^2 of pipe) than any other water company, creating the potential for higher hydraulic stress in the network.
- The flat topography leads to a high level of pumping and TW has the highest installed pumping capacity per length of main (kW/km) of all the companies. Pumping leads to turbulence in the network, even with good controls, and this can affect the performance of the system in terms of leakage and bursts.

We have investigated these hydraulic stress factors to determine their effect on performance. Their effects are reflected in the factors causing deterioration, namely high velocities, diurnal pressure variations and impacts from transients. These effects are all exacerbated by the poor condition of the network. As London’s population and demand continues to grow, their influence on performance will grow without steps to control them.

2. Comparing the factors impacting asset capability

Figure 4.66 compares London and Thames Water with the industry average and nearest comparator values for a selection of the factors listed in Figure 4.64. It shows that all the factors impacting the performance of TW's network are more severe for London, but also for TW as a whole, than the average for England and Wales and in most cases the nearest comparator.

Figure 4.66: Comparison of factors impacting asset capability



Source: Mott MacDonald analysis, data based on various data sources listed in Table 4.10

The main exceptional and foundational issue is the material and age profile of the asset base, the scale and age of which marks London out from other networks. This is compounded by the various situational factors, which themselves are more extensive and severe than other parts of the country such as the aggressive soils, various exceptional urban environment related factors and hydraulic factors. This has manifested as exceptionally poor asset health, poor performance and high risk (for example sensitivity to weather shock and high-profile catastrophic failures and major incidents) as clearly evidenced over many years making TW an industry outlier in terms of performance and public perception. This situation is likely to deteriorate as the assets age further and increased customer expectations and demands are placed upon them.

Note that the nearest comparator company is different for each factor, so there is no other company facing a similar combination of challenges.

3. Mitigating the factors impacting asset capability

We list below the ways in which the factors above could be mitigated:

a. Corroded cast iron distribution mains in aggressive soils

For water mains that are over 100 years old in corrosive clays and experiencing elevated repair frequencies and leakage recurrence, these warrant replacement or renovation with plastic materials that are resistant to the aggressive soils, have fewer joints than the cast iron pipes that they will replace and have the flexibility to cope with soil movement during wet and dry periods. TW has been having success with HPPE which has proved to be a resilient material.

For water mains that are not as badly affected, then continued find and fix may be the most economical solution, provided that overall service objectives can be achieved. To reduce the incidence of failures in corroded but serviceable mains, then find and fix can be supplemented with hydraulic interventions such as pressure management and calming measures (see below). Ultimately, a blend of these solutions will be required.

When renewing distribution mains, there is a choice between spot-replacement of the worst-performing pipes and replacement of all the cast iron pipes in a DMA where they are all in exceptionally poor condition. Analysis of benefits has shown that whole-DMA replacement of pipes leads to more sustained benefits, whereas spot-replacement can lead to transfer of the problem to the remaining pipes and erosion of benefits. Also, there is evidence that whole-DMA replacement of pipes is cheaper in terms of construction add-on costs (see Chapter 7: Cost of managing the network).

In choosing the right blend of solutions, account needs to be taken of the trade-offs between short-term and long-term benefits of different options and differences in cost. Although detection and repair, pressure management and calming measures are inexpensive compared with mains renewal and affect immediate benefits, they do not improve the corroded pipe network which will continue to deteriorate. Benefits will therefore erode over time, whereas renewal will secure benefits for decades. A whole-life cost benefit analysis can evaluate these trade-offs.

b. Joints and connections

There is a clear correlation between the number of joints and connections and leakage (using the kilo-joint formula). The age profile of TW's network and the limitations of early pipe manufacturing techniques gives it a disadvantage in this respect, so the long-term aim should be to reduce the number of joints and connections. Modern PE pipes require far fewer joints, so renewal of the network with plastic will help achieve this objective.

Opportunities to rationalise the network could also be explored. If the same customers can be served from a shorter length of pipe, then this will also reduce the number of joints and will be cheaper also. Replacement of old cast iron pipes that have seen many configurations of houses and blocks of flats connected to them over their lives will also resolve any legacy issues of former connections that are no longer used but may be a source of leakage.

Renewal of water mains should include renewal of service connections at the same time, as these are frequently also a source of leaks and costs of replacement are lower if delivered together. This is particularly so if there is an opportunity to replace lead pipes, which will deliver water quality benefits as well.

c. Pipe wall thickness - transmission mains

Thicker walled pipes such as transmission mains fail less frequently and widespread pipe renewal, as well as being unaffordable, may not be the most appropriate solution. Failure mechanisms are likely to be varied and highly localised (as the forensic review found) and thus the focus is one of monitoring to identify local asset health issues and risk-based intervention to mitigate the highest consequences. This is TW's approach.

Apart from localised replacement of degraded sections of trunk main, mitigation may include additional monitoring and associated enabling works, cutting in valves to enable rapid isolation and repair of failed sections and asset protection to minimise the risk of 3rd party strikes.

d. Hydraulic factors

A range of measures are available to mitigate the hydraulic factors identified, all of which require calibrated hydraulic models to optimise the network:

- Localised network reconfiguration to mitigate high and low velocities and improve hydraulic efficiency by reducing head losses in the system.
- Pressure management or rezoning to mitigate high diurnal pressure variance or, where this is not possible, renewal of vulnerable lengths of distribution main to improve resilience to pressure variance.
- Calming measures such as variable speed drives on pumps, anti-slam devices on non-return valves to mitigate transient risks (TW is implementing a programme of calming measures).

e. Weather resilience

Plastic pipes are more flexible and resilient to changing water temperatures and soil-moisture deficit, so replacement of brittle and corroded cast iron pipe with HPPE pipe will gradually improve the resilience of the network to weather effects.

Better understanding of the location and health of cast iron pipe joints to identify those that are locked with corrosion deposits and are most vulnerable to weather effects would help with targeting replacement of these pipes to accelerate resilience. This could be informed by data from previous winter leakage outbreaks and to identify pipes that fail repeatedly and seasonally.

f. Street works disturbance

TW's asset standards specify minimum distances of 5m for trunk mains and 3m for distribution mains for third parties working near its water mains to try to protect them from disturbance from street works, but TW cannot always be there to police these standards and TW does have instances of damage caused by contractors. One of the trunk main failures covered by the forensic review was a third-party strike.

TW has 31,550km of watermain and any building activity or street works in London will be near a TW asset, so it is not possible to police all activity. Operations is aware of large construction projects near TW's critical assets, and they are watched over by TW's asset protection team.

This targeted approach seems appropriate. New HPPE pipes are more resilient to soil movement than cast-iron pipes but will need protection from strikes. In Europe, they often place road markers along the alignment of their pipes so that contractors know not to dig there. TW could consider a similar approach for its most critical mains if it can obtain agreement from highway authorities to do so.

g. Traffic loading at junctions

Measures to mitigate failure mechanisms at road junctions will depend on the root causes. Where pipes are too shallow and therefore vulnerable to braking and acceleration forces, then pipes will need to be renewed and installed at greater depth or realigned away from the junction. At other locations there may be complex arrangements of valves and fittings that are vulnerable to traffic loading or disturbance, or the pipes may be too close to other services. In these cases, the layout of pipes and fittings may need to be simplified or re-laid to avoid services and obstacles. In each case, the root cause and most appropriate mitigation measure will need to be established through investigation.

h. Demand factors

The demand-related factors listed in Figure 4.64 affect the network at a local and strategic level. Item (d) lists mitigation measures for local hydraulic effects. To address the strategic effects:

- Plan for growth. It is important that all planned asset replacement, renovation and reconfiguration work is designed to accommodate forecast growth in demand.

- Reconfigure the network to reduce the impact of pumping.
  - Create greater separation between transmission and distribution where economically feasible, i.e. serve more customers by gravity from service reservoirs and limit the number on pumped supplies..
  - Reduce the number of customers directly fed from booster pumping stations

4. Priority actions for sustained improvements in asset capabilities

We have identified the following priority actions with respect to improving asset capability:

a. Tactical interventions

In analysing failures at road junctions, we found that many sites had a high number of repairs within short distances of each other over short periods of time (for example, one road junction had seven repairs in the same year). It is likely that a whole-life cost-benefit analysis at these sites would favour pipe replacement over continued repair.

We recommend that TW applies repair triggers (automatic monitoring of repair workorders in the same location) to flag such cases to asset planners to consider the case for local replacement instead of continued repair. Provided the site was not located in an area selected for wholesale mains replacement, most schemes would be small-scale and non-complex and could be delivered through DMC (directly managed capital).

b. Long-term strategy

A long-term strategy is required for London's water distribution system to map out the sustainable level of mains renewal or rehabilitation to meet long-term objectives for performance and service at least whole-life cost. The scale of the challenge from corroded cast iron mains in London means that a holistic multi-AMP improvement strategy is required that is a blend of mains renewal, pressure management and network calming measures. TW is developing such a programme.

Fundamentally, the improvements in performance and reductions in cost that are required cannot be achieved without significantly increasing mains renewal rates above those delivered in recent AMPs to offset deterioration (650 km/AMP). Increased renewal rates are required for the next few AMPs to restore the asset base to a condition that will fulfil customer and regulatory expectations and meet performance targets in an effective and sustainable way.

The strategy should take the opportunity to reconfigure and rationalise the network where feasible. It may not be necessary to replace all the pipes that TW currently operates and rationalising the network will save cost. It also presents the opportunity to resolve water quality issues in the network such as 'dead legs', excessive water age and reservoir turnover.

Once a long-term strategy is in place, then shorter-term five-year plans need to align with it.

A long-term strategy is also required for trunk mains. This needs to account for changes in demand and facilitate the integration of future sources of supply and treatment with the existing water supply system. It also needs to incorporate plans for improving resilience in east London and any future extensions to the ring-main that may be required to accommodate growth and strengthen resilience. This may fundamentally change the configuration of parts of the network at a strategic level and is required to set current plans for risk mitigation in a long-term context.

Our analysis of trunk main failures identified the 1000mm to 1299mm diameter range, which includes 42" and 48" pipes, to have the highest failure frequency at 7% per annum per km. This is three times higher than the failure frequency for 330mm to 400mm pipes (see Figure 4.16). Given that these are strategic mains whose failure can cause major disruption to supply, (never mind the risk to public safety when they fail) they are deserving of their own strategy to either gradually renovate the most vulnerable sections to improve their reliability and/or reconfigure the network to reduce reliance upon them. Given their length (110km) and the cost of renovation and enabling works, this will be a multi-AMP programme that needs to dovetail with plans for growth and resilience in east London.

c. Network policies

We recommend that TW reviews its policy on the number of customers it supplies directly via a pumping station as opposed to by gravity supply from a service reservoir. Gravity supplies from service reservoirs provide smoother, more consistent pressures and less disturbance to the network, resulting in fewer failures and service disruptions. Having assessed the current balance between gravity-supplied and pumped supplied customers, TW may wish to set targets to gradually reconfigure the network to increase the proportion of gravity-supplied customers.

Given that TW is embarking on a long-term programme to renovate its network, this would be a good time to review other network policies and standards and confirm that the performance criteria are appropriate for a modern network. Like other companies, TW has inherited many legacy issues such as dead legs, remnants of coal-tar linings, poor circulation in pipes and reservoirs that cause hydraulic and water quality issues. One would not wish to invest to renew the network and miss the opportunity to resolve these issues. This will also ensure that the investment delivers best value by capturing these secondary benefits to water quality and hydraulic efficiency as well as delivering benefits to leakage and bursts.

d. Improving asset knowledge

We have made observations and recommendations in this chapter on asset information and modelling, but this is discussed in more detail in Chapter 5. We only provide a summary of improvement actions here:

- Improving records for abandoned and renovated pipes
- Improving knowledge of asset health of pipes and joints through sampling and inspection
- Investigating the causes of failure at road junctions
- Improving the use of hydraulic models and their coverage
- Improving the systems and data for surge protection and network calming assets
- Improving capture of benefits from network interventions and how long they are sustained.

e. Targeted investment

TW has a good suite of tools for targeting investment in distribution mains and trunk mains such as DMA fingerprinting and AIM and these account for many of the factors described in this report that affect network performance and costs, but there are some that they do not directly account for. We recommend that TW refines its targeting by considering the following when identifying pipes for replacement:

- The higher incidence of failures at road junctions, having investigated the likely causes
- Incorporates leakage recurrence in targeting decisions (where there is confidence in the data) and uses it to assess potential opex savings from intervention
- Identifies high and low velocity pipes in the network using calibrated network models and compare them with frequency of repair in those locations to inform targeting decisions
- Does the same with head loss, as we show in Figure 4.53
- Takes greater account of hydraulic effects generally, and the potential for secondary benefits in addition to reductions in leakage and bursts

- Although further opportunities for pressure management are nearly exhausted, we recommend that TW keeps this under review as more of the network is covered by calibrated hydraulic models and valve technology evolves
- Undertakes some follow-on statistical analysis to examine the compounding effect of the full basket of factors identified in this report to better understand how to account for them in targeting investment

f. Calming the network

We recommend that TW continues to explore opportunities to calm the network through transient controls at pumping stations and elsewhere in the network. In implementing the AMP7 programme, it is important to capture the benefits to bursts, leakage, and other metrics such as customer complaints, to confirm or revise current estimates and justify further programmes of calming measures for future AMPs.

g. Improving hydraulic efficiency

The renewal of a degraded water network must present opportunities for improving hydraulic efficiency (reducing head losses) and in the pumped parts of the network, reducing dynamic head and power costs. We therefore recommend that TW uses its existing models (updated where necessary) to assess hydraulic efficiency, especially in old tuberculated cast iron mains, and explore opportunities to improve it when planning network renewals.

Once new models become available in AMP7 and if they are operationalised (connected to telemetry) then TW can use them to monitor hydraulic efficiency more closely and better understand its impact on costs and performance.

We also recommend in the future that TW uses its hydraulic models together with its other investment planning tools to develop hydraulic system plans that integrate hydraulic efficiency, asset integrity, leakage, growth, water quality and operational efficiency. Collectively, these should provide the detail to support the long-term strategy referred to in b). Such integrated hydraulic system plans would be an innovation for the sector that historically has used separate tools for planning for growth (hydraulic models) and planning for capital maintenance (deterioration models) as well as separate tools for capital investment and operations.

We support TW's plans to operationalise its hydraulic models so that it can provide live information to Operations on current pressures and flows in all parts of the system with interactive capabilities for operational planning and alarms to highlight hydraulic anomalies. TW's new SRV tool (discussed in chapter 6.7) is a step towards achieving this.

h. Driving innovation

In section 4.4, we identified a need to capture more information on asset health, in particular pipe joints, but capturing information on joint locations and their health is challenging.

We recommend that TW continues to research pipe inspection techniques to enhance knowledge of pipe and joint health. We understand that TW plans to trial new inspection technologies at its test rig at Kempton.

5 Organisational capability

Chapter summary

This chapter describes TW's organisational capability in managing London's water network, evidence of efficient investment decisions including the benefits of past investment, the quality of TW's asset knowledge and the insight it gains from it through analysis tools. We then draw conclusions on its organisational capabilities and where they might be improved.

Some of the key discussion points presented in this chapter are briefly summarised below:

- Factors impacting organisational capability
  - The decision to adopt an outsourced alliance model for delivery in AMP6 was not successful. TW intervened quickly to restructure the alliances and get delivery and performance back on track. AMP6 leakage targets were achieved by 2019/20.
  - TW has redesigned its delivery model for AMP7. It has moved to an intelligent client model with revamped inhouse capability to improve control over risk and value decisions. The early indications are that this model is more effective.
  - TW is developing a strategic long-term 50-year strategy to replumb London.
  - Past investments have delivered significant benefits in reducing leakage and bursts.
  - The quality of TW's asset knowledge and analytical tools to support effective decision making is in large parts as good as or better than other water companies. TW is also capturing accurate repair data and inspection data. TW's monitoring of trunk main asset health is in our view industry leading.
  - Further pipe sampling to understand pipe and joint health would aid targeting and validation of statistical models.
  - Improving and extending hydraulic modelling and using them to better understand hydraulic behaviour and it's impacts on the network would be beneficial.
  - TW has relatively low meter penetration which limits TW's ability to fully understand the water balance at DMA level. TW is implementing a metering programme in AMP7 which will improve this situation.
- Mitigating the factors impacting organisational capability
  - Allow the intelligent client model to mature and continue to support its success/
  - Develop a long-term strategy for London's water network to include increased level of mains replacement or renovation to improve performance and lower costs.
  - Continue to improve knowledge of the health of London's water mains and pipe joints through sampling, monitoring, and inspection.
  - Continue to build hydraulic understanding of the network and incorporate it into needs assessment and investment planning.
  - Integrate the use of analytical tools across multiple drivers (integrity, capacity, water quality) to create long-term hydraulic system plans that address all performance and cost drivers.
- Priority actions for sustained improvements in organisational capability
  - The priority actions focus on completing a long-term strategy for water, improving asset knowledge, refine targeting of investment, mitigating cost pressure, driving innovation.

5.1 Evidence of effective investment decisions

Chapter 4 explored asset capabilities and the factors impacting them and concluded that many of the factors were exogenous and outside TW's control. However, today's asset capabilities have been influenced by decisions taken in the past and as TW has been the custodian of London's water network for over 30 years, to what extent has TW's organisational capability and decision-making been responsible for today's poor asset health problems in London's water network?

To answer this question, we must first ask what TW's obligations with respect to stewardship of the water network were. Firstly, there was, and still is, the general duty under the 1991 Water Act for TW to maintain an efficient and economical system of water supply and to maintain, improve and extend its water mains to provide wholesome supplies of water to its customers. To determine whether companies had met this obligation, up until the end of AMP5 (2015), Ofwat required companies to *maintain stable serviceability*.

Serviceability was an Ofwat-defined output measure for capital maintenance, consisting of a basket of asset performance (e.g. bursts) and customer service (e.g. interruptions to supply) measures that were monitored and trended over time. Separate baskets of measures were used for each sub-service, so London's water network was assessed using the water infrastructure serviceability measures. If collectively the trends of the basket of serviceability measures were stable or improving, then companies were deemed to have fulfilled their obligation to maintain their assets, but if serviceability was marginal or deteriorating, then companies had to implement action plans to recover serviceability and if they failed to do so promptly, then they were 'shortfalled' by Ofwat, a term used to describe the issue of fines to companies to compensate customers for services not delivered. This pre-dated today's performance commitments and outcome delivery incentives which perform a similar incentive function.

This then was the context within which TW made decisions about how much to invest in capital maintenance to maintain the serviceability of London's water network up to the end of AMP5. To manage the effect of the poor condition and rate of deterioration of its London network to maintain stable serviceability since privatisation, TW has:

- Relined old cast iron pipes in the 1990s to address water quality problems
- Renewed old cast iron mains and communication pipes, particularly in AMP4 as part of the Victorian Mains Renewal (VMR) programme
- Implemented pressure management, network reconfiguration and transient controls to create calmer conditions to reduce leakage and bursts
- Undertaken monitoring, incident management and localised replacement of high-risk trunk mains to minimise the impact of bursts on customers
- Replaced customer supply pipes and
- Detected and repaired leaks.

Of these, the mains, communication pipe and supply pipe renewal activities and the relining activities have improved the condition of the network to offset the effects of deterioration. Pressure management and network calming measures help to reduce leakage and benefit serviceability, but do not improve the long-term health of the network.

On a comparative basis, the rate at which TW has renewed or relined mains versus other companies over the period from AMP1 to AMP5 is provided in Table 5.1. This indicates that while TW rehabilitated (relined or replaced) at a rate that was close to the average of the England and Wales companies excluding Thames Water (29% versus 31%), the proportion of mains renewed has been lower (12% versus 20%). This is despite the 1,868 km of mains renewed in AMP4 under the VMR, including 368km funded by TW shareholders.

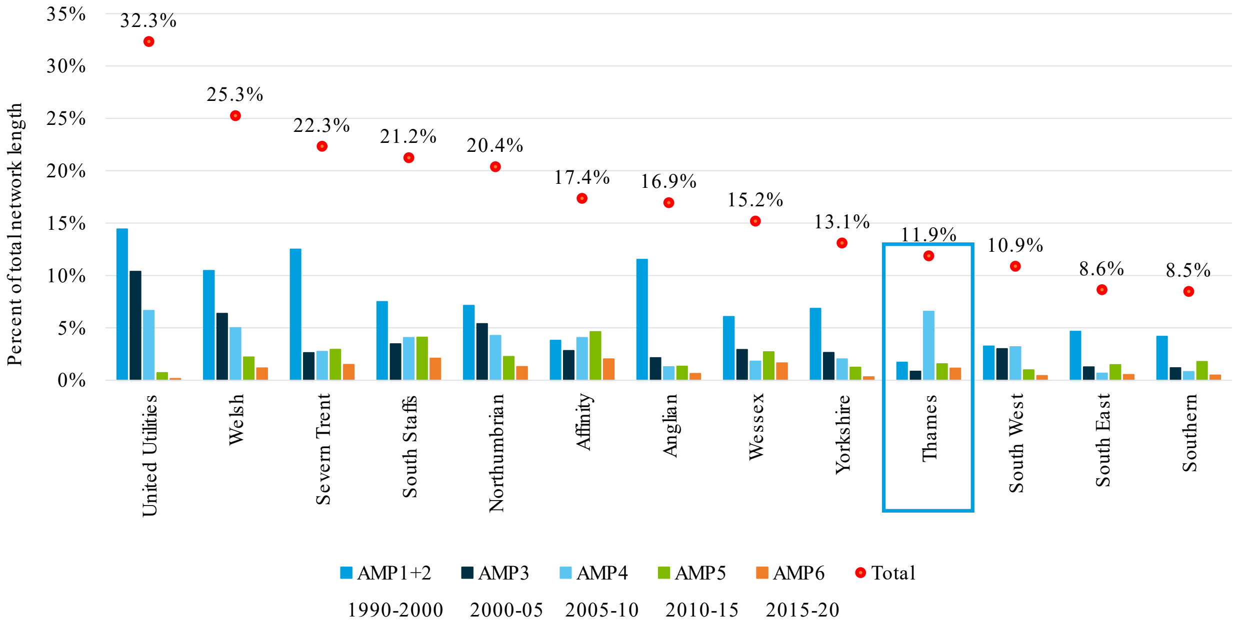
Table 5.1: Mains rehabilitation AMP1 to AMP5

	% of mains renewed or relined 1990 to 2015		
	Renewed mains AMP 1 to 5	Relined mains AMP 1 to 5	Total AMP 1 to 5
Thames Water	12%	17%	29%
England and Wales companies	19%	11%	30%
England and Wales companies excluding TW	20%	11%	31%

Source: Ofwat service and delivery reports for water companies in England and Wales

To illustrate this point further, Figure 5.1 shows the percentage of network renewed for all the companies since privatisation.

Figure 5.1: Mains renewed since privatisation



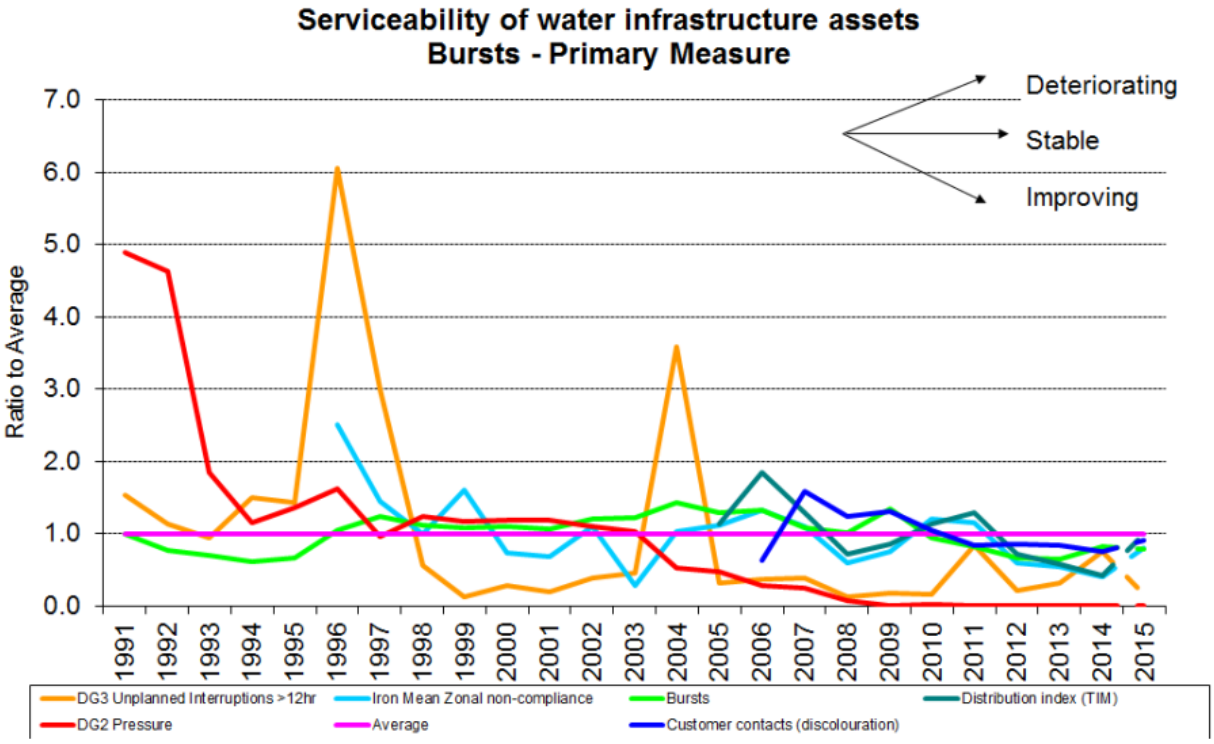
Source: TW presentation for Isle Utilities, Leakage management best practice workshop, mains renewal, Sept. 2020

Figure 5.1 confirms that relative to other companies, TW has replaced a smaller proportion of its network, especially in AMPs 1 to 3, though from Table 5.1, it has relined more of its pipes. Uniquely, TW replaced very little of its network in AMPs 1 and 2, whereas all the other companies replaced a lot of their networks, (for example UU replaced nearly 15% of its network) at a time when the regulatory pressure on funding was less, recognising that the former Water Authorities had a backlog of maintenance. These companies have benefited from that legacy, whereas TW now faces trying to renew its network at a time of funding constraints.

However, mains renewal is not the only option; it is the combination of all types of intervention that maintains service and TW was challenged to deliver efficiently. Mains renewal is expensive, especially in London where unit costs are comparatively high (as evidenced in Chapter 7: Cost of managing the network).

Despite replacing a smaller percentage of its water mains than other companies, TW successfully delivered stable serviceability in AMP4 and AMP5 as confirmed by Ofwat in its assessments of serviceability at PR09 and PR14. This is illustrated in the serviceability chart shown in Figure 5.2, taken from TW's AR15 water serviceability report.

Figure 5.2: Water infrastructure serviceability 1990 to 2015



Source: Thames Water AMP5 Serviceability Report June 2014

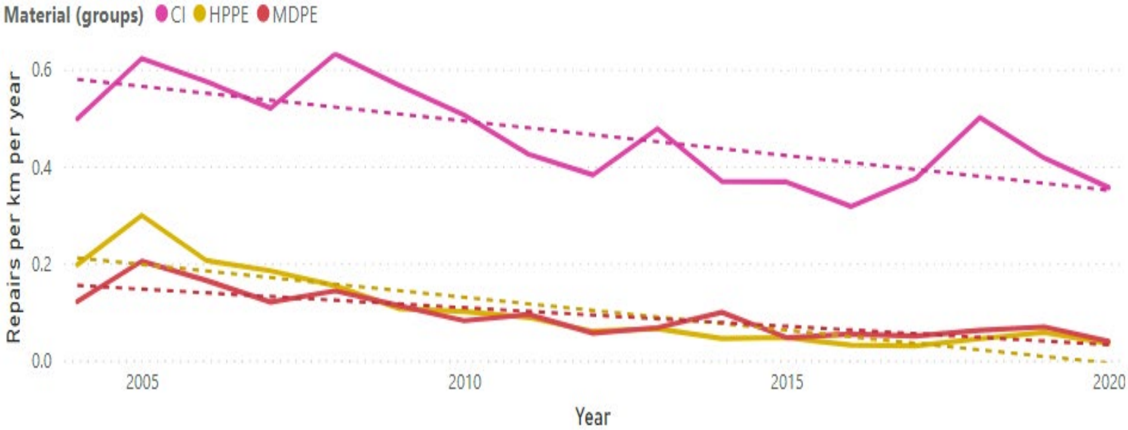
Figure 5.2 compares a range of metrics by normalising them by their averages. The chart can thus easily convey whether performance is improving, stable or deteriorating, which was the key determinant for serviceability. It can be seen that nearly all the measures are stable or improving over the period from 1991 to 2015, showing that TW had fulfilled its serviceability obligations. The one exception to this was DG3, the old interruption to supply measure which periodically had spikes of poor performance, here seen in 1996 and 2004 and to a lesser degree in 2011 and 2014. Such spikes were the result of trunk-main failures and this phenomenon was not unique to TW. All companies had similar serviceability charts for DG3.

Interestingly under the serviceability methodology, these were considered to be one-off incidents that were not indicative of the wider condition of the network. Today, such spikes are included in the overall figures for the interruptions to supply performance commitment and it is failures from trunk mains that continues to impact TW's interruption to supply performance.

Achieving its serviceability targets was a considerable challenge for TW given the condition of its network and it chose to invest more than its Final Determination allowances to achieve its commitments. TW did not achieve or claim cost efficiencies against its FD allowances for water infrastructure and in fact in AMP4 shareholders contributed to the funding of the VMR programme. It could not be said, therefore, that TW was in a position to do more, for example by investing 'efficiencies' in mains renewal to replace more leaky and bursty cast iron pipes.

Up until the end of AMP5, TW could legitimately claim that it undertook sufficient activity and investment to counteract the effects of deterioration but not to affect a material improvement in asset condition. Enhancements and operational improvements meant that performance improved, and the regulatory objective of stable serviceability was achieved, but the condition of the assets remained very similar to that inherited upon privatisation. Figures 2.13 and 2.14 which show the changes in asset stock since privatisation illustrate the second point, and Figure 5.3 shows that failure rates in cast iron pipes fell in AMP4 (2005 to 2010) with implementation of the VMR programme and that they have remained stable since then, (barring 2018 and the 'beast from the east') confirming that sufficient mains have been replaced to offset deterioration since AMP4 but no more.

Figure 5.3: Failure Rate by Material by Year (London only)



Source: TW Data: - GIS and mains repair database, 28 April 2021 processed in PBI
Note: AC and uPVC are not included as the relatively small lengths of pipe makes the yearly failure rate too erratic

For the AMP6 period the regulatory processes and control mechanisms were changed significantly from the previous periods with the introduction of Totex allowances, supported by broader performance commitments to key outcomes, and associated outcome delivery incentives (ODIs) to deal with over- and under-delivery. It was no longer sufficient to achieve stable performance as seen in Figure 5.2, as Ofwat set targets comparatively to drive improvements in performance for bursts, leakage, interruptions to supply and other metrics. Gaps in performance between TW and the rest of industry that were perhaps of secondary importance when the target was stable serviceability suddenly mattered a lot.

Failure to achieve regulatory targets occurred relatively recently in AMP6 with TW having to spend considerably in excess of FD14 allowances, asset health assessed as marginal throughout the period, leakage targets missed, and supply interruptions targets missed in two years of the period. The change in requirements for AMP6 left TW exposed as so much of London's network consists of old, cast iron pipe in poor health that achieving a step-change in performance would be difficult without an equivalent step-change in activity, which was not achievable within affordability constraints.

Early in AMP6 in 2016, TW experienced a number of high-profile trunk main failures that led to Ofwat challenging whether it was complying with its obligation to maintain its assets under Section 37 of the 1991 Water Industry Act. TW's response[15] reveals some of the reasons why performance deteriorated in AMP6:

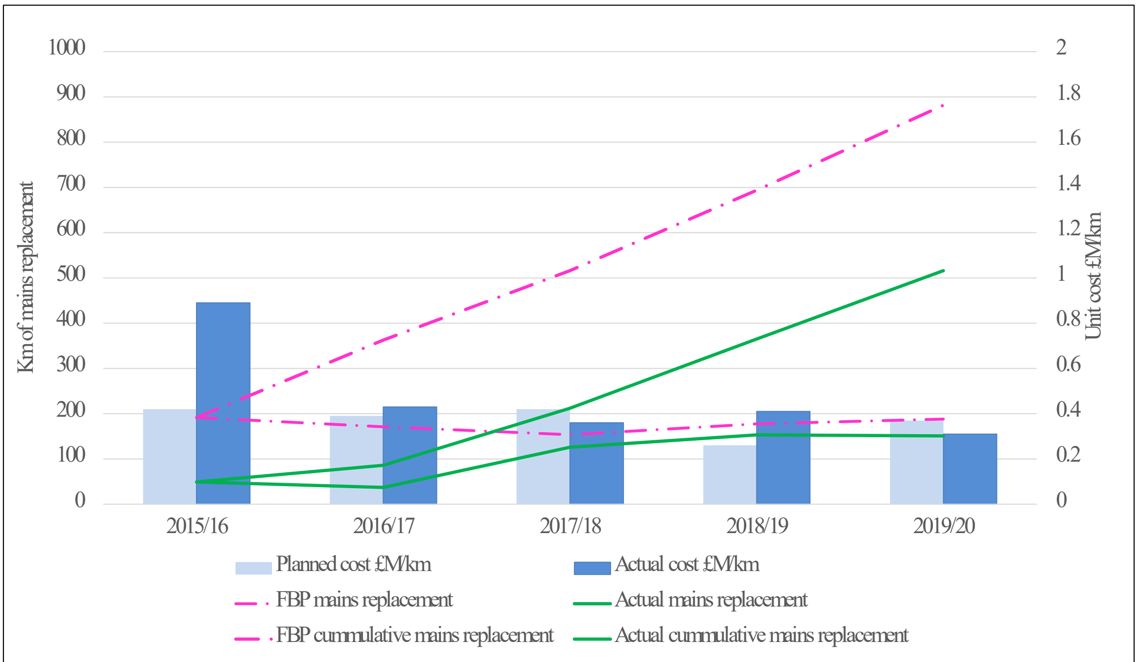
- Although serviceability was stable at the end of AMP5 and TW's leakage was within target, in 2015/16 TW reported marginal asset health and a deterioration in interruptions to supply over 12 hours (SI12) owing principally to a large event at Enfield.

[15] TW, London water network resilience – response to Ofwat's letters, March 2017

- Performance deteriorated further in 2016/17, when TW again reported marginal asset health, poor SI12 performance and missed leakage targets.
- On the capital side, TW implemented a new alliance-based delivery model in AMP6 to try to drive innovation and efficiency, but in the early part of AMP6 it was not delivering efficiently, with the cost of mains renewal in £M/km being more than twice that planned.
- TW curtailed the renewal programme to focus on improving efficiency which meant that mains renewal was less than planned in the early part of AMP6 (see below). The Alliance subsequently improved its efficiency and caught up with the renewal programme in the second half of AMP6.
- On the operational side, TW also implemented a new alliance-based delivery model for AMP6, the Infrastructure Alliance which was responsible for leakage control and find and fix activity. There were challenges embedding the new alliance in the business and this led to a loss of organisational capability and a deterioration in leakage performance.
- Other events also impacted performance in AMP6. As well as cold weather in 2016 there was the so-called 'Beast from the East' cold snap in 2018 which was followed by a dry period, causing movement of clay soils. These events resulted in significant leakage breakouts in London which took time to recover from. The impact of the 2018 freezing weather event in cast iron failure rates is presented above in Figure 5.3. Note that there is no similar spike in failure rates for MDPE and HPPE pipes in 2018, showing that the replacement of cast iron with PE pipes leads to improved resilience to cold weather.
- The high-profile trunk main failures in 2016, which had a significant impact on customers and businesses, also had a significant impact on TW, redirecting management and field resources away from leakage and other performance objectives.

To illustrate the impact of delays in the mains renewal programme, Figure 5.4 summarises actual mains replacement activity against final business plan (FBP) planned levels.

Figure 5.4: Comparison of planned and actual mains replacement in AMP6



Source: Chart created from data in TW, London water network resilience – response to Ofwat's letters, March 2017, p12, updated with annual return data for lengths of potable mains renewed

It can be seen from Figure 5.3 that far less mains replacement activity took place in the first part of AMP6 compared with planned. It can also be seen that cost efficiency in the first year was poor, which led to TW's decision to curtail the programme temporarily and modify the delivery model to ensure efficient delivery of the rest of the programme. TW eventually delivered 517km of mains renewal, which is far less than the planned length of 881 km.

One would not normally expect one or two years reduced mains renewal to have an immediate effect upon overall network performance, but in combination with the other things listed above, then perhaps the falloff in the rate of network renewal in 2015/16 and 2016/17 impacted performance in the first half of AMP6. By 2017/18, for example, the cumulative gap between actual and planned length of mains renewed was 300km.

In 2016/17 TW implemented an action plan to recover performance consisting of:

a. Restructuring the capital delivery alliance (Eight2O) to include a direct labour route to achieve efficiencies and accelerate delivery
a. Set a clear objective to rehabilitate at least 650 km of main (ultimately not achieved)
b. Take innovative opportunities to drive efficiency such as structural spray lining techniques
c. Implementing an action plan to improve SI12 including using temporary alternative sources to reduce the impact of failures on customers (e.g. Arlington tanks)
d. Working with the Infrastructure Alliance to send repair teams out quicker
e. Implementing a leakage recovery plan consisting of enhanced find and fix activity, pressure management and mains rehabilitation.

TW's action plan was eventually successful. Asset health remained marginal and leakage targets were missed throughout 2016/17, 2017/18 and 2018/19 but recovered in 2019/20. TW achieved a swing in leakage from 690 Ml/d in 2018/19 to 595 Ml/d in 2019/20, which compared with its FD14 target of 606 Ml/d. Asset health was restored to stable and TW met its interruptions to supply target as well as targets for low pressure and SoSI (security of supply index, assisted by achievement of the leakage target).[16]

Performance in 2020/21, the first year of AMP7 under a new and challenging set of performance targets has been mixed. TW only marginally failed its mains repairs target (270 repairs per 1000km compared with a target of 266) but met its leakage targets (636 Ml/d compared with a target of 643 Ml/d, based on a 3-year rolling average, not in-year measures). However, TW's interruptions to supply performance was more than twice the target. This was affected by four large trunk-main failure events, one in London and three in Thames Valley (two of which were due to WTW failures)..

Overall, after fulfilling its serviceability obligations well in AMP4 and AMP5, TW's water network performance in AMP6 deteriorated and it took a major recovery programme and additional investment above FD allowances to recover it. Performance did recover however by 2019/20 and leakage targets have now been achieved for two years in a row. The 20/21 results suggests that performance is only tentatively on target and remains vulnerable to events such as a repeat of the 2018 freeze-thaw event or failure of high-risk trunk mains which continues to damage TW's interruptions to supply performance.

TW's experience in AMP6 with the disappointing performance of the Alliance delivery model, which it had hoped would deliver improved outcomes for customers, led it to take stock, learn the lessons from AMP6 and redesign its delivery model for AMP7. The timeline was as follows:

2017 TW conducted an internal review and identified several delivery shortcomings:

– The Alliance model created confusion over TW's dual role as partner and purchaser

[16] TW Customer Challenge Group, Commentary on TW's performance commitments 2020

- Alliance partners were too remote from the ODI/SIM incentivisation, on-costs were too high, and the joint ventures lacked agility and responsiveness to emerging issues
- TW had a shortage of internal key skills to ensure success in delivery.

2018 TW implemented an amended structure to support the Alliance.

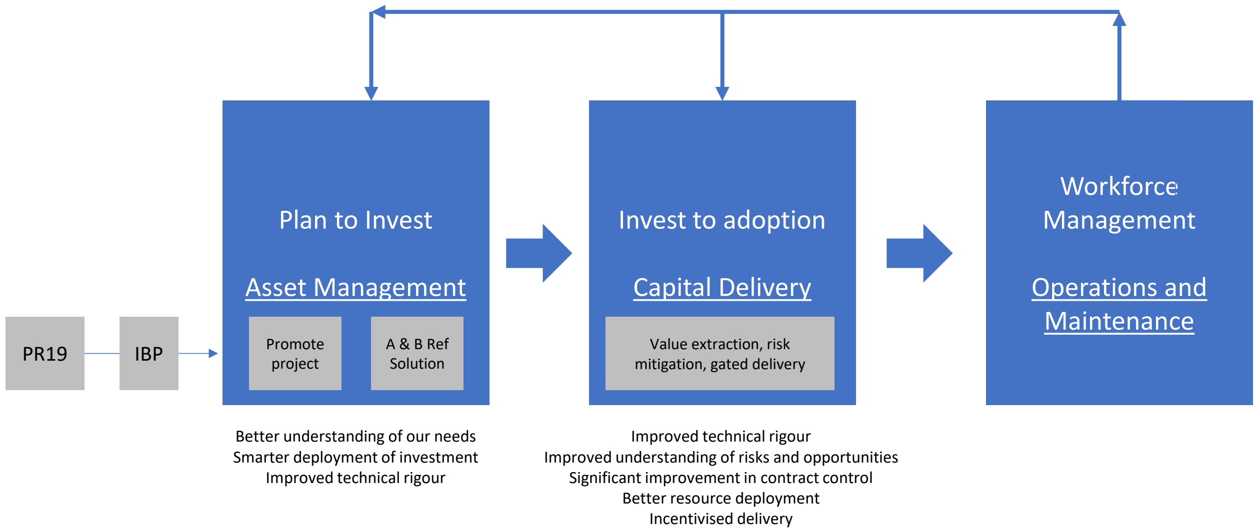
2019 The TW Board agreed to move to an intelligent client model, backing out of the outsourced Alliance model to an insourced model.

The decision to move to an intelligent client model meant TW growing its internal capability compared with AMP6 (and AMP5). Its purpose is to re-establish control of risk and value decisions, translate needs into plans that release projects at the right time and in the right order for efficient delivery, and align contractors with the projects that they can most efficiently deliver.

The new delivery model has four delivery runways for more efficient procurement; major projects, programmes, projects and directly managed work. These cover projects from the very large and complex to high-volume low complexity work. Most of the work is being let through the programmes route, which includes mains renewal work for example. Local tactical replacement of short lengths of distribution main is done through the directly managed route to accelerate delivery.

The way that the new delivery model integrates with asset management and operations is shown in Figure 5.5.

Figure 5.5: TW's integrated intelligent client model



Source: Thames Water

Transitioning out of the Alliance model to an intelligent client model took place in 2020 and is now operating successfully. Staff numbers have grown and will continue to grow through years 2 to 5 of AMP7 and the new model will mature over this period.

We conclude from this that:

- TW's organisational capability and decisions up to the end of AMP5 were effective in delivering the regulatory objective of stable serviceability.
- A combination of factors led to deterioration of performance in AMP6:
  - Under-delivery of the mains replacement programme in the early years of AMP6.

  - Poor embedment of the capital delivery Alliance leading to slow and inefficient delivery of the mains renewal programme in the early years of AMP6.
  - Poor embedment of the Infrastructure Alliance leading to inefficient find and fix activity, loss of control of leakage and failure of leakage targets in AMP6.
  - Cold weather in 2016 and 2018 which, owing to the poor condition of the network, in particular locked joints on old cast iron corroded mains had a disproportionate impact on bursts and leakage in those years.
  - A significant number of high-profile trunk-main failures in 2016 which redirected management and field resources away from leakage control activities.
- Implementation of a recovery plan from 2017 slowly recovered performance by 2019/20.
- TW's organisational capability has therefore been broadly effective in delivering regulatory commitments since privatisation, but there was a loss of control in AMP6 that required considerable investment above allowances and three years' effort to recover.
- The sudden change in regulatory requirements from stable serviceability up to the end of AMP5 to improved performance in AMP6, proved difficult to achieve with a network in such poor condition and planning mains renewal to merely offset deterioration was probably insufficient, though affordability constrained TW's wish to do more.
- AMP6 proved the importance of getting the delivery model right and properly embedded, both capitally and operationally. The impacts of getting it wrong in both cases was a loss of effectiveness and efficiency.
- The improvements delivered at the end of AMP6 have so far carried through to AMP7 as performance in 2020/21 has been encouraging. Leakage is within target, together with other metrics such as pressure and water quality events, but supply interruptions remain stubbornly high, partly driven by continued trunk main failures.
- TW responded quickly to the emerging issues with the Alliance and restructured it early enough to achieve effective delivery within the AMP. TW has also learnt lessons from AMP6 and redesigned and implemented a new intelligent client delivery model for AMP7. It is early days, but this is already showing signs of success.

A wider observation is that TW's approach of responding to Ofwat's changing Regulatory requirements on a 5-year basis has led to a somewhat short-term tactical approach to infrastructure planning. This approach worked well up to the end of AMP5 when the purpose of capital maintenance had consistently been to **maintain** the company's historical levels of service. It did not work well in AMP6 and will not be effective in the future as the purpose of capital and operational maintenance has shifted to **improving** service, on a competitive basis.

TW could perhaps have anticipated this, given its long-standing position as a performance outlier for leakage and other water infrastructure metrics owing to the degraded state of its network, and set longer-term goals to bring the health of its network in line with others. TW has a modest mains replacement programme for AMP7 and had wanted to do more, but a challenging AMP7 determination limited the opportunities to do so. The Conditional Allowance is an opportunity to make inroads into the renewal of its network, provided it can be done efficiently.

TW has recognised the need for a more strategic approach and is developing a 50-year strategy to replumb London. This envisages significant increases in renewal rates to 2050 and beyond, which we agree will be necessary to achieve performance improvements and make the network much more resilient to weather events than it is now. TW's relatively low historical level of mains renewal, though sufficient to offset deterioration, has not affected a sufficient improvement in performance and the network remains vulnerable to weather events and other hazards as set out in Chapter 4.

We say more on the efficiency of TW's network interventions in Chapter 7: Cost of managing the network.

5.2 Benefits from past investment

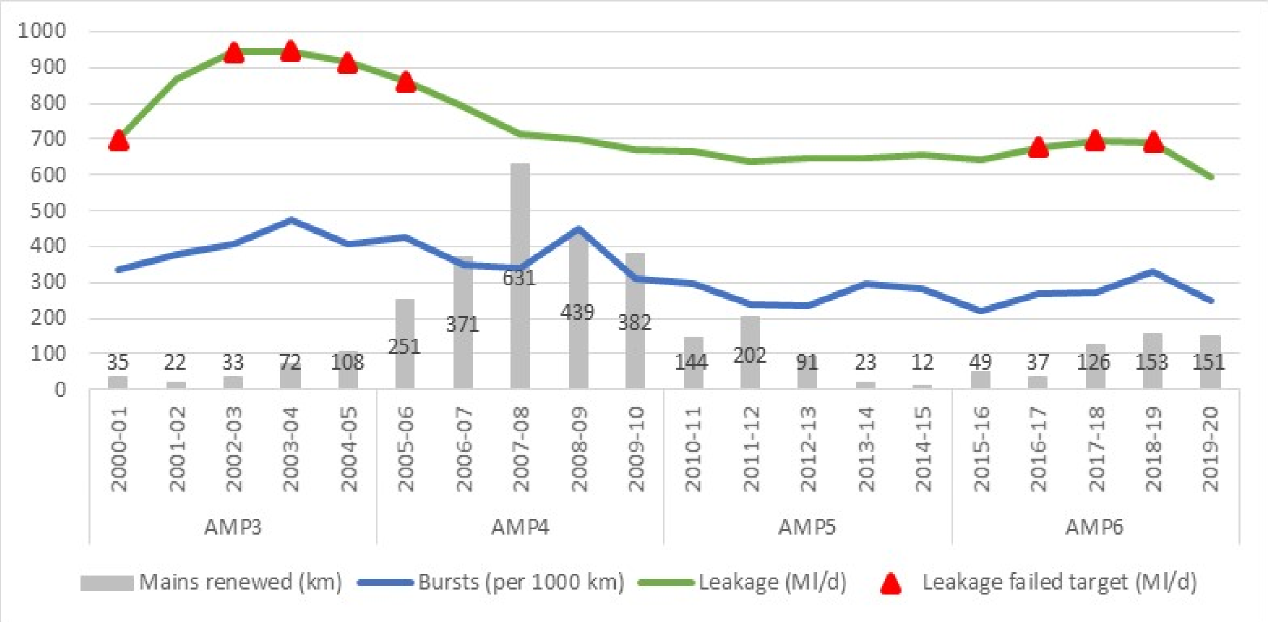
We know from the preceding section that TW decisions have led to achievement of regulatory targets (excepting some departures in AMP6) but what benefits have past investments delivered and has targeting of interventions been effective? To answer this, we first look at the benefits from the Victorian Mains Renewal (VMR) programme in AMP4 and then consider how past investment decisions at FMZ level have performed.

Benefits from the VMR programme

In the period up to 2000, leakage in London was reduced by finding and fixing leaks on the water mains and associated infrastructure. There was limited investment in replacing water mains. In late 2000 and early 2001, extremely wet and cold weather resulted in an increase in network asset breakage in North London. Following this, 'find and fix' activity was not as effective as previously seen and despite an increase in activity and expenditure, TW was unable to recover leakage to its previous levels.

TW subsequently undertook several studies and water mains replacement trials, and this led to the development of a mains renewal programme based on the replacement of all the mains in selected district metered areas (DMAs). The programme started in 2002 and continued through AMP4 into the first years of AMP5. In AMP4, 2074 km of water main were replaced. The profile of the mains replacement and its impact on bursts and leakage is shown in Figure 5.6.

Figure 5.6: Impact of VMR on bursts and leakage



Source: TW presentation for Isle leakage management best practice workshop, Sept 2020

It can be seen that leakage in AMP3, which was considerably higher than it is now and exceeding targets, reduced significantly during AMP4 as the replacement programme was delivered and stabilized in AMP5 as replacement activity reduced. A period of four years of reduced replacement activity at the end of AMP5 and the start of AMP6 was followed by a rise in leakage of about 50 Ml/d that meant that TW failed its leakage targets. A rise in mains replacements and find and fix activity at the end of AMP6 has brought leakage and bursts back under control and this has continued into the first year of AMP7.

The trend in bursts has a similar profile to leakage, except for spikes in 2008/9 and 2018/19 in which there were periods of very cold weather which caused outbreaks of mains bursts.

Although TW deployed other methods to control bursts and leakage in addition to mains replacement, in particular pressure management in AMP4, the cause-and-effect relationship seen in Figure 5.5 is very clear. Periods of high mains replacement were followed almost immediately by improvements in performance and periods of low replacement were followed by a deterioration in performance. The improvements in performance following the VMR programme have largely been sustained, but a period of four years of low mains replacement between AMPs 5 and 6 resulted in marginal deterioration. This shows how sensitive the network is and how important it is to maintain consistent levels of mains renewal year on year rather than allow it to ebb and flow between AMP periods.

Other facts and figures concerning the VMR programme are:

- When the VMR had fully started in 2004, leakage was 946 Ml/d, having increased from 688 Ml/d in 2000-01. By the end of 2009-10, TW had reduced leakage to 670 Ml/d, beating its target by 20 Ml/d.
- This was predominantly achieved through the VMR programme by replacing 2,074 km of mains in 160 DMAs, supplemented by implementation of pressure management and zonal reconfiguration schemes. The VMR programme delivered leakage savings of 174 Ml/d and reduced bursts by 100 per 1000 km.
- Average savings per 1000 km of pipe replaced were therefore 84 Ml/d of leakage and 48 bursts per 1000 km.
- Other leakage savings delivered in AMP4 were achieved through pressure management and zonal reconfiguration schemes.
- The average length of mains renewed in the AMP3 to AMP6 period was 167 km per annum, which is equivalent to a rate of 0.5% per annum.
- TW has not undertaken whole-DMA pipe renewal such as was delivered for the VMR programme since 2010. In AMP5 and AMP6, renewals focused on poor performing sections of main rather than whole DMAs.

The VMR programme improved performance in large parts of London through targeted investment in new, resilient HPPE pipes which have virtually eliminated distribution main failures in some parts of London. The reduction in bursts in VMR areas has brought wider benefits in reducing leakage and interruptions to supply. However, large though the VMR programme was, it only replaced 11.8% of London’s network and failures continue to occur in other parts of the network in large numbers.

Given that the VMR programme replaced the worst performing assets at the time, one would not expect to achieve the same level of benefits now. Indeed, the benefits of the programme to leakage and bursts from Figure 5.6 varies according to which two years are selected from 11km per 1Ml/d leakage saved to 40km per 1 Ml/d leakage saved and 2.0 bursts reduced per km to 0.8 bursts reduced per km. Assuming values of 24km per 1 Ml/d saved and 1.0 bursts reduced per km to allow for diminishing returns from a future VMR-type programme, if TW were to deliver performance improvements through pipe renewal alone, it would require:

- 3,300 km of water distribution mains renewals to reduce TW’s burst numbers from 270 bursts per 1000km (the 20/21 performance) to the current industry average of approximately 150 bursts per 1000km.

- 7,500 km of water distribution mains renewals to reduce TW's leakage from 19 m³/km/d to the current industry average of approximately 7.6 m³/km/d.

These are high-level estimates and in practice TW would employ a mix of interventions to improve performance, not just mains replacement, but this shows the scale of the challenge to improve asset health to catch up with the rest of the sector. It is infeasible and unaffordable to deliver in one AMP, so the solution will need to be delivered over multiple AMP-periods.

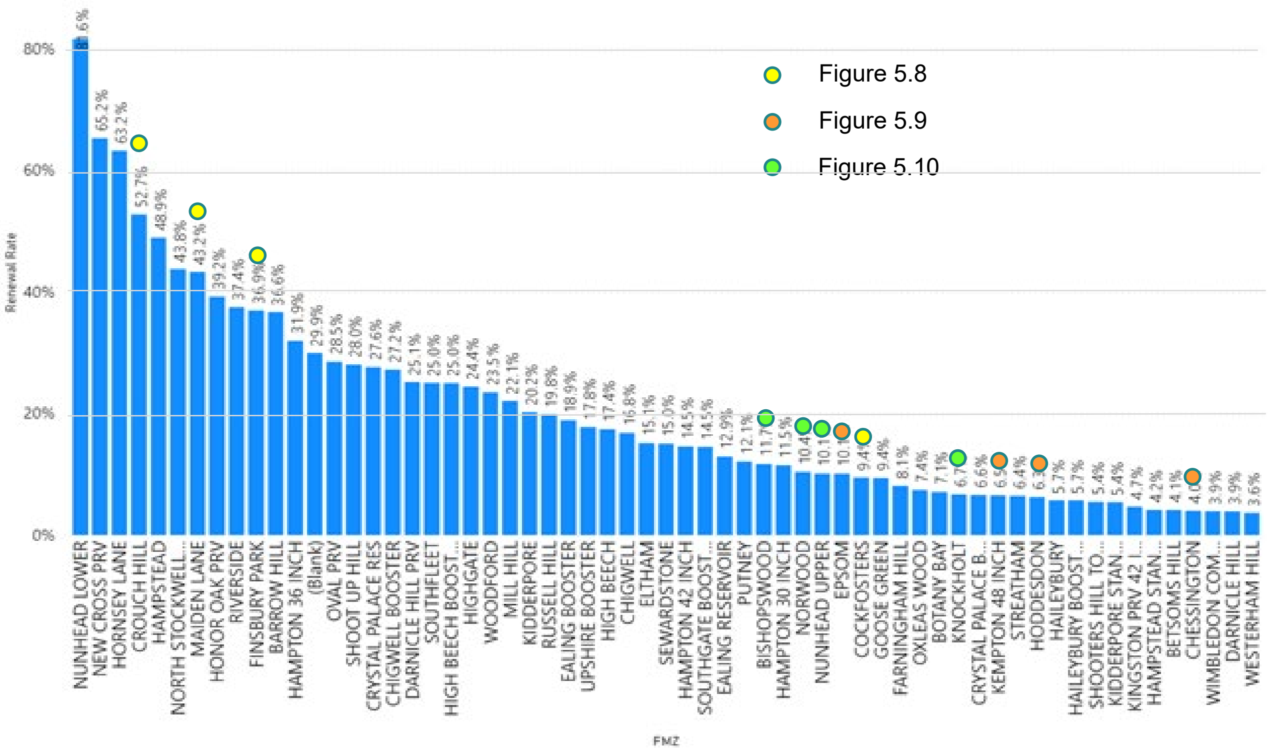
Taking the lower of the two estimates above, (3,300 km), if this length of pipe renewal to achieve industry average performance had been delivered uniformly since privatisation in addition to the mains that TW did replace, the overall rate of renewal would have been 0.74% per annum over 30 years. Total renewal since privatisation would have been 22.2% of the network, which would place TW third highest when compared with other companies (see Figure 5.1) and the average rate of pipe replacement would have been 1,182 km per AMP. This is higher than the level of mains replacement predicted from pipe sample data (see section 4.1), though it would have achieved performance parity with the rest of the sector in only 30 years.

Targeting efficiency

The above provides a big-picture view of the benefits of historical pipe renewal, especially the VMR programme which delivered a step-change in performance. We have also examined the impact of investment at a more granular FMZ level to assess whether past decisions have targeted investment effectively and delivered the expected benefits for customers.

The proportion of pipes that have been renewed in London FMZs over the last 20 years is shown in Figure 5.7. From this it can be seen that some FMZs have had a large proportion of their pipe stock replaced (through VMR) and others much less. This variability in renewal means that the effect of renewal in terms of reduced failures in an FMZ can be assessed and a view taken on whether investment has been targeted effectively.

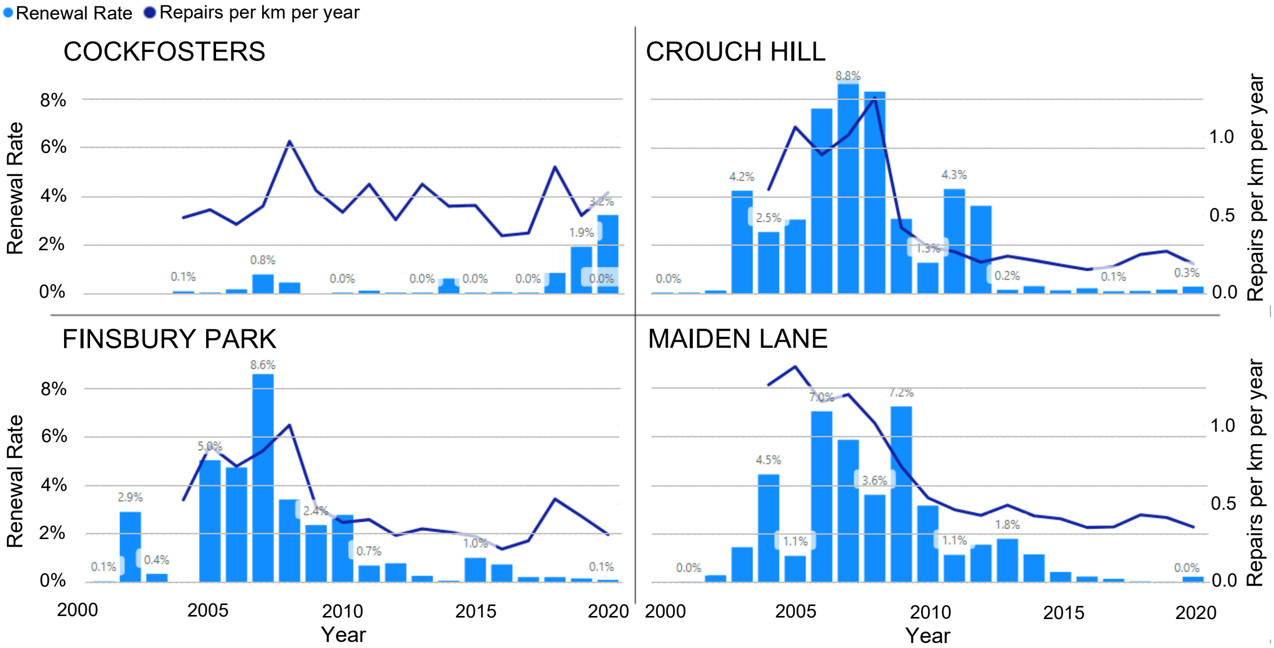
Figure 5.7: Renewal Rate since 2000 by FMZ (London only)



Source: Mott MacDonald analysis of TW GIS data. Note that %s include all new pipes laid since 2000, so include new pipes to serve new developments as well as pipe replacements

Figure 5.8 shows a sample of FMZs and compares the in-year renewal rate (bars) with the in-year repair rate (lines). Three of the zones, Crouch Hill, Finsbury Park and Maiden Lane had a history of high repair rates, well over 1 repair per km per year, compared with the company average of 0.27 repairs per km per year. As a result, they were selected for inclusion in the VMR programme in AMP4 and a big proportion of the pipes in those zones were replaced.

Figure 5.8: Renewal Rate vs. Repair Rate for sample of high replacement FMZs



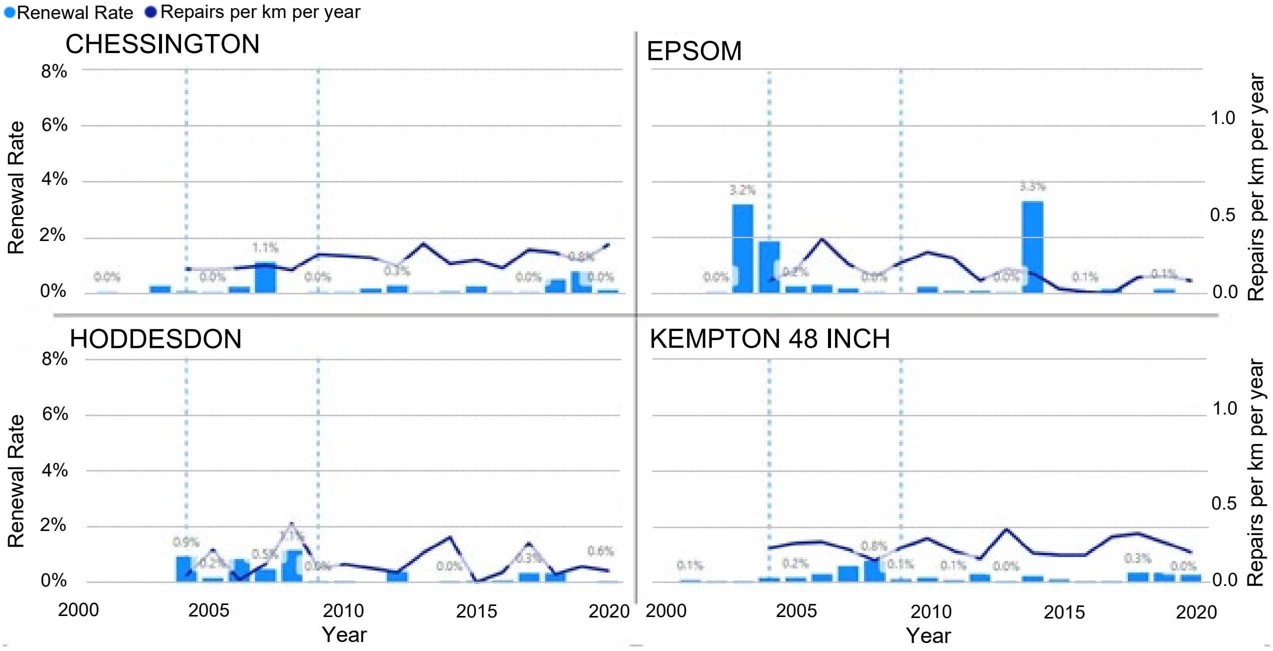
Source: Mott MacDonald – analysis of GIS and mains repair database

It can be seen that the large renewal programmes in Crouch Hill, Finsbury Park and Maiden Lane FMZs achieved a significant drop in bursts in the years following investment. What is more, the improvements in performance have been sustained. The failure profiles do show a small reaction to the 2018 freeze-thaw event, which indicates that there are still some DMAs within those FMZs that contain cast iron pipes that are vulnerable to weather events, but failure rates return to low levels afterwards.

The Cockfosters FMZ has a lower failure rate than the other zones (0.5 repairs per km per year) and as a result, was not selected for inclusion in the VMR programme. Performance has not deteriorated and as a result it has not been targeted for investment. An upturn in bursts in AMP6 has resulted in some limited renewal work on a targeted basis.

Figure 5.9 shows results for FMZs with low levels of mains replacement at the right-hand end of Figure 5.7. These confirm that failure rates in these zones are relatively low (approximately 0.2 repairs per km per year) and do not yet warrant significant intervention and have only had small amounts of localised pipe renewals and/or localised new mains to serve new developments. Performance in these zones has also been stable.

Figure 5.9: Renewal Rate vs. Repair Rate for sample of low replacement FMZs



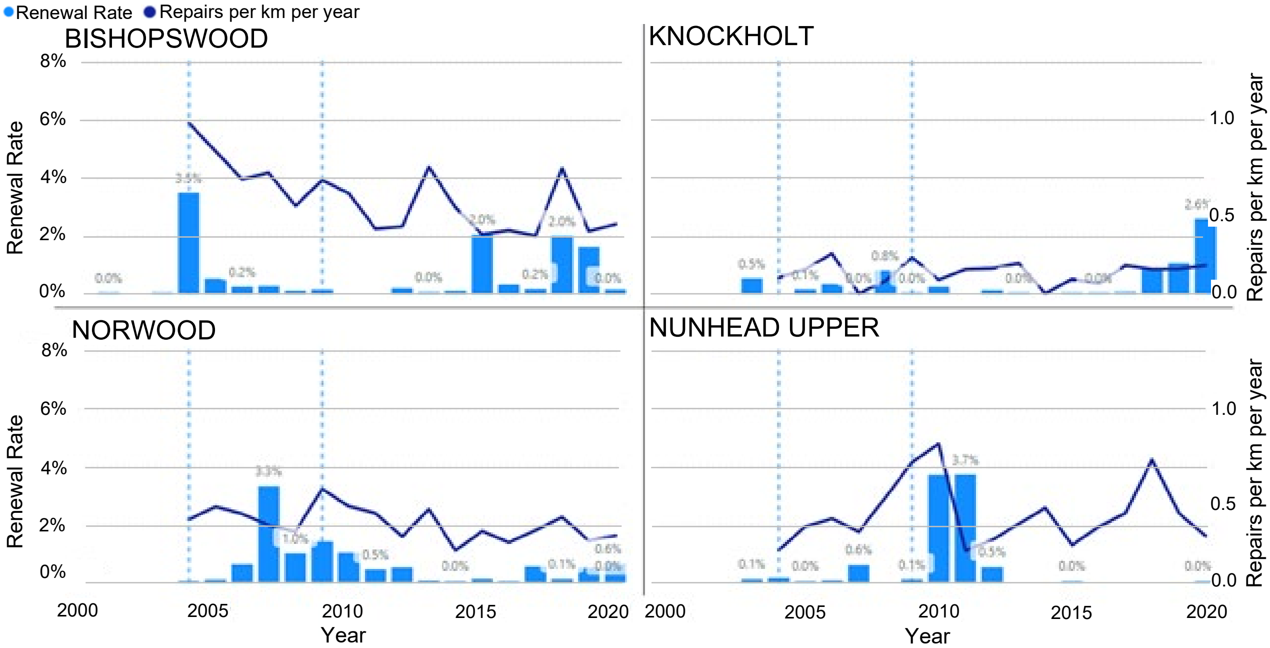
Source: Mott MacDonald – analysis of GIS and mains repair database

Figure 5.10 shows results for FMZs with modest levels of mains replacement undertaken on a targeted basis, rather than whole DMAs as for the VMR. This shows a mixed set of results:

- Bishopswood and Norwood: Targeted replacement in AMP4 reduced failure rates for AMP5 but further small amounts of replacement in AMP6 were necessary to keep failure rates steady.
- Knockholt: a low failure rate was sustained with localised replacement in AMP6.
- Nunhead Upper: A steep rise in failure rates in AMP4 was controlled and fell steeply with localised replacement at the start of AMP5. Failure rates have grown since with no intervention.

Figure 5.10 shows that TW has been successful at spot-replacing the burstiest pipes in these zones as the profiles all show bursts reductions following investment. However, not all the zones show that the benefits of spot replacement are sustained, as burst numbers have started to rise again, and further localised replacement has been necessary. This confirms TW’s experience that the impact of replacing individual pipe spans can sometimes be to transfer the problem to other mains in the zone by incrementally increasing pressures in adjacent pipes that were not replaced, resulting in some erosion of benefits.

Figure 5.10: Renewal Rate vs. Repair Rate for sample of FMZs



Source: Mott MacDonald – analysis of GIS and mains repair database

Overall, our analysis of past investments in pipe replacements at an FMZ level has shown that TW has been effective in targeting its investment and delivering benefits to bursts and leakage. FMZs with high failure rates have had high levels of replacement at a DMA level and this has delivered sustained reductions in repair numbers. FMZs with low repair numbers have had very little pipe replacement and those with medium failure rates have had spot-replacement of the burstiest pipes in the zone. The latter has delivered immediate benefits in reducing bursts, but there is evidence that the benefits are eroded by a corresponding deterioration in the performance of pipes that were not replaced. From this we conclude that:

- Analysis of the benefits from historical renewals confirms that investment was targeted at poorly performing DMAs/pipes, maximising benefit for the investment (i.e. targeting has been efficient).
- Replacing whole DMAs has been more effective and delivered longer lasting benefit for customers than replacing short sections of poorly performing pipe.

5.3 Quality of asset knowledge

Maintaining good quality asset information is an important aspect of organisational capability. Gaps in information can stand in the way of making fully informed decisions and decision-support tools may be limited in the insight they can give by poor information.

Overview of TW data systems and management

Data on TW's assets are stored on two principal systems; above ground assets are mastered in SAP with approximately 170,000 assets on the register and TW's network assets are mastered in an ESRI GIS system. These asset registers hold the attribute data on TW's assets including asset types, locations, dimensions, age, make, serial numbers, etc. TW's above ground assets are organised into an asset hierarchy to define the relationship between sites, processes and equipment.

TW has a Work and Asset Information Team that manages its asset registers, asset information, building information, maintenance plans and GIS data and has continuous processes to improve its asset data quality. There is a SharePoint platform where users (e.g. Field Teams) can provide information to update asset data and request asset information and analysis. When an asset information update is received, this team reviews the submitted data and updates the relevant asset information system, determining whether a maintenance plan update is required. Field teams are encouraged to identify and "redline" missing or incorrect data.

TW has a Maintenance Data Verification Programme that undertakes a cyclical 18-month review of assets by site to ensure asset registers are maintained and updated. On a prioritised basis, TW updates asset data held in GIS to ensure that work order data has the required asset reference.

Current specific data improvement initiatives include:

- Data review and validation of all assets within critical asset cohorts
- Simplification and relaunch of the asset registration process for new above ground assets
- Data review of 'under construction' network assets in GIS
- Development of compliance reporting for new connections
- Modernisation of workforce management systems to improve capture of work to assets.

Asset data (cost, performance, health, etc.) is updated by teams throughout the organisation so that the tools used reflect their needs. Cost data is reviewed, updated and improved through asset management and capital delivery within TW's Engineering Estimating System (EES). This includes cost attribute data such as contractor add-ons and location (see Chapter 7: Cost of managing the network).

Operational cost centres are structured on SAP and aggregate through site / region and operational business unit levels so that TW can understand the respective cost and operational performance across various assets and sites. This allows TW to scrutinise key cost drivers such as power and chemical consumption versus the process performance of its assets.

TW's digital and data strategies set out how it organises its data. They include the principle of "Do once and well" with single products or platforms. In the past two years TW has made a significant step forward with its Smart Water (and Waste) platforms. It has focussed effort on the most challenging business issues such as supply/demand balance for water, trunk mains risk and leakage. These are described in more detail in Chapter 6, Operational capability.

Network asset knowledge

In undertaking the work for this report, we have worked with TW's network data and therefore have some observations on its quality and where improvements would add value.

a. GIS and repair data

TW has up to date and generally accurate GIS information on the location, lengths and physical attributes of its network assets and on the location and date of mains repairs. This is true of the information collected in the last twenty years but understandably less so for older pipes. The age of its oldest pipe stock is often infilled to the nearest decade according to other contextual information such as the age of adjacent housing stock. Data infilling is common practice for all water companies. Pipe repair data are available from 1990 but are only reliably mapped to pipes in GIS from 2004, which limits use of the older data.

Our observations and recommendations for improvement are:

- Repairs of visible leaks are distinguished from repairs of detected leaks, but historically no information was captured on the type of failure, longitudinal or circumferential fracture. This data is now collected, starting from April 2021.

- Data on abandoned pipes, those replaced historically by new pipes, generally have far less information on them than operational pipes and the data are stored in separate files. This data is still very important, as there is a lot that can be learned from them and we recommend going forward that full records are kept of abandoned pipes.
- We also observed that when a pipe is lined, the record of the existing pipe (for example cast iron) is effectively overwritten by the lining (for example HPPE), this makes it very hard to track the history of the pipe before it was lined. It is good practice to create a new record for the lined pipe so historical repair data can be attached to the pre-lined cast iron main and a new repair record assigned to the HPPE lined pipe.

b. Data on joints

Research has shown that one of the reasons that old cast iron pipes are so vulnerable to temperature shocks is that the joints become locked with external corrosion deposits, preventing movement under temperature stress, resulting in fracture at the joint[17]. An understanding of the location and health of pipe joints is therefore important in identifying causes of failure and targeting interventions.

We observe that TW has limited information on the health of its trunk main joints and even less for its distribution mains:

- There is no information in the mains repair database on joint health
- The locations of joints are not recorded in GIS
- The trunk-main inspection database has some information, but it is difficult to use.

We recommend that TW:

- Records joint locations in GIS based initially on pipe material, age and manufacturing history and then updates the data over time as information comes in from the field.
- Improves the trunk main inspection database to better capture joint locations and health.
- Assesses the effectiveness of emerging in-pipe inspection technologies to capture information on joint health.
- If the technology proves effective, deploy it on a targeted basis to determine the health of joints (and pipes) to confirm the most suitable intervention.

It should be noted that in our experience, no water companies routinely capture information on the locations and health of pipe joints except for major trunk mains and aqueducts where proactive inspection is more common.

c. Pipe health

TW has good sources of pipe asset health information to support its deterioration modelling in its repair database for distribution mains and its trunk-main inspection database. These are supported with a database of pipe samples and associated pit-depth analysis. In addition, for trunk mains, TW undertakes Sahara leakage surveys and has on-line pressure monitoring and acoustic loggers to detect leakage and potential failures early.

However, the two streets report[18] showed that pipe conditions were highly variable with hotspots caused by localised factors such as tree roots, poor bedding and adjacent services. It emphasised the importance of having good asset health information at a local level.

We recommend that TW:

[17] See section 4.1

[18] Two streets Phase 1 – Final report and appendices 2003, + Two streets Phase 2 – Final report and appendices 2003

- Implements a new non-biased programme of pipe sampling and analysis of pit depths to continue and extend its pipe sample database that was discontinued at the end of AMP5.
- Invests in surveys to sample actual conditions through pipe sampling and/or inspection pigs and surveys to assess the loading environment as recommended in the two streets report. We suggest this is done on a targeted basis, informed by statistical modelling and/or DMA fingerprinting.

This information will help validate the outputs from statistical modelling of pipe deterioration using AIM or other analytical tools to verify the choice of interventions and likely benefits prior to construction.

d. Leakage recurrence

There is a strong correlation between leakage recurrence and repair density, showing that it is a good measure of asset health. We recommend that recurrence be developed and captured as an asset health metric at a DMA level and then aggregated up to regional and company level for reporting. However, further work is required to make recurrence a reliable indicator for all DMAs.

We recommend that TW:

- Investigate and resolve the data issues for those DMAs for which a reliable recurrence rate cannot be derived, or for which recurrence is negative, and to increase the number and percentage of DMAs for which consistent estimates of recurrence can be made. This could be an additional outcome of the DMA excellence programme.

e. Road junctions

We have shown that pipes fail more frequently at road junctions in London where there is a greater density of road junctions than other parts of the country. There are many factors which may cause pipes to fail more at road junctions, including traffic loading, and there would be value in TW understanding more about its pipes and their local environment in the vicinity of road junctions.

We recommend that TW:

- Improves the recording of pipe depth at road junctions where vehicle loading may be important. Identify road junctions where pipe depths are shallow (below TW's asset standard) to inform plans for the replacement and/or protection of these assets.
- Continue investigations into the causes of higher numbers of mains failures at road junctions, focusing on the higher burst frequency sites.
- Use the analysis to inform mains replacement programmes by identifying high risk mains at junction locations and spend-to-save opportunities.
- Consider field studies to improve understanding of the impact of acceleration and braking forces from vehicles on buried pipelines, especially larger diameter pipes that are more susceptible to horizontal loading.

f. Hydraulic characteristics

In Chapter 4 (section 4.7) we showed that there is evidence that hydraulic stresses caused by high demand growth and extensive pumping across the London network have an important role to play in the performance of London's water network. Although TW has extensive operational knowledge of pressures and flows through its telemetry system and it has a strategic hydraulic model of its trunk-main network, it only has 35% of its distribution system modelled at a detailed level. Some of those models are also out of date.

This has implications for understanding high and low velocities, localised diurnal pressure variations, hydraulic efficiency, and other important hydraulic features. TW has plans to update and increase its model coverage in AMP7, covering the whole of the London network by the end of the AMP. This, together with ongoing improvements to its DMA infrastructure, will enable it to better understand the hydraulic behaviour of its network.

In the short term, we recommend that TW:

- Uses the hydraulic models that it does have to identify pipes with high and low velocities, which are shown to have a high correlation with repair frequency, and overlay this information on the other DMA data it has when targeting interventions.
- Use existing models (updated where necessary) to assess hydraulic efficiency, especially in old tuberculated cast iron mains. Explore opportunities to improve efficiency, especially in DMAs where network renewal is being considered.
- Make the intelligence from existing hydraulic models more generally known and visualised. The current ZPA reports are not very informative or readily disseminated.

In the long term we recommend that TW:

- Uses its new hydraulic modelling capability to support the development of hydraulic system plans, integrating hydraulic considerations with asset integrity, growth, water quality, operational efficiency and other drivers.
- Operationalises its hydraulic models to provide live information to Operations on current pressures and flows with interactive capabilities for operational planning. The new SRV tool is a step towards this. As part of this, incorporate auto-updating and calibration of models so that they always reflect the current state of the network.
- Builds in alarms whenever the difference between modelled and actual flows and pressures falls outside expected thresholds, to alert Operations to hydraulic anomalies as they occur (for example, bursts).

In addition to hydraulic information, TW's systems for recording information on surge protection and network calming assets are fragmented and span the infrastructure and non-infrastructure worlds. We recommend that TW:

- Creates an information system for surge protection and network calming assets, either through a new database or by integrating records from existing systems.
- Creates an asset group for surge protection and network calming assets to provide greater visibility of the investment needs of these assets.

g. Cost information

TW has good information on capital costs which is captured in its Engineering Estimating System (EES). Network costs are captured by pipe diameter, installation technique and location. In London, location is captured by one of four zones, inner London to outer London and more recently by local authority. Although it is possible to identify differences in the cost of doing similar work in different areas, more productivity data should be captured to explain why costs are different. We say more about costs in Chapter 7: Cost of managing the network.

Network operating costs are captured for three regions: north London, south London and Thames Valley. Costs are captured by volumes of activity and unit costs broken down into leak detection and repair, network maintenance and other costs, including street-works and labour. Unit costs are averaged across the three regions, rather than by job or grouped by DMA.

Cost is a key challenge going forward, especially in London where costs are higher owing to high urbanisation, traffic management, congested utility services and low productivity. Although TW has good cost information and models compared with others, continuously improving data on the drivers of cost is important going forward. We make some recommendations in Chapter 7: Cost of managing the network about improvements in cost and productivity data.

Overall, although we have made some recommendations on data improvements, the quality of network data available to TW's planners and operators is good and, in our experience, as good as most UK water companies. The area that needs most attention is improving knowledge of hydraulic characteristics and using this more actively to inform decisions on network interventions.

Consumption data

One of the main areas of information deficit for TW in managing its network and in particular leakage is consumption data. TW has a relatively low meter penetration compared with other companies, especially those who are leading on leakage performance and this affects TW's ability to understand the water balance at a DMA level. London is a 24-hour city and the common assumptions about legitimate night-use do not apply in many areas, but TW has limited metered consumption data to allow it to verify its DMA leakage estimates. TW has a metering programme that it is implementing in AMP7 which will address this, but the leading companies for leakage already have higher meter penetration.

One might question whether TW could have done more to increase its meter penetration in the past. Firstly, it could only install a meter with the customer's permission before 2012 as it was not until then that compulsory powers were granted. Secondly, TW proposed a bigger programme of selective metering for AMP5 than Ofwat ultimately allowed in its PR09 Final Determination. In its 2009 WRMP, TW proposed compulsory metering of 365,193 customers in AMP5 and installation of AMR on all new meters, justified with a cost-benefit analysis[19]. Ofwat rejected TW's proposals on the grounds that the cost-benefit case was not made and reduced the size of the proposed metering programme by 65%. Ofwat cited over-estimated marginal operating cost savings and energy cost savings[20]. At PR09, TW was not forecasting a balance of supply deficit, so a cost-benefit case for metering was harder to make. In hindsight, one could argue that Ofwat's decision has slowed the delivery of technology that would have benefited customers and TW's present circumstances in improving its leakage performance.

Apart from funding restrictions, TW also faces challenges in increasing its meter stock economically owing to the prevalence of flats in London. Studies TW undertook at PR09 showed that 60% to 70% of flats require an internal meter[21], which is more expensive to install and operate than an external meter. The maximum economic level of household meter penetration at company level was therefore expected to be 80% at PR09, compared with other companies who were citing figures of over 90%.

The information gap arising from low meter penetration impacts leakage performance evaluation and targeting of leakage detection activities. Lack of metering leads to incomplete understanding and reliable measurement of the:

- night use component of minimum night flows used for calculation of leakage;
- number, distribution and typology of private mains in a DMA and the magnitude of leakage on private mains;
- customer side leakage part of distribution leakage, which is combined with trunk mains and service reservoir leakage for the calculation of leakage;
- number of different property types [flats, shared supplies, terraced, semi-detached and detached] and their water use and wastage.

[19] TW WRMP09 September 2009, Main report, section 7.3.3

[20] Ofwat PR09 Final Determination, TW supplementary report, section 4.4.1.3

[21] TW WRMP09 September 2009, Volume 3, Appendix D section D2.1.6

This problem is not unique to TW; there are other UK water companies who have low meter penetration. However, TW is disadvantaged compared to leading companies for leakage management (e.g. Anglian Water). This is further discussed in chapter 6.

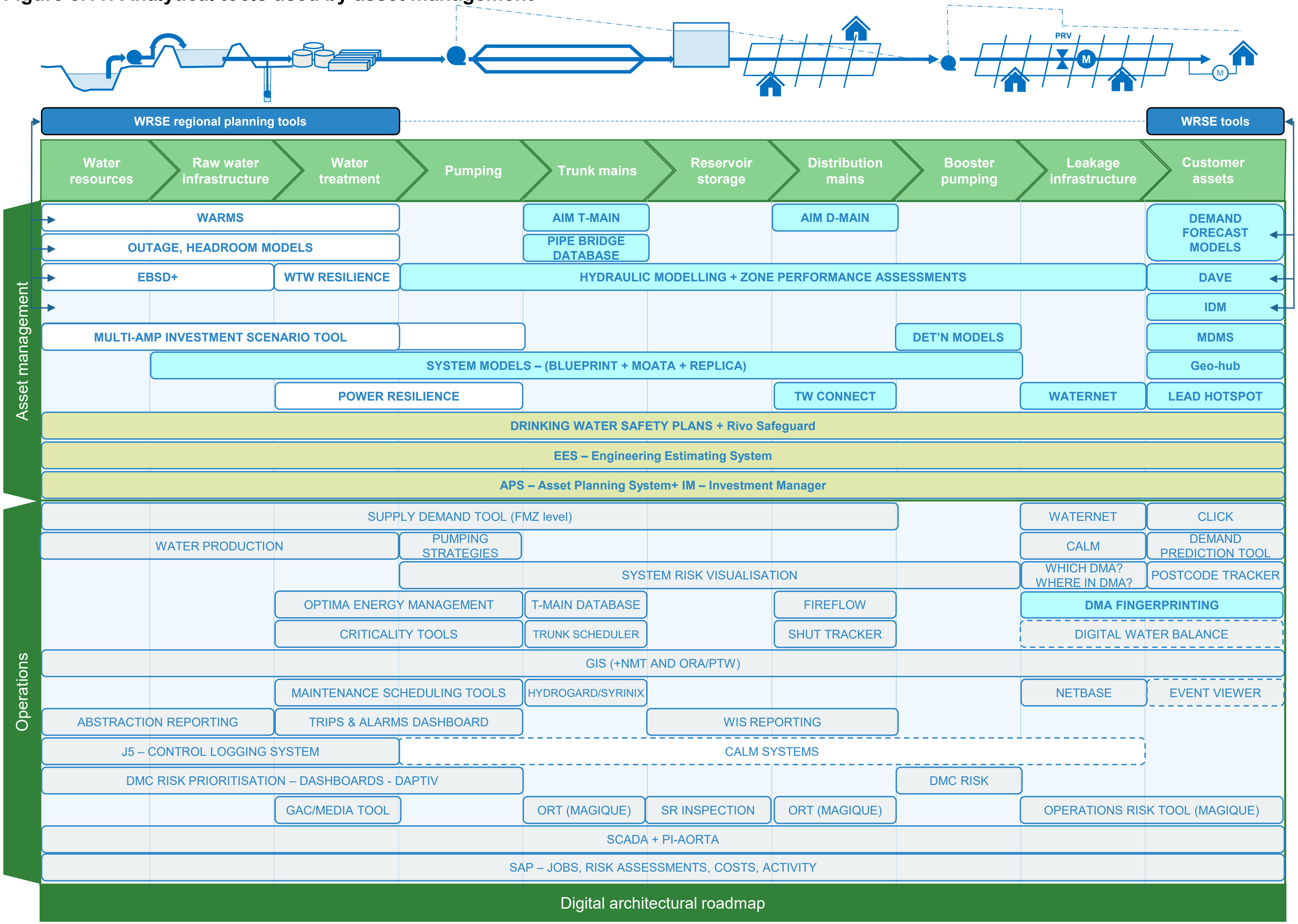
The information gap from low meter penetration introduces uncertainties into leakage performance calculations, with consequences for sub-optimal targeting of leakage detection and reduction efforts. We can conclude therefore that an improved level of meter penetration in London would yield additional information on actual usage, leakage and wastage which would reduce uncertainties in DMA water balances and leakage calculations with better targeting of leakage detection and reduction efforts.

Currently, meter penetration in London is about 40% compared with Southern Water at 85%. TW is rolling out a smart meter programme in AMP7 which will increase meter penetration to 65% by the end of AMP7. The programme will continue into AMP8 where current estimates are that meter coverage will increase to 85%.

5.4 Insights from analytical tools

TW has a range of analytical tools available for managing London’s water network, forecasting its performance and targeting investment. Figure 5.11 maps TW’s decision-support tools to the water supply value chain, focusing on asset management (Operations is covered in Chapter 6).

Figure 5.11: Analytical tools used by asset management



Source: Mott MacDonald

In Figure 5.11 we have highlighted the analytical tools used for planning investments in the network in blue and the cross-cutting tools, such as cost estimating systems, in green. We have also highlighted one tool from Operations, DMA fingerprinting, which is used for tactical planning as well as operational management of leakage.

For water infrastructure planning, TW uses two AIM (asset investment manager) investment planning tools, one for distribution mains and the other for trunk mains. The former is mature and well validated and has been used since AMP4 to forecast the optimum activity and investment required to offset deterioration in the distribution system. The latter is newer and has recently been updated to improve the modelling of flooding from trunk-main failures to refine the assessment of trunk main risks. Both AIM models use advanced statistical modelling techniques to forecast the deterioration of the pipe network and optimise investments in pipe renewals to achieve multiple service outcomes at least whole-life cost.

For strategic planning, the AIM tools provide a good basis for long term management of asset integrity for distribution and trunk mains and importantly, they provide a whole-life view to optimise investment over the life of the assets. This ensures that essential but expensive interventions, such as mains renewal in central London, are not forever deferred in favour of cheaper but short-term interventions, creating a cost burden for future generations. It is important therefore that short-term decisions align with the long-term view from AIM.

One disadvantage of the AIM tools is that they take time to set up and run. As a result, they have only been updated and run to support 5-year business plans in the past to forecast long-term investment requirements. TW has an aspiration to run AIM more frequently, perhaps annually, to inform short-term planning.

AIM models the most important factors impacting asset performance, such as pipe material, diameter, age and soil corrosivity and shrink-swell, but there are some factors noted in this report that it does not. These include the factors causing pipes to fail more at road junctions and hydraulic factors such as velocities, pressure variance and transients. These are localised factors impacting local failure rates, rather than long-term effects and other tools are better suited to modelling them, especially the hydraulic factors. Rather than make AIM more complicated than it already is, we recommend assessing these factors separately and overlaying them on the AIM results to refine the targeting of interventions.

Referring to Figure 5.11, other analytical tools that TW uses include hydraulic models. These are used mainly to plan for growth and to investigate local operational issues. As noted in section 4.7, hydraulic modelling is not as well developed as it could be: more could be done to understand hydraulic characteristics and their impacts on leakage, and bursts and the impact of hydraulic efficiency on network performance and costs. Zonal performance assessments (ZPAs), which are hydraulic modelling reports, could be redesigned to extract more value from the models that already exist and the models that are being developed for AMP7. In the long term, greater benefit will come from live hydraulic modelling, which TW plans to implement.

In our view, the insight from hydraulic modelling needs to be better integrated with that from other analytical tools. One example of this is the Blueprint trunk-main 2100 tool. The tool was used at PR19 to assess the impact of different water resource options on the future configuration of London’s trunk-main network and in doing so combined the outputs from demand forecasts, water balance models, hydraulic models and asset integrity models (AIM) in the same GIS environment. This brought together and visualised insights from different analytical tools.

One tool we highlight in Figure 5.11 for water distribution planning is TW Connect. TW Connect is a GIS tool for visualising mains renewal programmes geospatially. It has data-feeds from other utilities such as gas companies so that planners can see how TW’s plans overlap with other utilities’ programmes on the same map. This is used as a collaboration tool to coordinate the timing of interventions to reduce disruption and reduce Traffic Management Act (TMA) permitting costs.

There has been good recent development of innovative operational tools for leakage management such as: Which DMA, Where in the DMA and DMA fingerprinting, which we report on in Chapter 6. DMA fingerprinting is particularly valuable in bringing together multiple network performance measures in one tool, including bursts and leakage. As well as supporting Operations, this tool is a valuable tactical planning tool for prioritising DMAs by performance characteristics, enabling planners to target interventions effectively. The value in bringing multiple performance measures together, (in the same way as the Blueprint trunk-main 2100 tool does), is that it facilitates evaluation of multiple benefits. DMA fingerprinting is principally aimed at targeting leakage savings, but it will also identify benefits for bursts, interruption to supply, opex savings and customer contacts.

The one limitation of DMA fingerprinting is that it only considers current and past performance. Its value could be extended if it could also provide forecasts that would account for future deterioration of the network. This could be achieved by incorporating the results from the AIM models. This would have the added benefit of continuously validating AIM model output.

Another cross-cutting tool shown in Figure 5.11 is drinking water safety plans (DWSPs). DWSPs are a good end-to-end process for capturing and reporting water quality risks and managing their mitigation, but the process is somewhat separate from other planning activity. There is an opportunity to expand the use of DWSPs and integrate them with other analytical tools to support better management of water quality risks.

As can be seen from the above, TW has a good set of analysis tools for water infrastructure with which to identify needs and plan interventions. TW really needs a way of bringing all the analytical tools and performance and cost drivers together in one environment. The analysis tools are somewhat driver-specific at present and do not talk to each other. The one recent study that did bring several sets of analysis results together was the Blueprint trunk-main 2100 project. Similar principles could be applied at a hydraulic system level to produce integrated long-term plans that address all performance and cost drivers.

In summary, we recommend that TW:

- Ensures broad alignment between short-term (5-year) decisions and the optimum whole-life cost-benefit view from AIM to ensure intergenerational equity.
- Runs AIM more frequently (annually) to inform short-term as well as long-term planning.
- Explores local factors such as pipe failures at road junctions and hydraulic failure mechanisms separately and overlays and compares the results with outputs from AIM.
- Develops its hydraulic modelling capability and repurposes zonal performance assessments to extract more value from models to assess hydraulic impacts on performance and costs.
- Better integrates hydraulic modelling with other analysis tools.
- Builds on the success of DMA fingerprinting by incorporating results from AIM to provide forecasts of performance alongside actual performance.
- Better integrates DWSPs with other analysis tools to support better management of water quality risks in the network.
- Brings all analysis results and insights together into hydraulic system plans.
- Continues programme of NDT testing and inspections including review of contractors under the new pipe condition assessment framework.

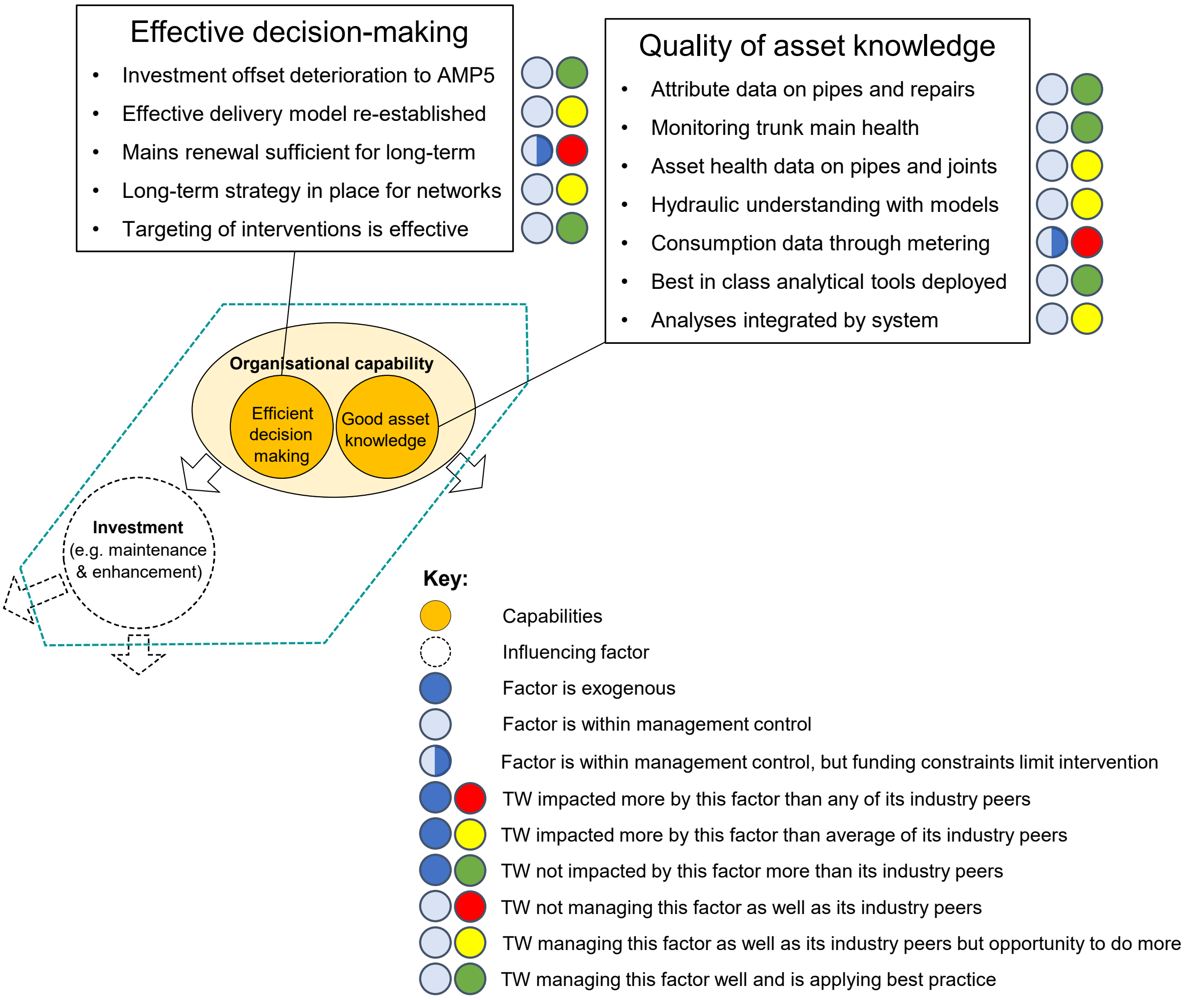
5.5 Conclusions on organisational capability

In this section, we draw some conclusions on TW's organisational capability in managing London's water network. We consider the evidence that decisions have been effective, the benefits delivered by past investment, the evidence that targeting has been effective, the quality of TW's asset knowledge and the effectiveness of its analytical tools to identify needs and efficient solutions. We also make some recommendations on improvements in organisational capability to improve the effectiveness of decision making in the future.

1. Factors impacting organisational capability

Figure 5.12 summarises the key factors impacting TW's organisational capability, the extent to which they are exogenous or within management control and the severity of their impact compared with water industry peers or TW's success in managing them.

Figure 5.12: Key factors impacting TW's organisational capability



Source: Mott MacDonald

As organisational capability is about making effective and efficient decisions, most of the factors impacting capability are within management control, unlike asset capabilities in chapter 4 where many of the factors were exogenous.

In terms of decision-making and outcomes, TW's decisions were effective up to the end of AMP5 when the regulatory objective was to maintain stable serviceability. It is true that TW did not replace as much of its water network as many other companies, (circa 12% since privatisation compared with an industry average of about 17%), but it was not the lowest and it implemented other measures to manage leakage and bursts such as pressure management, which offered better value in achieving the objective while keeping bills affordable.

A combination of factors led to a deterioration of performance in AMP6 with high-profile trunk main failures and failed leakage targets all leading to reputational damage and increased regulatory scrutiny. The decision to adopt an outsourced alliance model for both capital and operational delivery in AMP6, although embarked upon for the right reasons to drive efficiency, was not successful. Performance of London’s fragile water network was also badly affected by periods of cold and dry weather.

However, TW intervened quickly to restructure the alliances and get delivery and performance back on track. A recovery plan implemented in 2017 was ultimately successful and AMP6 leakage targets were achieved by 2019/20. Importantly, TW has learnt the lessons from AMP6 and has redesigned its delivery model for AMP7. It has moved away from an outsourced alliance model with its confused lines of responsibility to an intelligent client model with revamped inhouse capability to improve control over risk and value decisions. The early indications are that this model is already more effective with greater clarity of roles and flexibility in decision-making. However, the new model is still young and although showing early signs of success, still needs to mature. We have therefore given it a yellow designation in Figure 5.12.

In the context of a deteriorated and failing network that consequentially is costing too much to manage and operate, a key organisational decision concerns how much network to renew. Historically, TW has not renewed as many of its water mains as other companies and one might question this, but pipe renewal is expensive and funding it within affordability limits has always been a challenge. TW would have liked to have replaced more of its water mains but has always felt constrained from doing so by the demand to address other risks and needs in the business and to constrain the whole within an affordable bill for customers. This is shown as a ‘red’ in Figure 5.12 but funding constrained.

TW has lacked a long-term strategy for water networks, in common with many companies. This is particularly important now that Ofwat has changed the purpose of base maintenance from maintaining the company’s historical levels of service to improving service, on a competitive basis. TW has recognised the need for a more strategic approach and is developing a 50-year strategy to replumb London. This envisages significant increases in renewal rates to 2050 and beyond, which we agree will be necessary to achieve performance improvements, reduce costs and make the network much more resilient to weather events than it is now.

We have assessed TW’s ability to identify needs and target investment effectively and conclude that past investments have delivered significant benefits in reducing leakage and bursts. The VMR programme in AMP4 delivered a step-change in performance through replacement of all the pipes in target DMAs and targeted replacement of pipes in problem DMAs and FMZs in AMP5 and AMP6 has offset deterioration successfully.

The quality of TW’s asset knowledge and analytical tools to support effective decision making is in large parts as good as or better than other water companies in our experience. There are areas where it could be better to address the specific needs of London’s water network, which we have indicated in Figure 5.12.

TW has generally good attribute data on its distribution mains and trunk mains and it is capturing accurate repair data and inspection data, though there are some recommended areas for improvement. TW’s monitoring of trunk main asset health, which is notoriously difficult and expensive, is in our view industry leading.

Although TW has good asset health data to support its deterioration modelling, we feel that further pipe sampling and an understanding of the location and health of its pipe joints would aid targeting and validation of statistical models. We also feel that improving and extending hydraulic modelling and using them to better understand hydraulic behaviour and it's impacts on the network would be beneficial.

One area of information deficit compared with other companies is consumption data, as TW has relatively low meter penetration. This limits TW's ability to fully understand the water balance at DMA level and hence impacts the measurements and targeting of leakage. Other companies with higher meter penetration are at an advantage in this respect. TW is implementing a metering programme in AMP7 which will improve this situation. TW wished to implement a metering programme in AMP5, but Ofwat rejected TW's proposals on cost benefit grounds.

Finally, TW has a good range of analytical tools for managing London's water network, forecasting its performance, and targeting investment, some of the best in the industry. These have been enhanced recently by the development of real-time operational tools to track leakage and performance at a granular level. One observation we have is that TW really needs a way of bringing all the analytical tools and performance and cost drivers together in one environment. The analysis tools are somewhat driver-specific at present and more could be done to integrate them at a hydraulic system level to produce integrated long-term plans that address all performance and cost drivers.

2. Mitigating the factors impacting organisational capability

Focusing on the factors with a yellow designation in Figure 5.12, we list how TW might mitigate the factors impacting organisational capability:

- Allow the intelligent client model to mature and continue to support its success to ensure efficient and timely procurement and delivery.
- Develop a long-term strategy for London's water network to include increased level of mains replacement or renovation to improve performance and lower costs.
- Continue to improve knowledge of the health of London's water mains and pipe joints through sampling, monitoring, and inspection.
- Continue to build hydraulic understanding of the network and incorporate it into needs assessment and investment planning.
- Integrate the use of analytical tools across multiple drivers (integrity, capacity, water quality) to create long-term hydraulic system plans that address all performance and cost drivers.

3. Priority actions for sustained improvements in organisational capability

We have identified the following priority actions with respect to organisational capability:

a. Long-term strategy

Complete a long-term strategy for water networks with long-term targets for performance and cost and optimal whole-life cost-benefit intervention strategies. Ensure that any short-term plans (five-year) align with the long-term strategy.

b. Improving asset knowledge

- Improve GIS records for abandoned and renovated pipes as recommended in section 5.3.
- Improve knowledge of the health of London's water mains and pipe joints through sampling, monitoring, and inspection.
- Improve capture of pipe depth and investigate the causes of pipe failure at road junctions.
- Improve hydraulic modelling coverage and use of models to assess needs and solutions.

- Improve information systems for surge protection and network calming assets.
- Improve the capture of the benefits of interventions to improve understanding of the sustainability of benefits delivered (long-term versus short-term).

c. Targeting investment

- Refine the targeting of investment to account for the relatively high frequency of failures observed at road junctions (having first confirmed the causes).
- Use existing (and new) hydraulic models to identify high and low velocity pipes and pipes that experience high diurnal pressure variations as there is evidence that they fail more frequently.
- Take greater account of these hydraulic effects in the targeting of investment and plan to improve hydraulic efficiency to reduce pumping costs.

d. Mitigating cost pressure

- Support continued maturity of the new intelligent client delivery model to drive cost efficiencies.
- Build relationships with highway authorities and other key stakeholders whose support TW will need in securing permits and scheduling the work.

e. Driving innovation

- Through digital innovation, aim for greater integration of asset management and operational planning tools to ensure that long-term forecasts of performance are accounted for in short-term decisions and that there is increasing confidence in long-term forecasts through continuous validation with operational data.

6 Operational capability

Chapter summary

This chapter focuses on TW's operational capability in managing London's water network. We consider the factors affecting operational capability and their impact on the speed of repair and leak detection. We consider how well TW manages these factors. We also make some recommendations on improvements in operational capability.

Some of the key discussion points presented in this chapter are briefly summarised below:

- Factors impacting operational capability
  - The density of London's urbanised environment has an impact both on the cost of working and the time it takes to do it.
  - TW is using a dedicated planning team to manage the logistics and engage with stakeholders. This has reduced repair times. TW is managing speed of repair well despite the challenges and is applying best practice.
  - The combined effect of hard surfaces and clay subsoils means that fewer visible leaks appear on the surface than elsewhere in the country. This means that TW must detect a higher proportion of leaks than its industry peers. TW detects and repairs 50% more invisible leaks for each visible leak than the industry average. This impacts TW's leak detection volumes and explains TW's high opex costs.
  - TW's leakage technicians are effective and efficient at leak detection and TW has installed 27,000 acoustic loggers to aid leak detection. However, TW's DMA infrastructure has relatively low operability which effects TW's ability to accurately measure leakage and target detection efforts effectively. TW is implementing a DMA excellence programme to understand the issues and gradually improve operability.
  - Low meter penetration limits the availability of good consumption data with which to refine leakage estimates and target leak detection effort.
  - TW has been installing and operating pressure management schemes since AMP3. These are operated with remote-controlled PRVs which allow pressures to be flow-modulated. We have assessed TW's pressure management to be effective and note that there may be limited opportunity for further pressure management going forward.
  - TW has a good set of smart digital tools to support Operations, detect anomalies and enable rapid response. They are, by their nature, tactical and rely on current performance data and recent history. There may be opportunity to increase their value by integrating them more with asset management forecasting tools.
- Mitigating the factors impacting operational capability
  - Implement the DMA excellence programme to address the issue of poor operability.
  - Include in the programme (if not already) actions to redesign DMAs in London where they are currently over-large and over-complex, to arrive at a larger number of smaller and simpler DMAs for better leakage targeting.
  - Expand the value of existing metered consumption data by incorporating new data as the AMP7 metering programme is delivered and more data becomes available.
- Priority actions for sustained improvements in operational capability

  The priority actions focus on tactical interventions, improving asset knowledge, targeting investment, mitigating cost pressures, driving innovation.

6.1 Factors affecting operational capability

TW generally has good operational capability, as confirmed by the trunk-main review[22]: "*Thames Water has the building blocks necessary to deliver its plans and commitments*". However, the efficiency of operations in finding and fixing leaks is impacted by several exogenous factors:

a. London is densely urbanised with extensive hard surfacing which affects the cost of any work done to expose and repair below-ground assets and then reinstate the surface.
b. The urbanised environment and associated permitting slow the repair of assets.
c. The underlying clay and predominant hard surfacing in the London area means that a greater proportion of leakage is invisible below the surface in London than elsewhere in the country. This results in the need for TW to detect more invisible leaks (a greater proportion of all leaks) than other companies to achieve the same level of leakage saving, which increases TW's leak detection volumes and costs compared with others.

The effects of these factors are offset to some degree by enablers to support operations:

d. TW's DMA infrastructure for measuring leakage to target detection effort
e. The adoption of noise correlation loggers and monitoring equipment to detect leakage
f. The use of pressure management to control leakage
g. Smart metering and smart tools to gain insight from data and enable rapid response.

These themes are explored in the following sections.

6.2 Comparative urbanisation

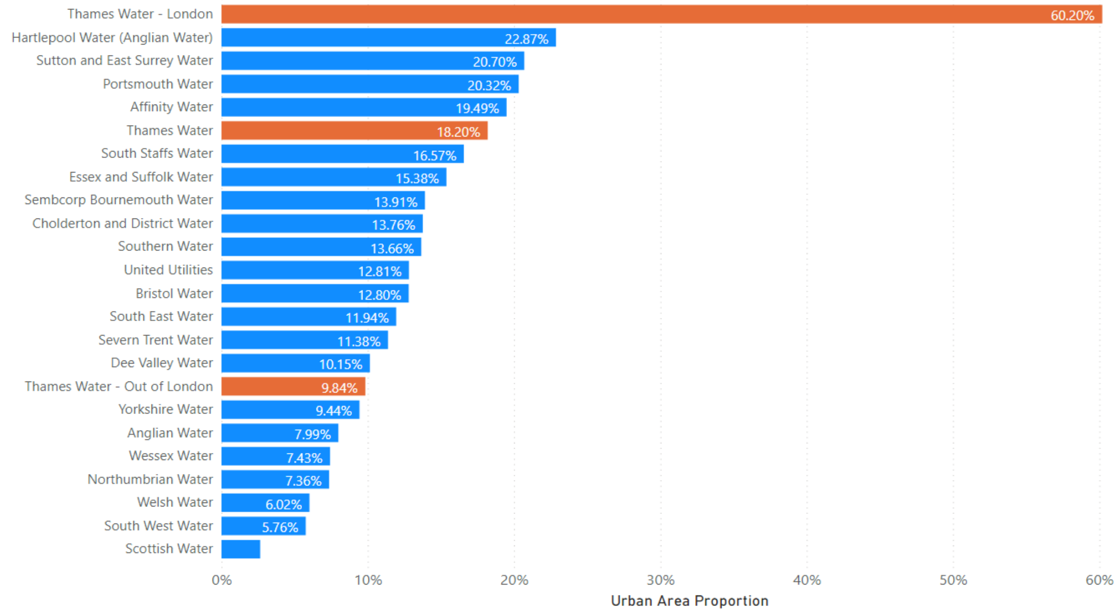
There are several impacts from high levels of urbanisation. A higher proportion of pipes are laid in roads and highways which increases the cost of repair, reinstatement and renewal and requires more traffic management, permissions and charges from Local Authorities compared with non-urbanised areas. Higher population densities lead to a greater demand for, and density of, utility services which can be problematic and costly for pipe renewals and repairs, requiring a greater amount of hand-dig in place of more productive mechanical excavation.

The evidence that London is highly urbanised compared with other water companies is shown in Figure 6.1, which shows the proportions of urban area. TW as a whole has the fifth highest % urbanised area of the other water companies, with about 18% of its surface being urban. However, considering the larger companies, TW has the highest proportion of urbanised area of the water and sewerage companies, Southern Water being the nearest at 13.7%.

When splitting TW's area in two between London and the Thames Valley, the London area is by far the most urbanised area, with an urban coverage of 60%. The Thames Valley is towards the other end of the spectrum with an urban coverage of 9.8%, among the least urbanised.

[22] Thames Water trunk main forensic review, Paul Cuttill OBE, March 2017

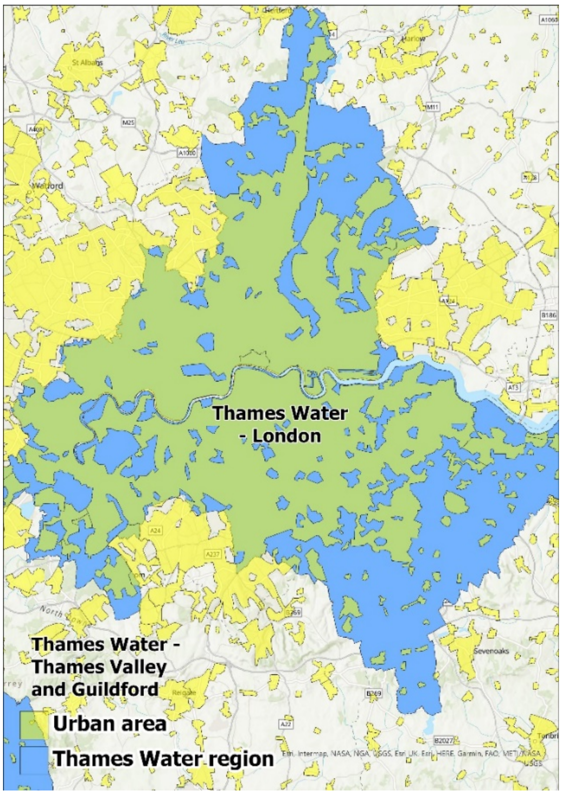
Figure 6.1: Urban Area Proportion by water company



Source: Mott MacDonald 2021. Based on analysis of *OS urban region strategic* data intersected with *UK Water Company Boundaries polygons*

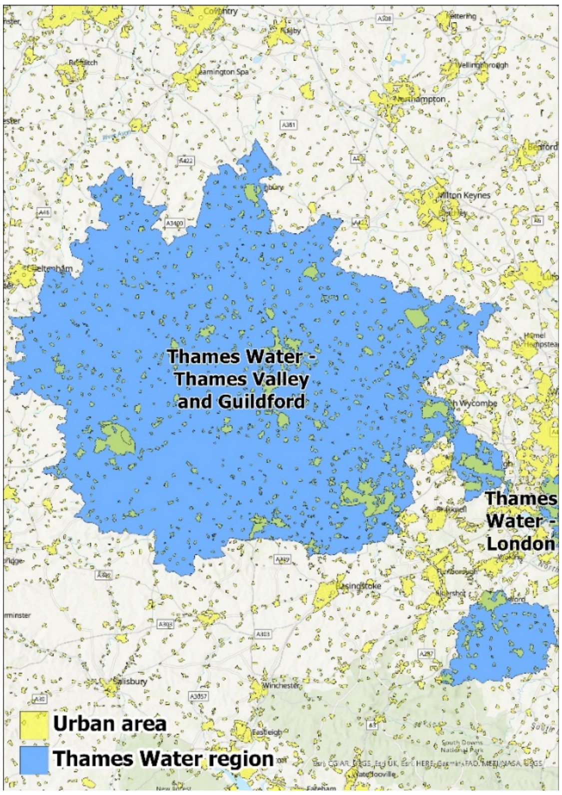
The contrast in urbanisation across TW's area is shown for London and the Thames Valley in Figure 6.2 and Figure 6.3.

Figure 6.2: Urban area in the Thames Water region - London



Source: Mott MacDonald 2021

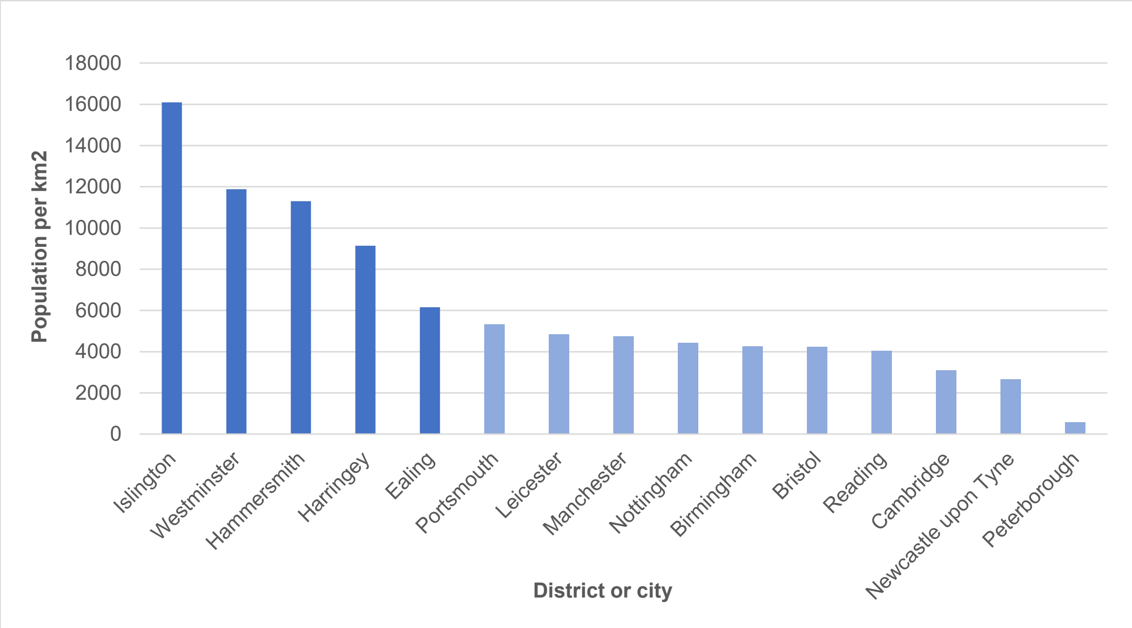
Figure 6.3: Urban area in the Thames Water region – Thames Valley



Source: Mott MacDonald 2021

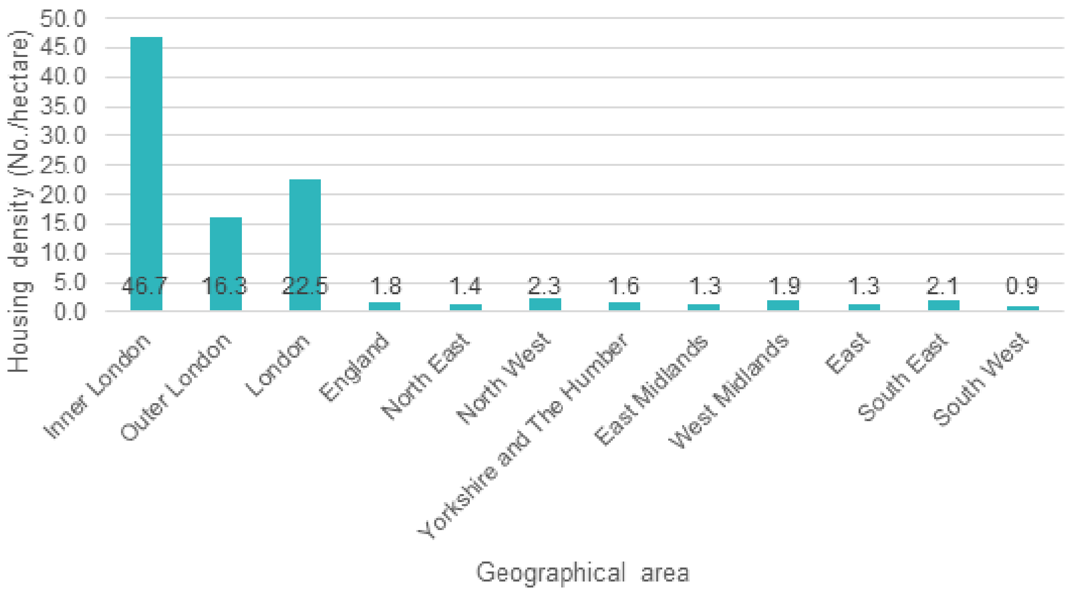
As well as having a high proportion of urban area, the population density of London is high, with many boroughs having a higher population density than anywhere else in the country, as shown in Figure 6.4. This affects the density of housing and utility services in the streets of London. Figure 6.5 compares the density of housing in London.

Figure 6.4: Population densities in London and other cities



Source: ONS data for 2019

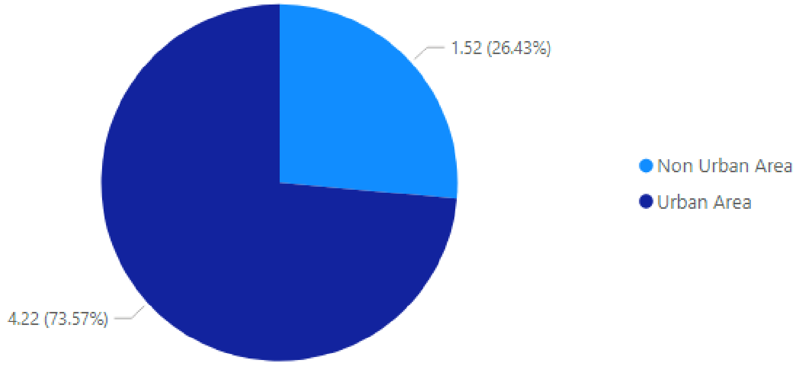
Figure 6.5: Housing densities in London and other regions of UK



Source: ONS data for 2019

High urbanisation impacts costs and speed of working, but also the performance of the network. An analysis of TW’s repair database and urban area maps shows that the rate of repairs on the network in urban areas between 2004 and 2020 (4.22/km) was nearly 3 times that in non-urban areas (1.52/km) as shown in Figure 6.6.

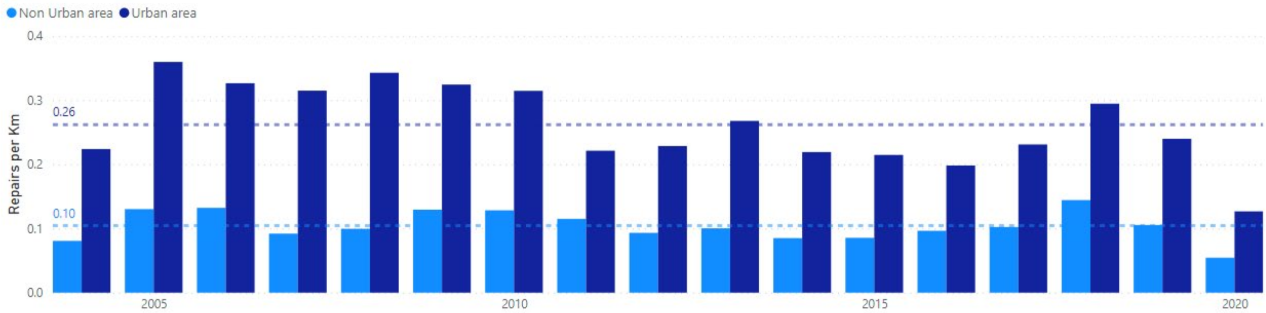
Figure 6.6: Mains repairs per Km



Source: Mott MacDonald 2021 Based on analysis of OS urban region strategic data and TW repair database

Figure 6.7 shows that this is a consistent finding year on year.

Figure 6.7: Mains repairs per Km per year



Source: Mott MacDonald 2021 Based on analysis of OS urban region strategic data and TW repair database

Based on TW's mains repair dataset, a high proportion of repairs on the TW network materialise in urban areas (approximately 88%). Given that repairs in urban areas are more expensive than repairs in non-urban areas, owing to the need to dig through and reinstate hard surfaces and carriageways, this has a high impact on operating costs. In effect, three aspects of urbanisation conflate to increase TW's operating costs relative to others:

- A higher proportion of TW's area is urbanised, especially in London where it is three times higher than any other company.
- The cost of repairing pipes in urban areas is higher than non-urban areas.
- For historical reasons, TW's network is older and its asset health worse in urban areas, so there are more repairs to do.

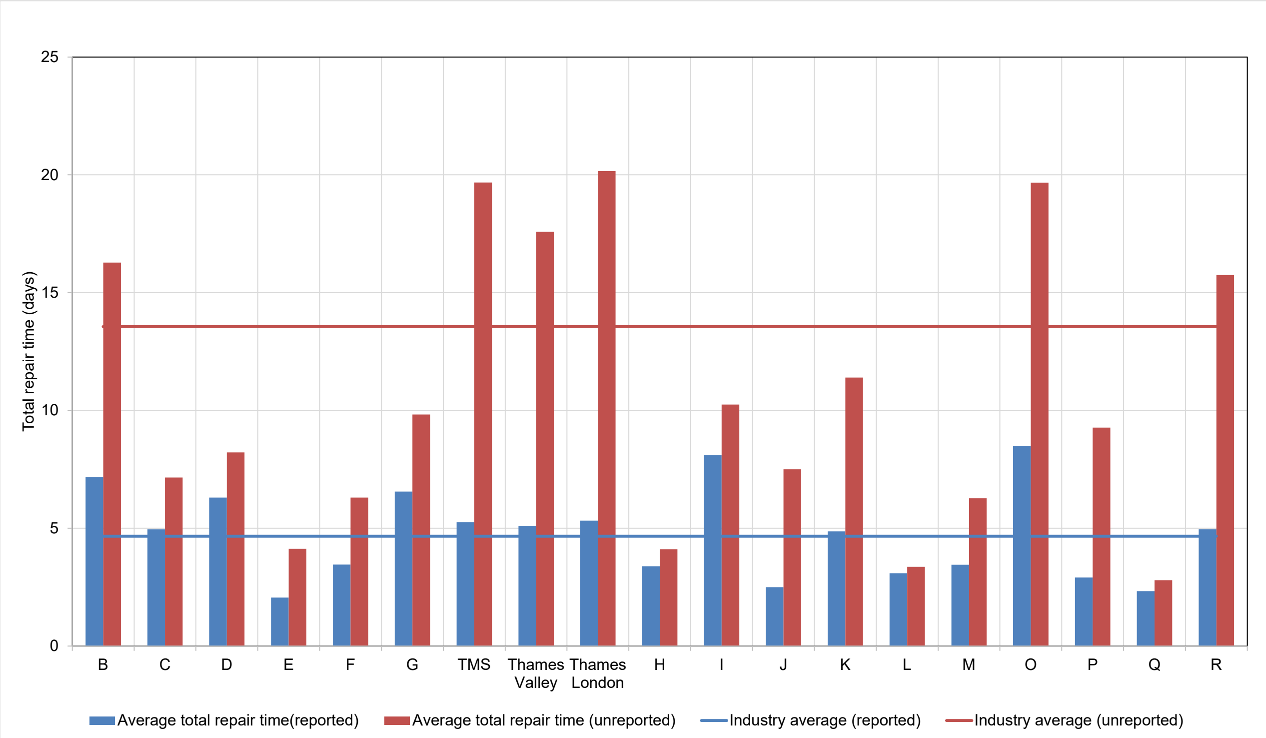
If the health of TW's network was closer to the industry average, then there would be fewer repairs to do, but it would still cost more to operate because more of it exists in urban areas where the costs of repair are higher.

6.3 Impact on speed of repair

One of the potential impacts of high urbanisation and busy streets is that repairing bursts may take longer than in non-urbanised areas or less densely populated towns. Leak repair times affect leak run times and ultimately leakage volumes.

Using Water UK LPI shared company data, Figure 6.8 compares leak repair times for reported (visible) and non-reported (active) leaks for TW, London and Thames Valley with other UK water companies.

Figure 6.8: Comparative leak repair times



Source: Water UK LPI data 2003 to 2014

Figure 6.8 shows TW to be repairing reported (visible) leaks in a time that is close to the industry average, but TW's repair times for unreported (active) leaks are higher than industry average by quite a margin. Repair times in London are shown as the highest in the industry.

It is worth noting that these observations are drawn from old data (2003 to 2014) and do not represent the current situation. Figure 6.8 is however a useful baseline to show the recent historical comparative context. Overall, it is evident from the figure that active leaks take longer than visible leaks to be repaired, and this is common to all water companies.

The explanation for this is that companies prioritise visible leaks for repair owing to the reputational damage of allowing such leaks to run for days unattended and the fact that leakage from a visible leak is normally higher than from an active leak. Visible leaks may also be a hazard and are generally accepted by Local Authorities as emergencies so the usual permissions required for planning work in a road carriageway can be waived, allowing faster contractor access. Unreported (invisible) leaks, however, do not cause an immediate problem to pedestrians or traffic on the surface and the usual permissions for planned works do then apply, which adds significantly to repair times. This situation is not unique to TW and differences between reported and unreported repair times can be seen for all companies in Figure 6.8.

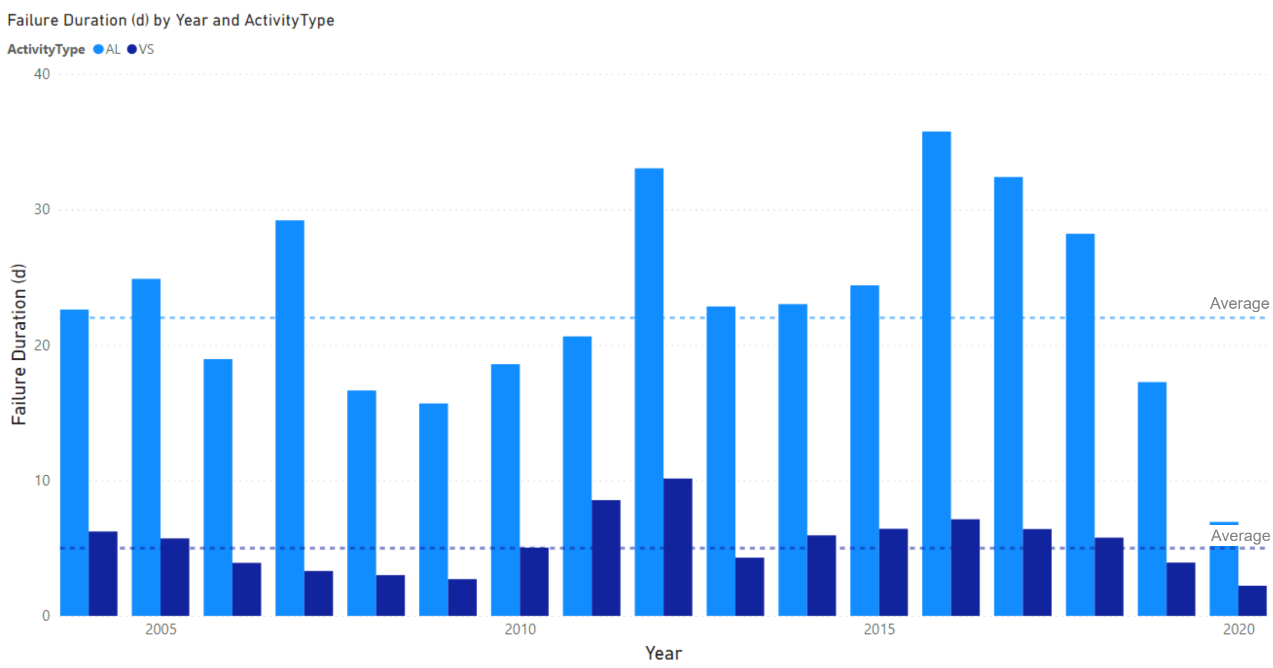
There are some reasons why active leak repair times in London might be longer than elsewhere. A facet of high urbanisation in London, TW faces:

- More traffic management act (TMA) permitting restrictions than other areas
- More lane rental schemes
- More parking bay and bus-stop suspension schemes
- Longer journey times owing to higher levels of traffic congestion
- High density of railway structure which may require consultation with additional third-parties.

London also has more red routes (priority roads used by buses) which have their own onerous restrictions limiting access for repairs. London also has over 50 boroughs, many of which have different requirements for planning works including traffic permitting.

An analysis of TW's reported (visible) and non-reported (active) repair times shows some variation over the years, but a consistent difference between visible and active repair times (see Figure 6.9).

Figure 6.9: TW speed of repair by year



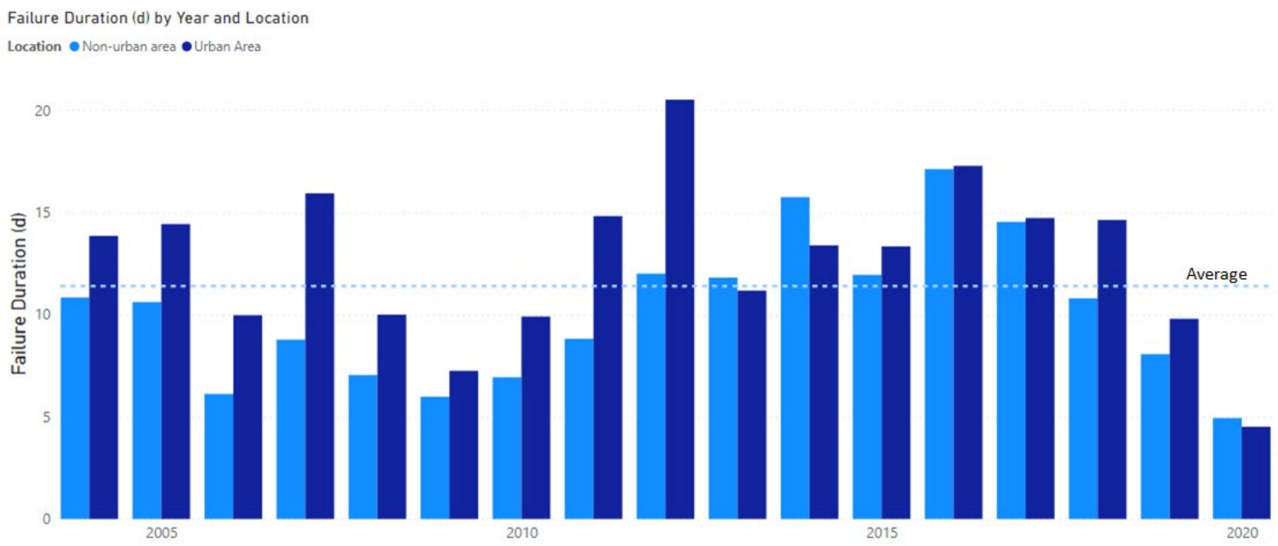
Source: Mott MacDonald, based on analysis of TW mains repair data

The speed of repair appears to be consistent with Figure 6.8 up to the middle of AMP6, with an average duration of 5 days for reported (visible) leak repairs and 22 days for non-reported (active) leak repairs. However, repair times fall in the second half of AMP6 in response to a TW initiative to cut repair times (see below).

The speed of repair is sensitive to the location of the repair (urban or non-urban) as shown in Figure 6.10. This shows the average speed of repair in days, split between urban and non-urban areas. In non-urban environments, the average speed of repair is about 10 days, while in urban areas this is just above 12.5 days. This confirms that urban repairs take longer than non-urban repairs. The reasons for the differences are listed above, the greater need for traffic controls and permissions creating repair delays compared with non-urban environments.

An additional observation from Figure 6.10 is the consistent fall-off in repair time throughout AMP6, with effort to reduce speed of repair resulting in a decrease for both urban and non-urban located repairs.

Figure 6.10: Average of speed of repair by location (days)

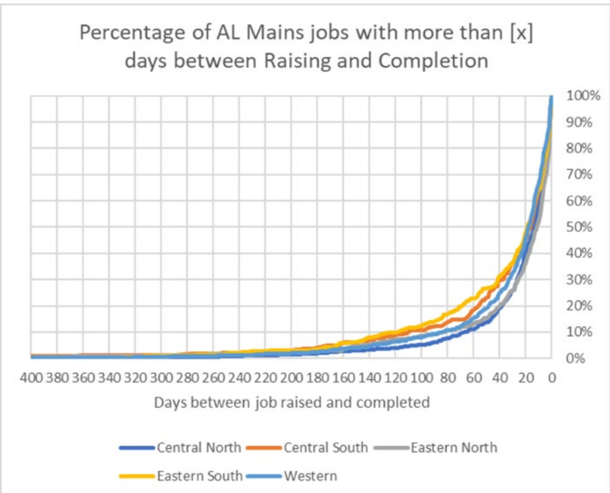


Source: Mott MacDonald

More recent speed of repair data from 2016 to 2019 is available from leakage monitoring data, for active leak repairs and visible leak repairs. The data is divided into five regions. Central North, Central South, Eastern North and Eastern South represent the four quadrants of London, (plus Guildford in Central South) and Western represents the Thames Valley.

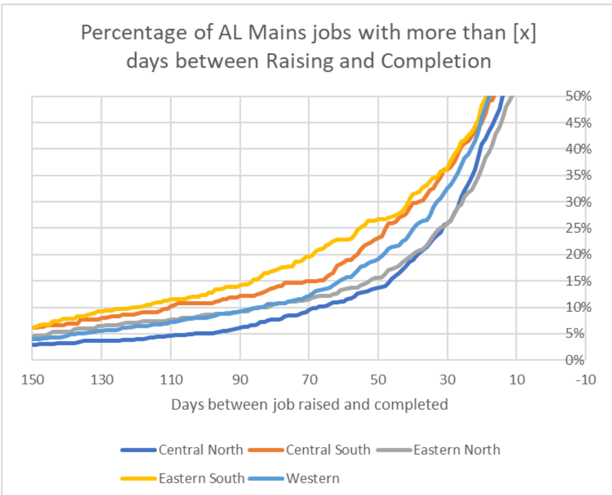
The distribution of active leak repair times is shown in Figure 6.11, Figure 6.12 being a zoomed version of the same curves.

Figure 6.11: Active leaks repair time



Source: TW - Leakage Growth Patterns AL Mains v5.xlsx

Figure 6.12: Active leaks repair time – Zoomed version

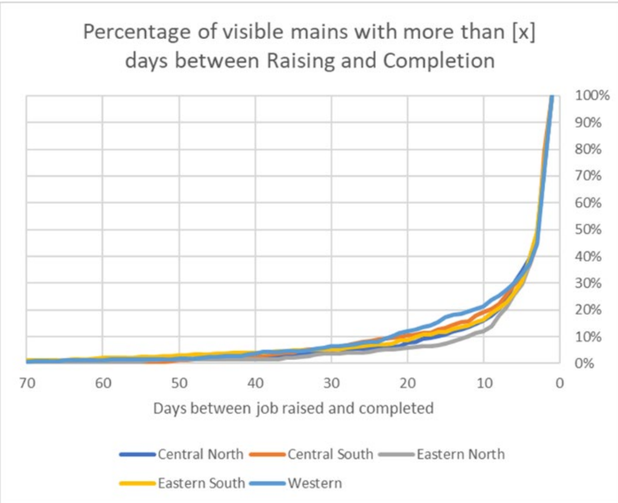


Source: TW - Leakage Growth Patterns AL Mains v5.xlsx

The above figures show that half of the active leaks are being repaired within a timeline of 0 to 20 days depending on the region of occurrence. The regional differences are not strongly marked between the London area and the Thames Valley, which indicates consistency in addressing these leaks within the TW area. A small percentage of active leaks can take over six months to repair.

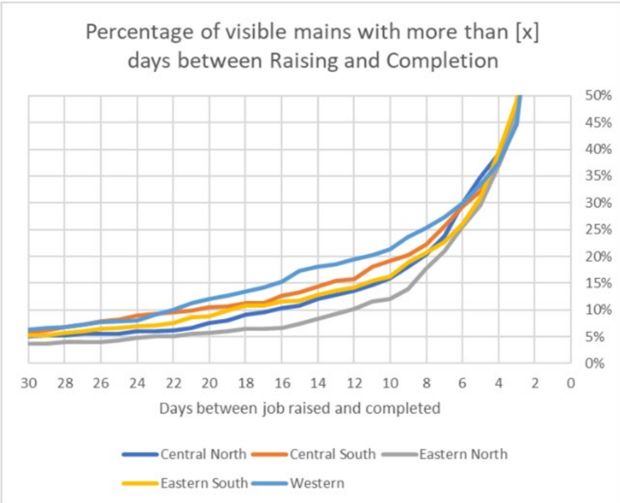
The distribution of visible leak repair times is displayed in Figure 6.13 below, Figure 6.14 being a zoomed version of the same curves.

Figure 6.13: Visible leaks repair time



Source: TW - Leakage Growth Patterns - Visible Mains v5.xlsx

Figure 6.14: Visible leaks repair time – Zoomed version



Source: TW - Leakage Growth Patterns - Visible Mains v5.xlsx

The above figures show that half of the visible leaks are being repaired within a timeline of 3 days depending on the region of occurrence. This is a 40% improvement on the 5 days reported prior to 2014 (see Figure 6.8). The regional differences are not strongly marked initially between the London area and the Thames Valley, which indicates consistency in addressing these leaks within the TW area. However, if leaks take longer than 3 days to repair, then leaks in the Thames Valley and Central South London take longer to repair than in Eastern and Central North London. A small percentage of visible leaks can take over a month to repair.

The improvement in leak repair time in the second half of AMP6 has been achieved by:

- Creating a ring-fenced and co-located resource with the right skills and capabilities to actively manage internal and external stakeholders to streamline the process.
- Setting targets to complete new incoming work within 24-48 hours through ringfenced teams.
- Focusing on the enablers such as removing parked cars and creating permits to work and approving the required pipeline shuts.
- Prioritising large leaks and negotiating with Highway Authorities for early starts.

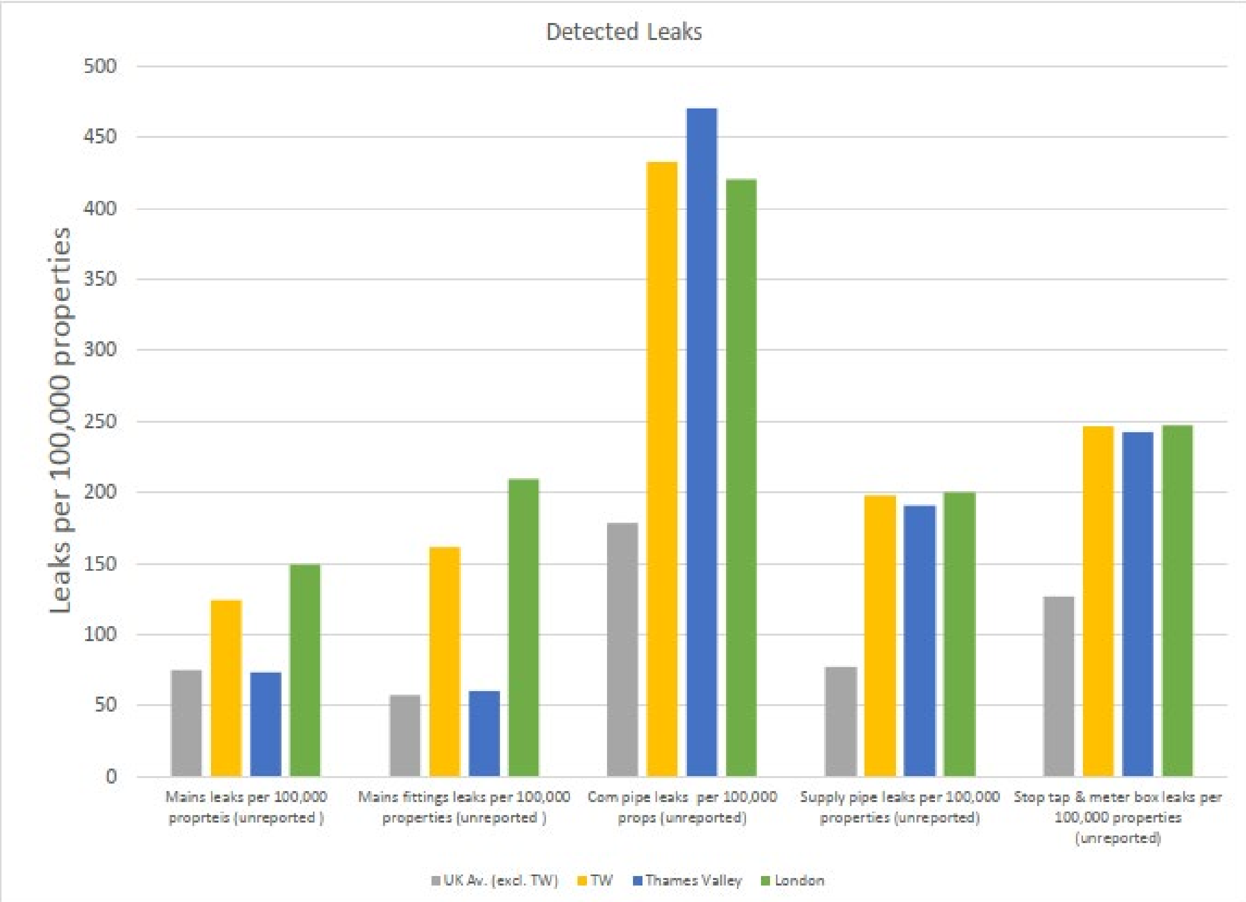
Referring to Figure 6.8, the recent improvements in repair times places TW at around the industry average for active leaks and below average for visible leaks. This assumes that repair times for the rest of the industry have not reduced significantly in recent years. Despite the challenges of high urbanisation, therefore, TW is managing to keep pace with the rest of the sector on leak repair times.

6.4 Impact on leakage detection

Although TW is keeping pace with the industry on speed of repair despite high urbanisation, the impact of the clay subsoils and predominantly hard surfacing in the London area means that a greater proportion of leakage is invisible below the surface in London than elsewhere in the country . This results in TW having to detect a greater proportion of leaks than other companies.

Figure 6.15 Shows the average number of detected leaks for mains, fittings and service pipes based on Water UK data.

Figure 6.15: Detected leaks by category



Source: Water UK LPI data set

This shows that in London, Thames Water carries out by far the highest number of proactive leak repairs based on repairs per hundred thousand properties. Considering mains leaks only, Table 6.1 compares the ratio of detected to visible leak repairs based on Water UK data.

Table 6.1: Ratio of detected to visible leak repairs

Entity	Reported leaks (per 1000 km)	Unreported leaks (per 1000km)	Ratio	% more leaks detected
Thames Water	233	136	1.7	136%
London	310	203	1.5	152%
Thames Valley	139	55	2.5	91%
Industry average	109	47	2.3	100%

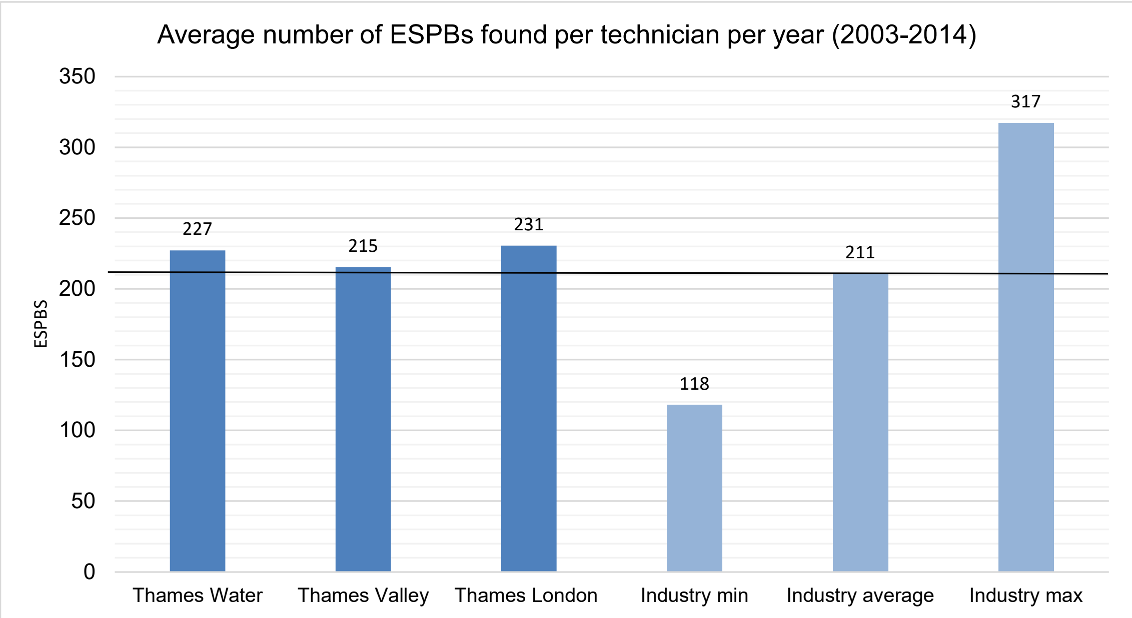
Source: Water UK LPI dataset

Table 6.1 shows that for Thames Water as a whole and for London in particular, the ratio of reported (visible) leaks to non-reported (active) leaks is much lower than the industry average and as a result in London, TW detects and repairs 50% more invisible leaks for each visible leak than the industry average. This has a significant impact on TW's leak detection volumes and costs compared with other companies.

The difficulties of finding leaks in London were confirmed in the two streets report. Here it was found that 'soil conditions are highly corrosive London clay, and the impermeable nature makes it difficult for any leakage to pass through the soil. This affected acoustic leakage detection techniques, which were unable to locate the leaks pre-exhumation'.

TW aims to ensure that its leak detection activities are as efficient and effective as possible. One way to test this is to compare the number of ESPBs (equivalent supply pipe bursts) detected per technician and Water UK has collected and shared this data across the industry. ESPBs allows the value of the detected repairs across asset categories (mains bursts, fittings, communications pipes) to be combined to produce an overall effectiveness rating. Figure 6.16 compares TW's detection activities with the rest of the industry.

Figure 6.16: Comparison of leak detection rates



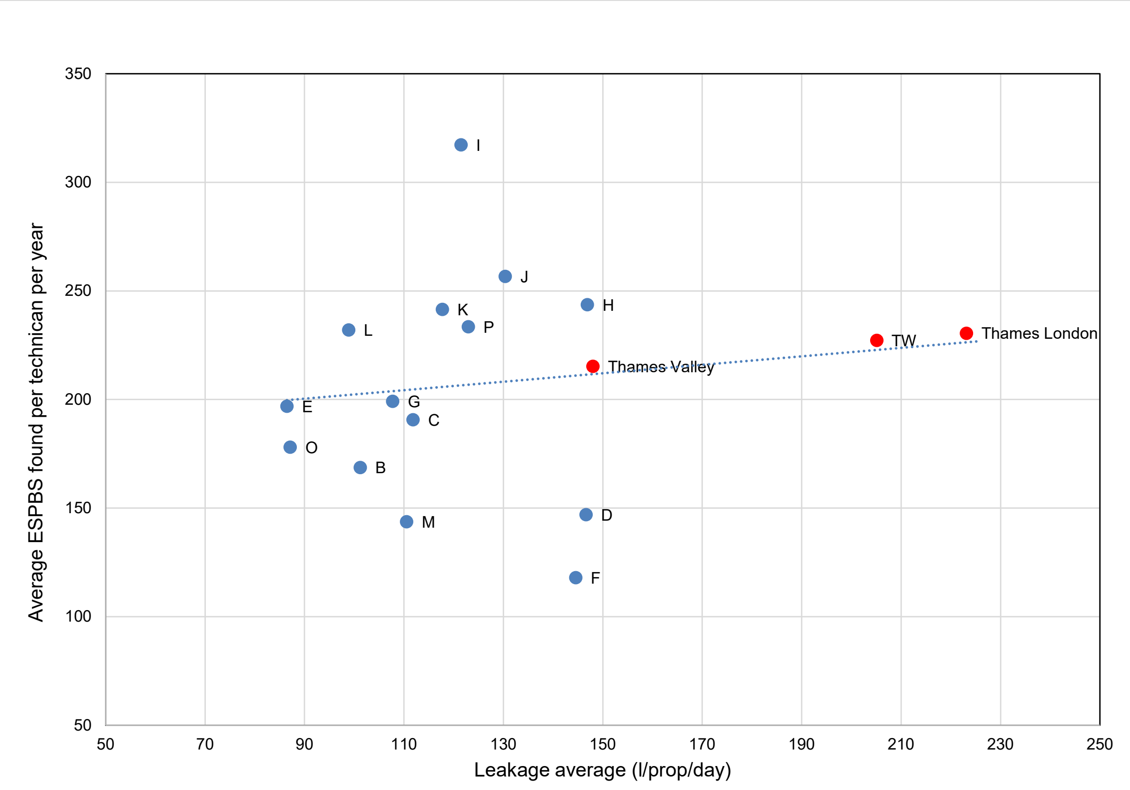
Source: Water UK LPI data set, 2003 to 2014

Figure 6.16 shows that on a comparative basis, TW's leakage technicians are able to find more leaks per year than the industry average. Some companies achieve a higher detection rates and others are significantly lower.

Given that TW is an outlier for leakage, one would expect its leak detection productivity in Figure 6.16 to be higher, as leaks are supposedly easier to find in leakier networks than low-leakage networks. In practice, given the difficulties of finding leaks in London, for the reasons described above, TW's productivity is nearer industry average than the frontier performance one might otherwise have expected. The impact of hard surfacing and clay sub-soils effectively prevents TW from attaining frontier performance

To check that leak detection rates in Figure 6.16 are compared on a fair basis given that leakage levels vary between companies, we have compared leak detection rates with average leakage in litre per property per day in Figure 6.17. This shows a slight upward trend, suggesting that there is a weak relationship between detection rates and levels of leakage. This is intuitively correct because you would expect leaks to become harder to find at lower levels of leakage and vice versa. Figure 6.17 also shows a high level of scatter around the trend and that TW is performing on trend just above average, which is consistent with the finding in Figure 6.16.

Figure 6.17: Comparative leak detection performance



Source: Water UK LPI data set, 2003 to 2014

In summary, we conclude that:

- The clay subsoils and predominant hard surfacing in London restricts the seepage of leakage to the surface, resulting in TW having to detect a greater proportion of leaks than other companies.
- In London, TW detects and repairs 50% more invisible leaks for each visible leak than the industry average. This has an impact on TW's leak detection volumes and costs compared with other companies.
- Comparatively, TW's leakage technicians find more leaks per year than the industry average.
- Analysis shows that there is a weak relationship between detection rates and levels of leakage, i.e. leakage technicians find fewer leaks if leakage is already at a low level.
- TW is performing on trend above the average for the industry.
- Overall, evidence supports the view that TW's leak detection is efficient.

Leak detection has been developing fast in the last few years with new technologies being deployed to aid achievement of tough leakage reduction targets in AMP7. The comparative picture presented above may therefore change in the future.

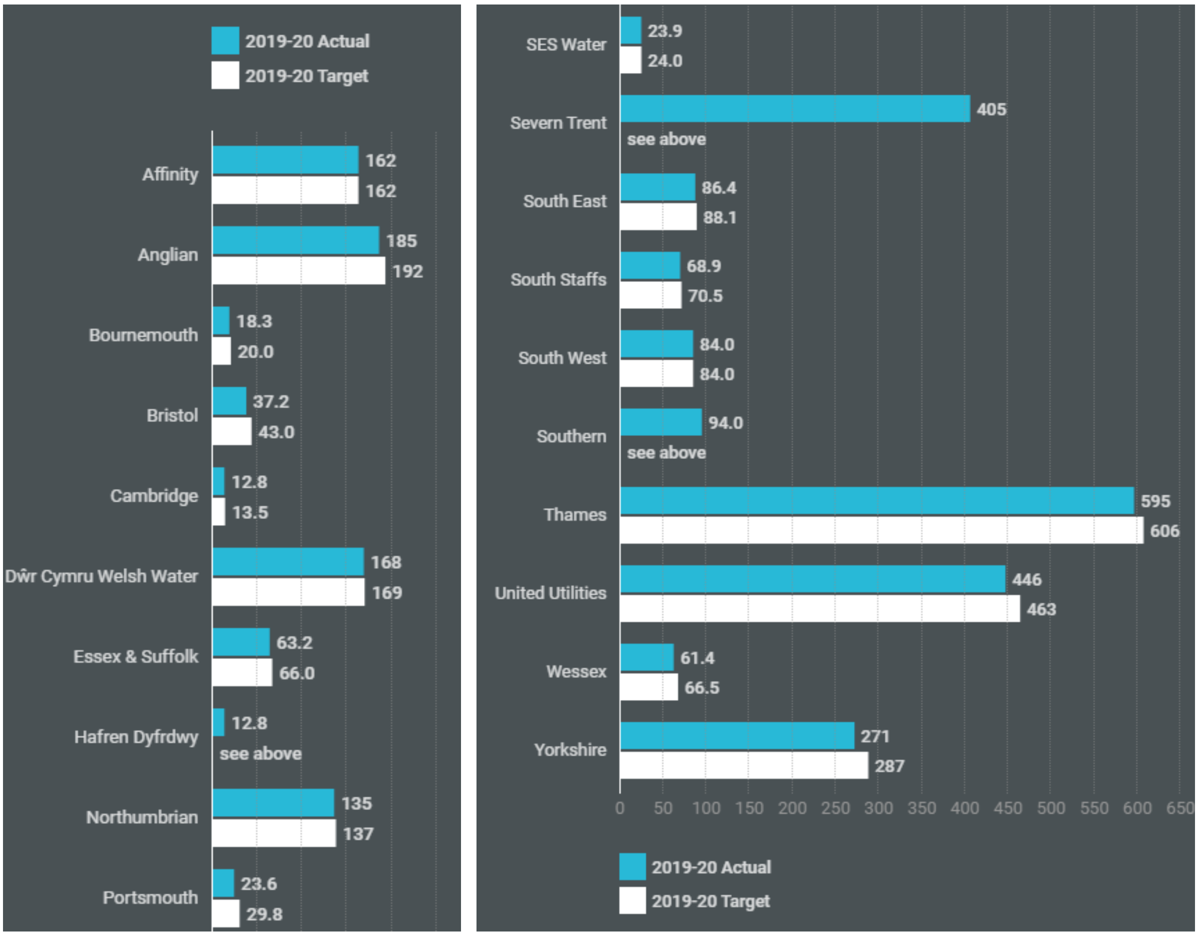
6.5 Comparative leakage analysis

This section compares TW's leakage performance with the rest of the industry. The analysis depends on what measure of leakage is used. TW has the highest level of leakage in England and Wales in absolute terms (Ml/d) and also using the two conventional comparative measures:

- Litres per property per day (l/prop/day)
- Cubic metres per kilometre of main per day (m3/km/day)

Figure 6.18 compares TW's leakage performance in Ml/d with other companies for 2019/20, showing clearly that its leakage is much higher than other companies, although this does also reflect the relative size of companies.

Figure 6.18: Discover Water leakage comparison (Ml/d)



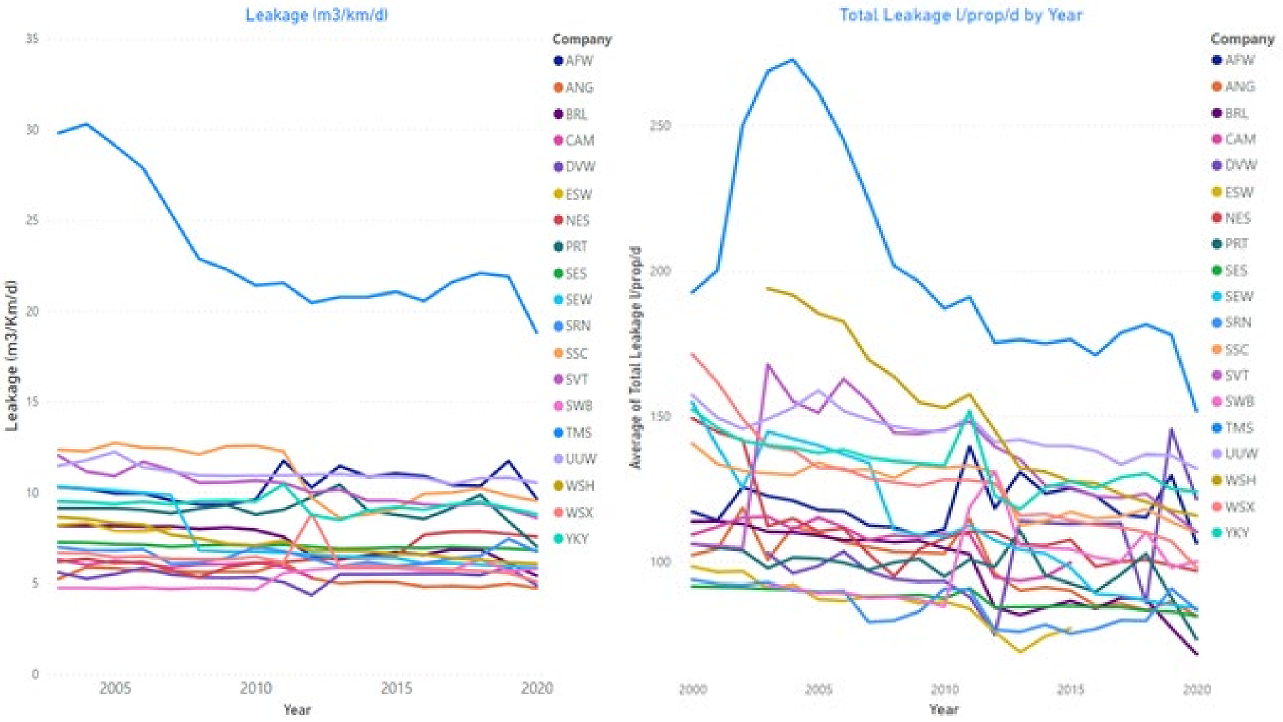
Source: DiscoverWater (en-GB)

Figure 6.19 compares and trends leakage performance for m3/km/day and l/prop/day respectively and Figure 6.20 compares and trends % of distribution input.

Thames Water is currently an outlier on m³/km/d and l/prop/d (Figure 6.19), though the recent fall in leakage at the end of AMP6 has brought TW closer to the rest of the industry on the second measure. The best comparative measure for TW is % of distribution input, where it is comparable with the rest of the industry since leakage is included in distribution input, though at the high end (Figure 6.20).

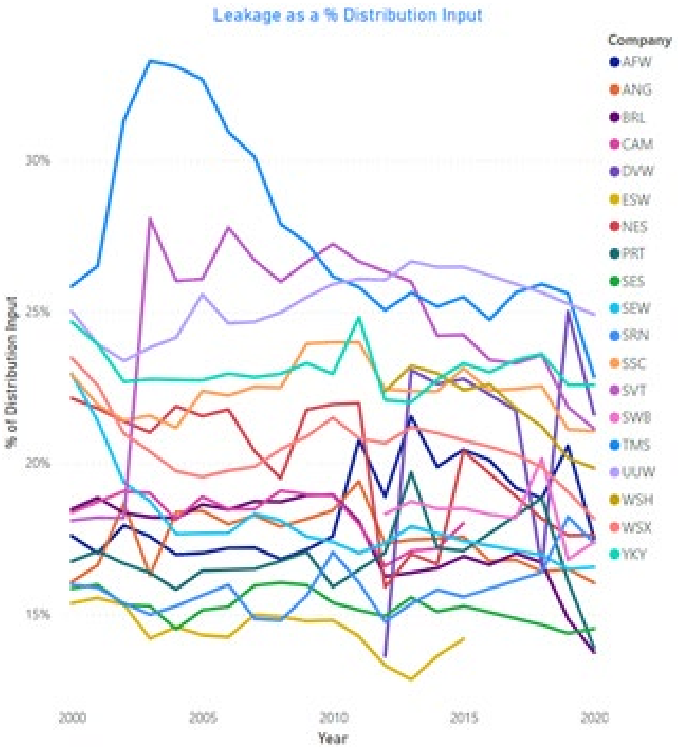
Generally, % of distribution input is not preferred by regulators as a representative or comparable measure of leakage. This is because variations in distribution input can impact the leakage figure, particularly in high growth areas, and apparent reductions in leakage may only reflect changes in distribution input not leakage control effort. % of distribution input is however a simpler and more understandable measure for customers

Figure 6.19: Comparative leakage performance normalised by mains length & properties



Source: Consolidated annual return data

Figure 6.20: Comparative leakage performance normalised by % distribution input (Ml/d)



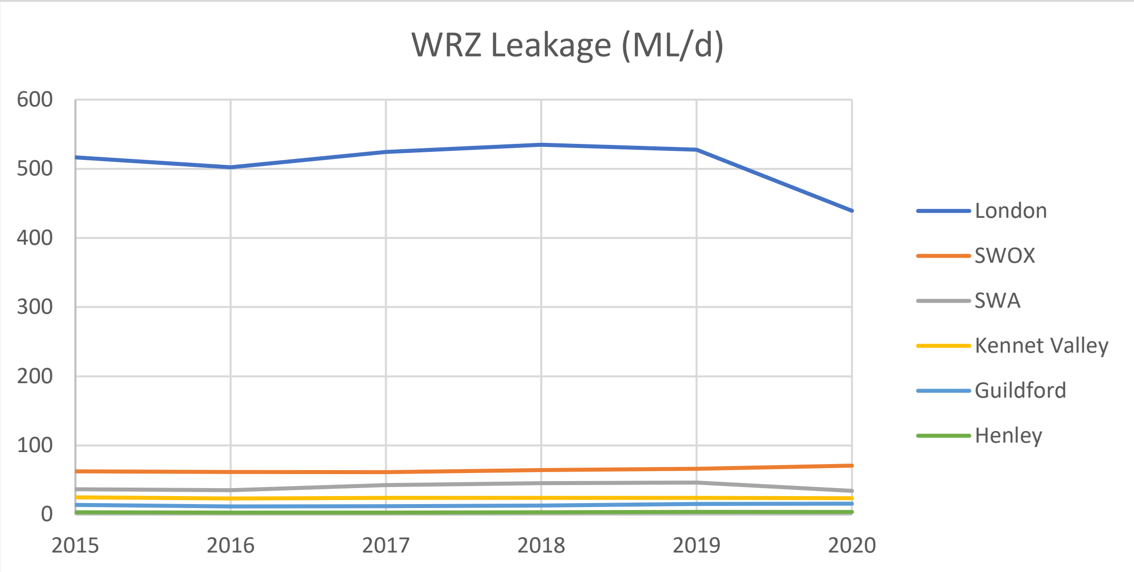
Source: Consolidated annual return data

On all measures, TW's leakage has fallen since 2000 at a similar rate to the rest of the industry. When normalised by numbers of properties or distribution input, TW's leakage climbed significantly in AMP3 (2000 to 2005) and then fell again in AMP4 (2005 to 2010). The fall corresponds with the Victorian Mains Renewal (VMR) programme in AMP4. Leakage reductions achieved by the VMR programme have been sustained since AMP4, but leakage has fallen very gradually since then, corresponding with periods of reduced mains renewal in AMP5 and AMP6 compared with the VMR programme and greater reliance on pressure management.

In 1997, Ofwat set the water industry the medium-term objective of achieving the economic level of leakage (ELL) by 2002-03 and started to set Ml/d leakage targets for each company on an annual basis. Since the 2004 Price Review, targets for each year of the five-year AMP period have been set in Ofwat's Final Determinations. Since the establishment and bedding in of Economic Levels of Leakage (ELL) across the industry (taking 2004-05 as the start point), Thames Water has reduced leakage by over 40%, the highest proportion of all companies in England and Wales.

Figure 6.21 considers the variation in leakage across TW's area by Water Resource Zone (WRZ). It can be seen that leakage in London is far higher than the other water resource zones, comprising approximately 75% of total leakage.

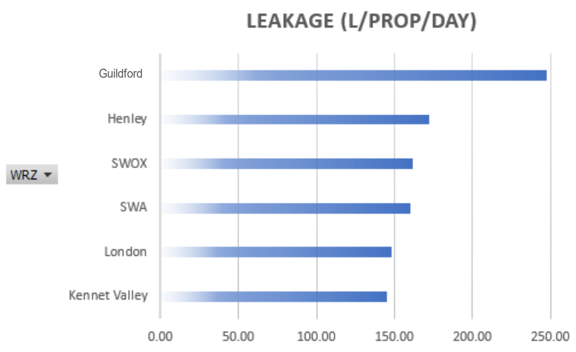
Figure 6.21: TW water resource zone leakage (Ml/d)



Source: TW Water Resources Management Plan – Annual Review - June 2020

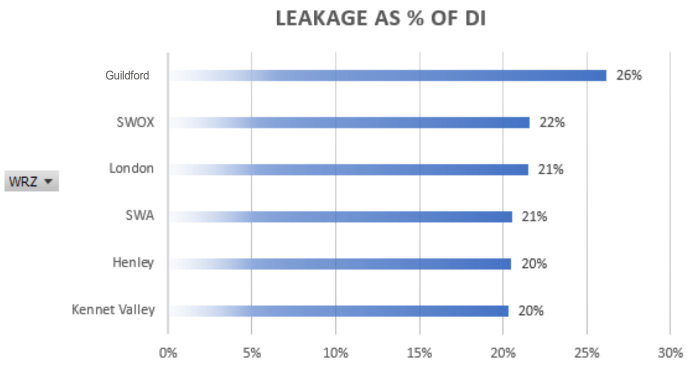
Figures 6.22 and 6.23 compare leakage by WRZ by l/prop/day and % distribution input. Guildford performs worse than London on % of distribution input leaked and leakage per property. None of TW's water resource zones can currently match the performance of the best performing companies for these two 'headline' Leakage metrics.

Figure 6.22: WRZ Leakage (L/Prop/Day)



Source: TW Water Resources Management Plan – Annual Review - June 2020

Figure 6.23: WRZ Leakage as a % of Distribution Input



Source: TW Water Resources Management Plan – Annual Review - June 2020

6.6 Managing leakage

There are several elements in a leakage management strategy for water distribution networks, consisting of:

- Active leakage control enabled by well-designed DMA infrastructure
- Good meter penetration to measure consumption and leakage accurately
- Efficient detection and speed and effectiveness of repair
- Pressure management, and
- Network renewal and rehabilitation.

Leakage can be managed efficiently by applying the right combination of these activities.

Active leakage control

To enable active leakage control, TW is reliant upon its district metered area (DMA) infrastructure (district meters, boundary valves, etc) to monitor and report leakage and target its detection activity. DMAs were first implemented in the 1990s to enable the following benefits:

- Aiding the targeting and reduction of nonrevenue water by active leakage control
- Simplifying the implementation of pressure management
- Increasing the speed of burst detection
- Increasing the speed of isolation to protect the rest of network from accidental or malicious contamination events.

DMAs also come with trade-offs, such as reduced redundancy in network connectivity and the reduction of system pressure, which results in lower network preparedness for emergencies such as firefighting and asset failures. Water quality may also deteriorate owing to the reduction of available flow paths. DMAs therefore must be well designed to mitigate these factors.

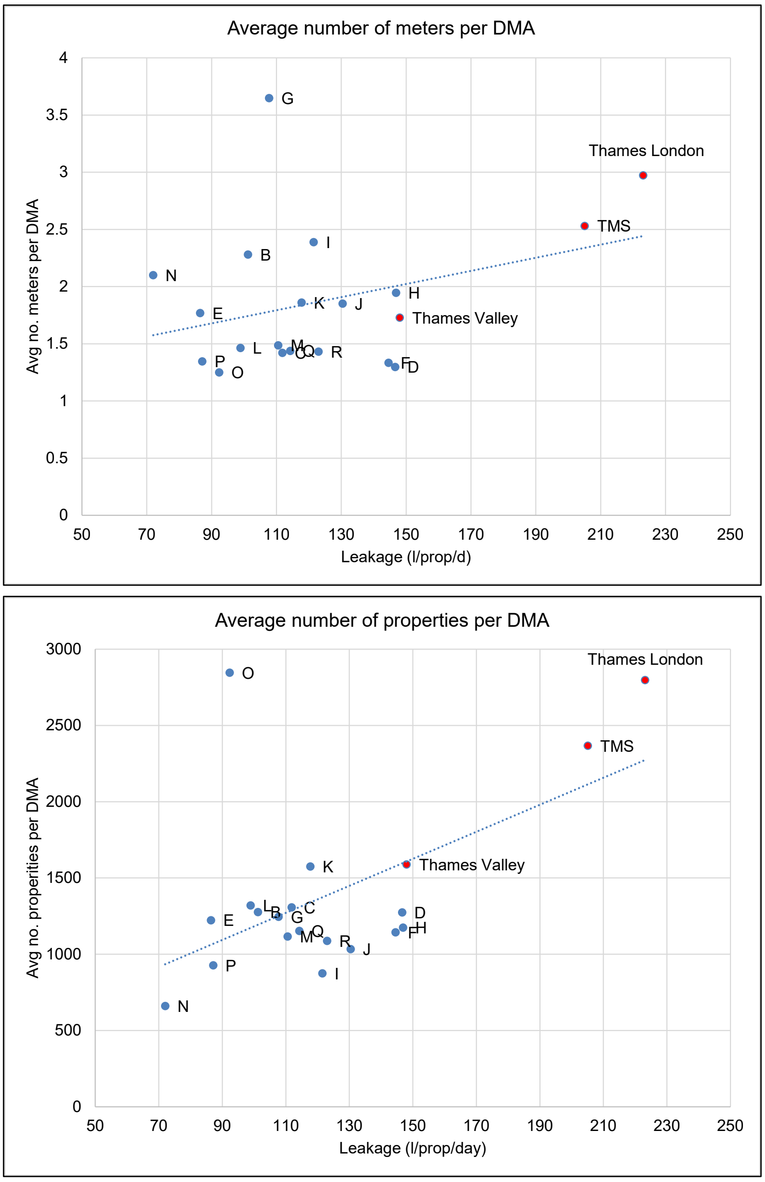
In London, TW has good DMA availability (when meter and logger infrastructure is working correctly, and boundaries are tight) but relatively poor DMA operability[23] (when DMAs provide valid data for robust estimates of leakage). DMA operability in London is challenging owing to demand growth, complex boundaries and the presence of private mains.

[23] In September 2018, about 90% of DMAs in London were available, but only 62% DMAs were operable

The operability of TW's DMAs deteriorated in AMP6 which contributed to its leakage control problems. TW has worked hard to increase the number of proven DMAs and restore TW's oversight of leakage across its network, which was inconsistent. Operability improved from 62% in 2018 to 66.6 % in 2020 but slipped to 63.6% in 2021 owing to impacts from the Covid19 pandemic. However, there is a longer-term programme to improve DMA operability (called the DMA excellence programme) which will contribute to improving TW's leak detection and repair efficiency.

Apart from operability, some of TW's DMAs are large compared with other companies and are complex with multiple metering points on the boundaries, increasing the chances of meter errors when establishing the water balance. Figure 6.24 confirms that TW's DMAs are comparatively large and complex, especially in London owing to complexities of the network. DMA and meter density in Thames Valley is similar to that of other companies, though at the high end. Note that there appears to be a relationship between DMA density and leakage, showing that companies with smaller DMAs are better able to measure and control leakage.

Figure 6.24: Comparative DMA and meter density



Source: Water UK LPI data set (2003 to 2014)

TW recognises that the design of its DMAs could be improved to reduce their size and simplify metering arrangements. The DMA excellence programme, which started in 2020, has identified 129 DMAs with long standing operability issues for improvement. The work includes reconfiguring the network and redesigning and reproving the DMAs to improve their operability. Nine have been completed to date and TW will continue to improve the rest.

Low DMA operability, over-large and complex DMAs in some parts of London and low consumption information resulting from low meter penetration (see below) are constraints limiting TW's understanding of the components of the water balance driving leakage performance evaluations and prioritisation of leakage reduction activities. TW's DMA excellence programme is starting to address these long-standing issues.

In addition to its DMA infrastructure and to support its leak detection activities, TW has installed approximately 27,000 acoustic loggers and is repairing the leaks identified by the loggers. Loggers have helped TW detect over 12 Ml/d of leakage since the start of April 2021.

TW's monthly leakage for June '21 was 562 Ml/d, 7 Ml/d better than their internal target and one of the lowest levels of leakage that TW has ever achieved. TW fixed 5,051 leaks in June, which is below the ambitious 7,111 that it planned to do. The lower number of non-visible leak repairs was partly due to focussing on repairs to older outstanding leaks in TW's backlogs. These often involve more work, such as extensive planning to carry out repairs in busy road junctions and careful excavation around other utilities' apparatus to access pipes.[24]

Metering to measure consumption and leakage

Metering is an important component of any leakage management strategy. Metering, especially smart metering, enables companies to better understand consumption, legitimate night use and leakage. We highlighted TW's relative lack of consumption data in section 5.3.

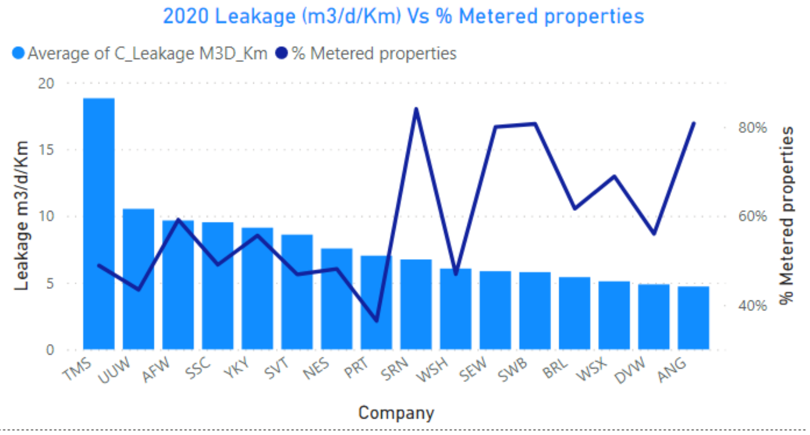
Thames Water's meter penetration figure (approximately 50%) is significantly lower than several other UK companies whose meter penetration is over 80%. It has not been possible to identify the % of smart meters in comparative figures, however prior investigations identified that Thames has relatively low levels of digital metering (as a proportion of its metering fleet) in comparison to the UK peer group (Isle Utilities, 2020). However, Thames Water's metering strategy is based on installation of digital metering as a priority.

TW has recently achieved the key milestone of having installed 500,000 smart meters. Smart meters consistently provide better information about water use at all types of properties. Using this data has helped to prevent over 7 Ml/d of leakage since the start of April 2021.

Figure 6.25 compares meter penetration with levels of leakage (in m^3/day/km) across the industry. It shows that there is a strong relationship between the level of meter penetration and achievement of low levels of leakage and that TW has comparatively low meter penetration.

[24] https://www.thameswater.co.uk/about-us/performance/leakage-performance

Figure 6.25: Comparison of leakage (m³/d/Km) with meter penetration (2020)



Source: Mott MacDonald analysis, based on annual return data from 2020

Speed and effectiveness of repair

Speed of repair is addressed in section 6.3. It was concluded that despite the challenges of high urbanisation, after recent improvements in performance, TW is managing to keep pace with the rest of the sector on leak repair times (see section 6.3). Analysis also shows TW's leakage technicians to be comparatively efficient in detecting leaks (see section 6.4)

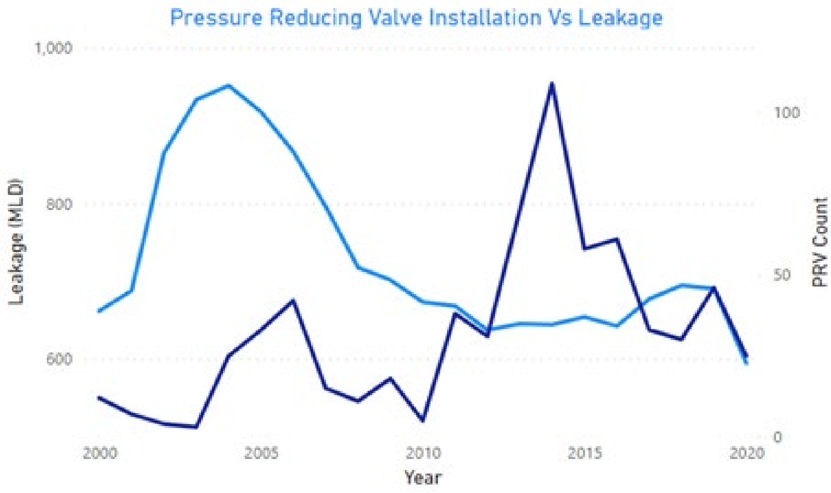
Pressure management

Pressure management is an important means of controlling leakage, especially in networks that are in poor health. We discuss pressure management in section 4.7.5 and note that TW has relatively low average and maximum pressures compared with its peers, including those with lower levels of leakage. This is partly the relatively flat topography compared with other companies and TW's efforts to manage leakage through its pressure managed areas (PMAs).

Figure 6.26 shows that TW's historical investment in pressure management, expressed as the number of PRVs installed, versus its leakage profile. It shows that pressure management started in earnest in AMP4 and, in conjunction with the VMR programme, helped to deliver significant reductions in leakage from 2005 to 2010. In AMP5, although the count of PRVs rose steeply, TW only delivered smaller PMA schemes as the larger schemes had already been delivered in AMP4. This continued into AMP6 where pressure management combined with mains replacement, repair of customer side leakage from newly metered properties and enhanced find and fix activity delivered (eventually) a reduction in leakage by 2020.

In AMP7, TW plans to reduce its investment in new pressure management schemes as there are limited areas remaining that are available or viable for pressure management. The available pressure management schemes that are delivered in AMP7 will contribute to offsetting water network deterioration and achieving further leakage reductions.

Figure 6.26: Evolution of TW's pressure management and leakage



Source: Mott MacDonald analysis, based on annual return data from 2000 to 2020

TW anticipates that opportunities for additional large scale pressure management will have been exhausted in London by the end of AMP7, and it has no current plans for continuing to implement new schemes beyond AMP7. However, TW should continue to review opportunities for pressure management in AMP8 and beyond. From AMP8 onwards, all pressure management activity will be to maintain the benefits achieved from pressure management schemes previously installed.

Benchmarking studies (see section 4.7.5) show that TW has a relatively low density of PRVs compared with UK peers, but has the highest proportion of remote-controlled PRVs[25] which allow pressures to be flow-modulated. TW's WRMP19 assumption that there are limited further pressure management opportunities in the network is based on the current configuration of the network and understanding of pressure and flows. As noted in section 4.7.6, TW is constrained in its understanding of its network by a lack of up-to-date calibrated hydraulic models (only 35% coverage). This limits the information required to make robust decisions on increasing the rollout of PRVs. In addition, TW's long-term plans to replumb London will result in reconfiguration of the network, perhaps creating greater separation between transmission and distribution mains. This may in turn create more opportunities for pressure management.

Network renewal and rehabilitation

Network renewal or rehabilitation is an effective if expensive way to achieve long-term savings in leakage. As noted in Chapter 5, relative to other companies, TW has replaced a smaller proportion of its network, even allowing for the VMR programme in AMP4, and the asset health of London's water network is worse than other companies' networks in terms of bursts and leakage. The reasons for this are explained in chapter 4, but the vulnerable state of the network, especially to cold weather events, presents the most significant challenge to TW's efforts to manage leakage.

The long-term solution to managing TW's leakage must include increased levels of mains replacement, as described in Chapter 5.

[25] Isle Leakage Management Benchmarking. Utility Report – Thames Water. 16th October 2020

Overall, we conclude that there are many positive aspects to the way TW is managing leakage in circumstances of poor network asset health and high levels of urbanisation but there are some areas for improvement.

Pros:

- TW has reduced leakage significantly in the last few years.
- TW started a DMA excellence programme in 2020 to redesign DMAs with long-standing issues to reduce their size, simplify metering and improve operability.
- TW has installed 27,000 acoustic loggers. These are already delivering leakage savings.
- 500,000 smart meters have been installed. Intelligence from them is reducing leakage.
- Despite high urbanisation, TW's speed of repair is comparable with the rest of the industry.
- TW's leakage technicians are comparatively efficient in detecting leaks.
- The network has relatively low average and maximum pressures, achieved through good pressure management.
- Pressure management has been implemented since AMP4 and TW has a high proportion of remote controlled PRVs.

Cons:

- Poor DMA operability has limited TW's ability to measure leakage. This is now improving.
- Some DMAs in London are over-large and complex to target leakage effectively.
- TW has low meter penetration compared with others which limits understanding and measurement of leakage.
- Opportunities for further pressure management beyond AMP7 are currently thought to be limited, but future plans to reconfigure the network may present opportunities.
- TW is constrained by a lack of up-to-date hydraulic models, though TW plans to build more in AMP7.
- The poor asset health of London's water network, especially its vulnerability to cold weather events, poses the most significant challenge to managing leakage.

6.7 Digital tools supporting operations

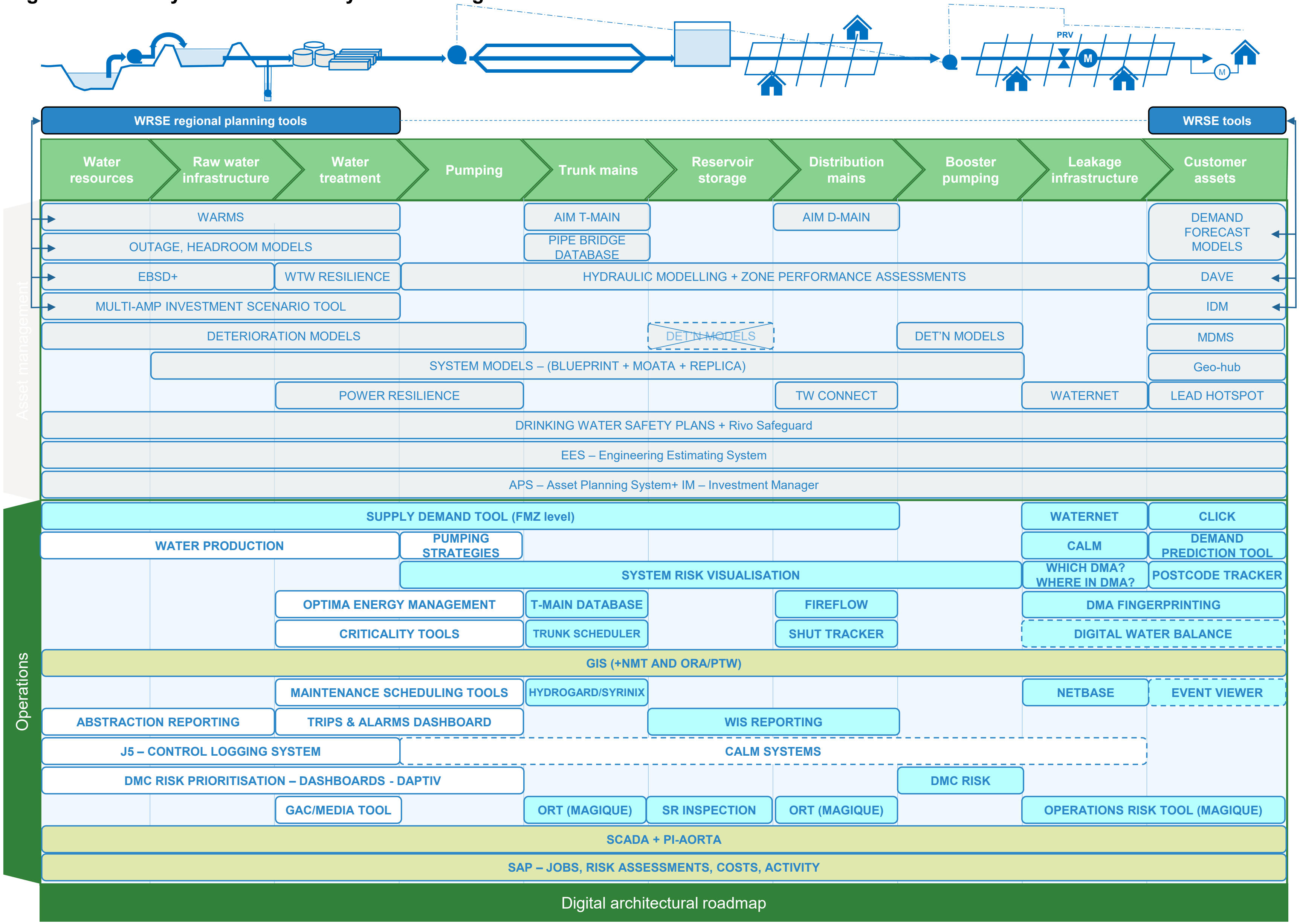
TW has a range of live digital tools available for managing London's water network on a day-to-day basis. Figure 6.27 maps TW's decision-support tools to the water supply value chain, focusing on Operations (asset management is covered in Chapter 5). Figure 6.27 highlights the digital tools used for planning operations and managing work on the network in blue and the cross-cutting tools, such as SCADA, in green. We describe some of the tools that Operations use as follows:

Supply-demand tool

The supply demand tool takes short-term forecasts of demand from a demand prediction tool and allocates it across all of TW's water supply systems and flow monitoring zones (FMZs). It operates in near real time by hydraulic system, presenting actual (via SCADA) and forecast supply, demand, and storage. Operations use it to plan and manage the balance of supply at a local level, for example in determining ring-main pump shaft outputs or planning outages.

The demand prediction tool associated with the supply demand tool forecasts demand for the next 10 days taking account of the weather and temperatures (e.g. freeze-thaw events) and soil-moisture deficit. It works for both London and Thames Valley.

Figure 6.27: Analytical tools used by asset management



Source: Mott MacDonald

DMA fingerprinting

DMA fingerprinting is a tactical tool to provide a regional and localised view of leakage performance to understand the drivers and develop action plans at a DMA level to achieve ambitious leakage reduction targets. It stemmed from the AMP7 leakage action plan, began development in 2020 and gathered support from the digital SMART Water initiative.

It is a digital tool that combines datasets on assets with cost data, performance data, operational data and water balance data. It generates performance dashboards, updated in near-real time, to benchmark performance across DMAs, zones and systems. Insights from the dashboards enable planners to target leakage control activities at problem DMAs. TW is currently developing a solution selection framework, which will guide the choice of the most appropriate interventions to deliver operability, performance and cost improvements within geographical areas. It is also a repository for DMA action plans.

TW also has plans for system planners to use the tool to develop DMA action plans with 1yr, 5yr and 15yr horizons. These will co-ordinate capital and operational activities to achieve primarily leakage reduction targets but also asset health targets, such as burst numbers and interruptions to supply, as well as cost efficiencies and reduced customer contacts. DMA action plans will be used to brief the Infrastructure Alliance (find and fix), Capital Delivery (mains replacement) and Customer Solutions. DMA fingerprinting can also assess and track benefits from interventions.

Although DMA reporting is common practice, real-time DMA fingerprinting is a new and innovative development.

System risk visualisation

System risk visualisation (SRV) is a tool to manage network performance issues in near real time. It was developed in response to the findings of the independent trunk mains forensic review.

SRV analyses and shows pressures and flows in real time from 5000 district meters and critical pressure points. It provides Operations with live readings from these monitors on a GIS map. It also shows reservoir levels and pump status (so operators can see a rapid fall in reservoir level if a trunk-main bursts). Anomaly detection algorithms alert operators to issues. It has the ability to detect bursts as they happen and localise where the burst occurred, enabling operators to identify and control them as they arise. It provides the ability to respond faster to an event to reduce the occurrence and severity of supply interruptions.

Waternet

Waternet is a leakage management tool similar to Netbase, but TW uses its pressure management module for designing and operating pressure management areas (PMAs). It identifies the best locations and settings for PRVs and includes a tall building database to ensure that these properties are catered for in PMA design. The tool is live, so is also used by Operations. It reports the availability of PRVs and the operability of PMAs. Other modules support the maintenance of PRVs.

Which and Where in the DMA

Which DMA is a back-office tool for targeting DMAs for leakage detection and repair effort. It is designed to increase the productivity and leakage yield of detection operations by focusing on the leakiest DMAs. It simplifies targeting by integrating data into one tool.

Where in the DMA is a field-based tool for directing the leak detection teams to the leakiest pipes in a DMA. The aim is to improve leak detection efficiency (i.e. reduce the hours/leak).

- It incorporates probability of failure data from AIM into a pipe-level risk model.
- A printed map of the risk model directs field teams where to go.
- TW has now launched a mobile app version.
- It improves the leak output of a 27,000 fixed network of acoustic loggers.
- It reduces the days spent inefficiently detecting within a DMA, improving productivity by 24%.

At the UK App Awards, Thames Water won the IoT App of the Year award for its Where? app which uses artificial intelligence to help technicians detect leaks.

Hydroguard and Syrinix

Hydroguard and Syrinix are two types of trunk main monitoring device that identify pressure anomalies that are indicators of leakage and/or impending bursts. The devices automatically raise email alerts for Operations to investigate using GIS and Scada. The devices also log and detect transients. They are TW's prime monitoring devices for its trunk main network.

TW has a good set of smart digital tools to support Operations, detect anomalies and enable rapid response. They are, by their nature, tactical and rely on current performance data and recent history. The value of DMA fingerprinting, for example, could be improved if it could also provide forecasts that would account for future deterioration of the network. This could be achieved by incorporating the results from the AIM models, which would have the added benefit of continuously validating AIM model output. We also think that Operations would benefit from more hydraulic information, which live hydraulic models could provide (see section 5.3), though this would be a medium-term aspiration.

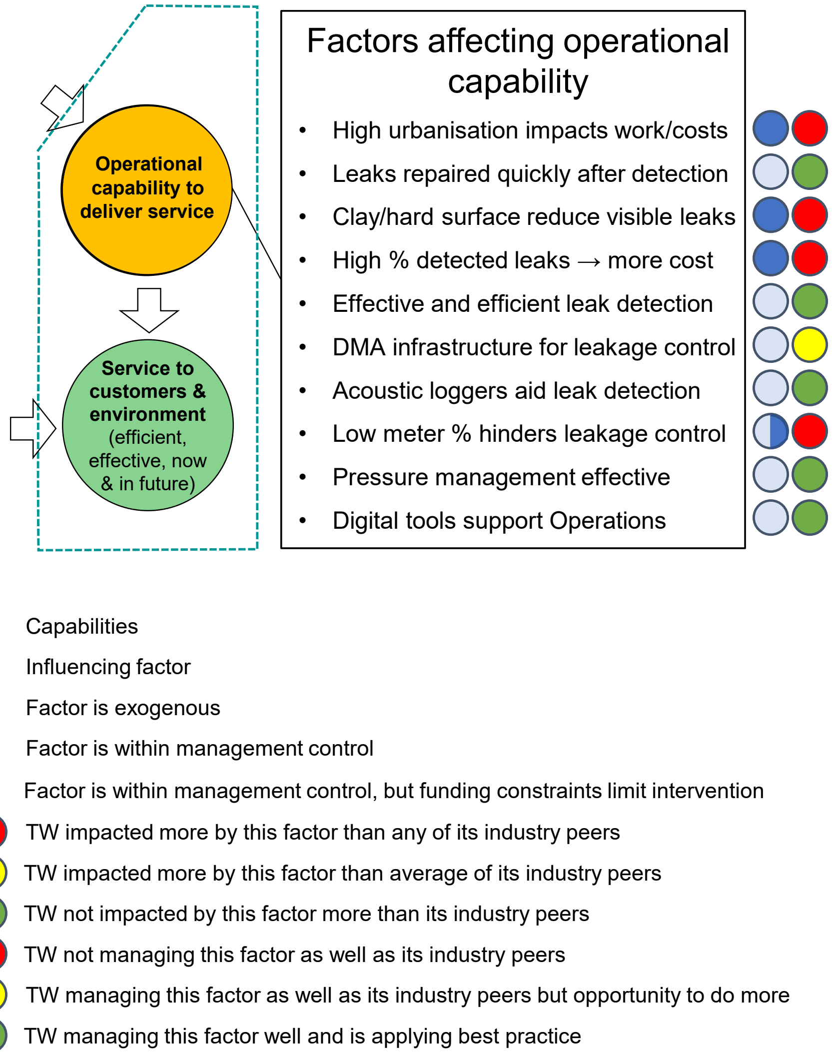
6.8 Conclusions on operational capability

In this section, we draw some conclusions on TW's operational capability in managing London's water network. We consider the factors affecting operational capability in the London area and their impact on the speed of repair and leak detection. We consider how well TW manages these factors in controlling leakage and the effectiveness of its digital tools to support operations. We also make some recommendations on improvements in operational capability.

1. Factors impacting operational capability

Figure 6.28 summarises the key factors impacting TW's operational capability, the extent to which they are exogenous or within management control, and the severity of their impact compared with water industry peers or TW's success in managing them.

Figure 6.28: Key factors impacting TW's operational capability



Source: Mott MacDonald

The factors impacting TW's operational capability are largely within management control, but in London's urbanised environment, some are exogenous, as shown in Figure 6.28.

Firstly, London is the most densely urbanised environment in the UK, which has an impact both on the cost of working on London's water network and the time it takes to do it. London has the highest level of urbanisation (urban area/total area), the highest population density and the highest housing density, leading to densely packed buried services and prevalence of hard surfaces and bound concrete layers in carriageways. The impact of this on costs is explored in Chapter 7: Cost of managing the network.

We investigated the impact of high urbanisation on speed of repair in case this was a factor in controlling leakage. TW has recently streamlined its processes for leak repairs using a dedicated planning team to manage the logistics and engage with stakeholders. This has reduced repair times significantly, so that TW's repair times are now below industry average for visible leaks and on average for detected leaks. We conclude therefore that TW is managing speed of repair well despite the challenges and is applying best practice.

The combined effect of hard surfaces through high urbanisation and the clay subsoils means that TW needs to detect a greater proportion of all leaks than other companies elsewhere in the country. This means that TW must detect a higher proportion of leaks than its industry peers. Data shows that the ratio of reported (visible) leaks to non-reported (active) leaks is much lower than the industry average and as a result in London, TW detects and repairs 50% more invisible leaks for each visible leak than the industry average. This has an impact on TW's leak detection volumes and costs compared with other companies, which explains TW's high opex costs (see Chapter 7: Cost of managing the network).

The available comparative data supports the view that TW's leakage technicians are effective and efficient at leak detection and TW has installed 27,000 acoustic loggers to aid leak detection efforts which are already delivering leakage savings. However, TW's DMA infrastructure, although improved, still has relatively low operability which effects TW's ability to accurately measure leakage and target detection efforts effectively. TW is implementing a DMA excellence programme to understand the issues and gradually improve operability. This considers DMA design and options to reconfigure the network to reduce the size and complexity of some of London's DMAs. Data shows that TW's DMAs are large compared with other companies and that there is a correlation between DMA size and leakage.

Another hindrance to efficient leakage control is comparatively low meter penetration which limits the availability of good consumption data with which to refine leakage estimates and target leak detection effort. This was referred to in Chapter 5. However, one benefit of implementing its metering strategy later than others is that a large number of TW's meters now installed are smart meters. These provide a better appreciation of real-time changes and the potential to build high-confidence models for consumption and night use that are representative for London.

TW has been installing and operating pressure management schemes since AMP3 and has extensive coverage of London's network with pressure managed areas. These are operated with remote-controlled PRVs which allow pressures to be flow-modulated. We have assessed TW's pressure management to be effective and note that there may be limited opportunity for further pressure management going forward, though this should be kept under review.

TW has a good set of smart digital tools to support Operations, detect anomalies and enable rapid response. They are, by their nature, tactical and rely on current performance data and recent history. There may be opportunity to increase their value by integrating them more with asset management forecasting tools.

2. **Mitigating the factors impacting operational capability**

In Figure 6.28, there is only one factor impacting operational capability with a yellow designation, which is DMA infrastructure for leakage control. A lack of consumption data is also a challenge. We provide a short list of mitigations:

- Implement the DMA excellence programme to address the issue of poor operability.
- Include in the programme actions to redesign DMAs in London where they are currently over-large and over-complex, to arrive at a larger number of smaller and simpler DMAs for better leakage targeting.
- Expand the value of existing metered consumption data by incorporating new data as the AMP7 metering programme is delivered and more data becomes available.

3. **Priority actions for sustained improvements in operational capability**

The following priority actions with respect to operational capability build on plans that TW already has in place:

   a. Tactical interventions:

- Building on the success of the AMP6 initiative to increase the speed of repair, negotiate criteria with Highway Authorities to increase the number of detected leaks that can be classified in the same way as visible leaks for the purpose of permitting, so that they can be fast-tracked for repair.

- Implement the DMA excellence programme to improve DMA operability and leakage targeting.
- Divide the largest DMAs into smaller and simpler DMAs to improve leakage targeting and management.
- Increase coverage and use of acoustic loggers and other technologies to improve leak detection.

b. Improving asset knowledge

- Continue to track and improve leak detection performance and costs to capture the benefits of technology and other initiatives and show improvements in efficiency.
- Improve the availability of consumption data as the metering programme is delivered and use it proactively to improve water balance calculations and leakage control activity.

c. Targeting investment

- Explore further opportunities for pressure management as plans to replumb London are developed and coverage of the network with calibrated hydraulic models increases.
- Keep under review advances in automated valve operations which may have potential to expand pressure management into areas previously discounted.

d. Mitigating cost pressures

- Given the high proportion of repairs undertaken in costly urban areas, research alternative and cheaper repair techniques that reduce excavation and reinstatement costs and/or disruption for traffic and businesses.

e. Driving innovation

- Continue to identify and pilot leak detection technologies that can cope with the challenges of hard surfacing and clay sub-soil conditions in London.

7 Cost of managing the network

Chapter summary

This chapter describes the costs of managing London's water network, the factors impacting costs and how these compare with other companies' networks. We also examine cost efficiency, and what would be required to move to a more efficient whole-life cost position.

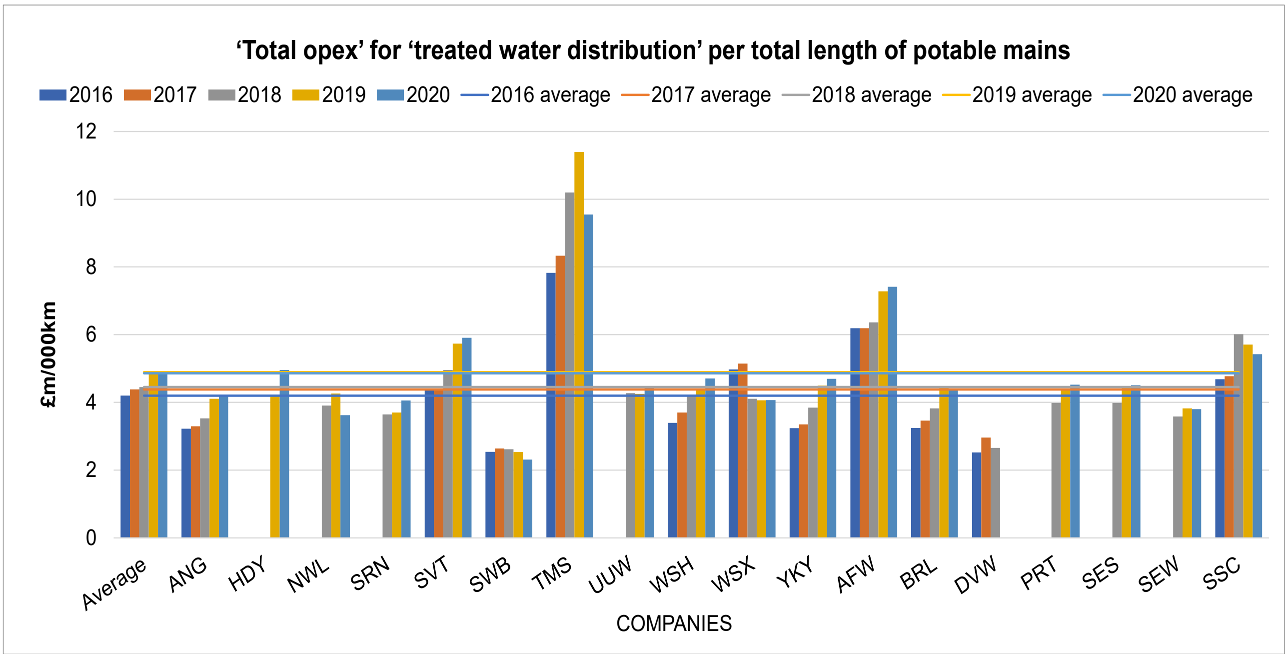
Some of the key discussion points presented in this chapter are briefly summarised below:

- Factors impacting the cost of managing London's water network
  - TW's capital and operating costs are higher than its industry peers and one aspect of this is higher pipelaying costs in London than industry benchmarks by 5% to 30% for distribution mains and about 70% for trunk mains.
  - The main factors impacting the cost of capital works in London are the nature of the streets, such as the prevalence of concrete bound layers increasing, high density of buried services, high traffic management costs, and the high labour costs in London.
  - There is evidence to show that the impact of these factors is more severe in London than elsewhere in the country and that inner London is affected more than outer London. Also, trunk mains with their deeper excavation and wider construction envelope are more affected by the factors than smaller diameter distribution mains.
  - TW costs and benchmark costs for distribution mains are broadly efficient compared with benchmarks when adjusted for location using BCIS location indices. However, trunk mains, appear to be inefficient compared with benchmarks by 35% in London.
  - In examining TW productivity data, we were unable to identify the specific factors impacting costs for trunk mains or to compare these with similar information associated with benchmarks to quantify the effects
  - A whole-life cost benefit analysis of London's water network has shown that the current balance of capital and operational costs is uneconomic in the long term and that to reduce operating costs and maximise the benefits from improved service, TW needs to increase the level of mains replacement. Early analysis suggests this should exceed 1,000 km per AMP. TW is undertaking further work to refine this analysis.
- Mitigating the factors impacting the cost of managing London's water network
  - A cost-efficient programme of mains rehabilitation needs to maximise opportunities for trenchless techniques where their advantages can be fully exploited.
  - Aim to reduce the length of pipe to be replaced by rationalising the network in the DMAs that TW selects to renew.
  - Scale and package the work to reduce construction add-ons.
  - Co-ordinate street-works with other utilities to limit the impact on London's traffic by closing off streets once for multiple utility replacement work.
  - Engage with the supply chain to use innovative pipe renovation techniques where these offer resilient solutions at lower whole-life cost.
  - Further use of pressure management where opportunities arise.
  - Network calming measures, including improved control of transients.
- Priority actions for improvements in managing the cost of London's water network
  - The priority actions focus on improving knowledge of costs, achieving inter-generational equity, mitigating cost pressures, and driving innovation.

7.1 Historical cost of managing London's network

In Chapter 2 we showed that a consequential effect of the poor condition and performance of London's water network compared with other companies is that the cost of managing the London water network is higher than other companies. We presented evidence of this for AMP6, and we show this again in Figure 7.1 which compares reported operational expenditure on treated water distribution per 1000 km of pipe and Figure 7.2 which compares reported capital expenditure.

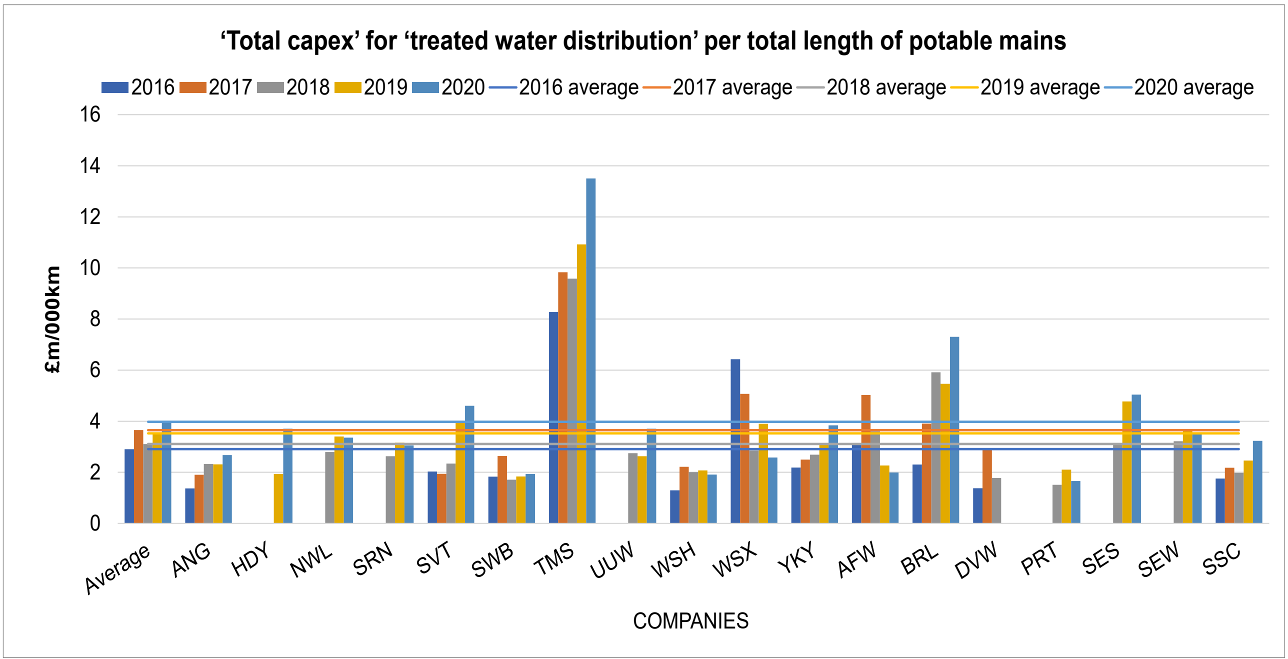
Figure 7.1: Comparative Opex for water infrastructure (AMP6)



Source: APR data-tables for 2015/16 to 2019/20 (opex for treated water distribution Table 4J, mains length Table 4P)

Figures 7.1 and 7.2 show that for both opex and capex, TW's costs in AMP6 were much higher per unit length of pipe than that of other companies.

Figure 7.2: Comparative capex for water infrastructure (AMP6)

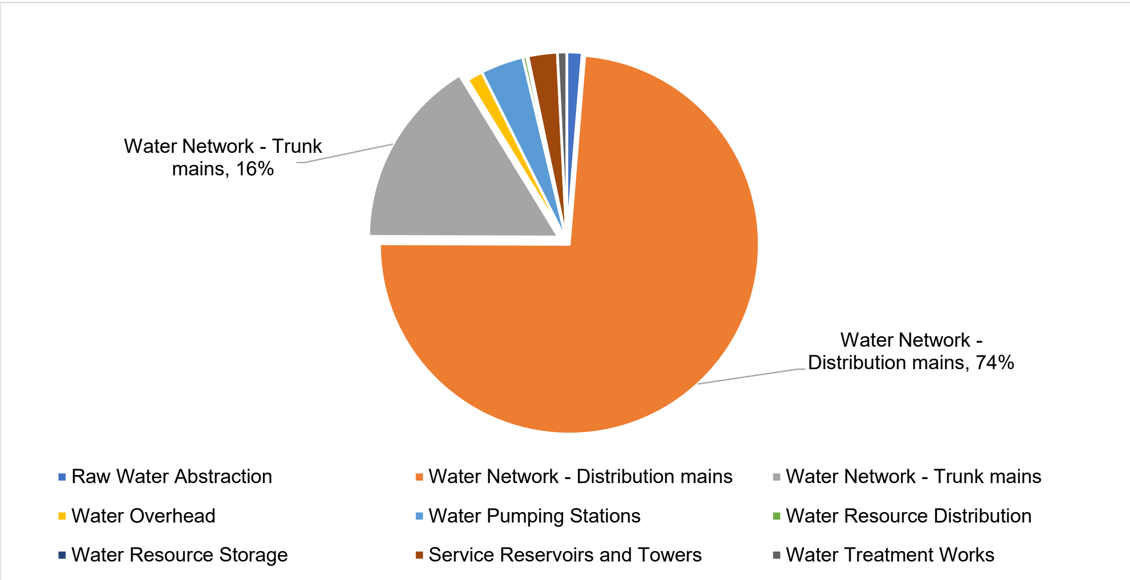


Source: APR data-tables for 2015/16 to 2019/20 (Totex for treated water distribution Table 4J, mains length Table 4P)

Capital costs accounted for 48% of Totex for water infrastructure and a breakdown of the capital costs shows that 63% of the costs were for base expenditure and 37% for enhancement, which includes growth. TW had the highest rate of growth and highest number of new connections in the sector in AMP6, which is reflected in the relatively high levels of enhancement expenditure.

Figure 7.3 shows a breakdown of water infrastructure capital costs for AMP6.

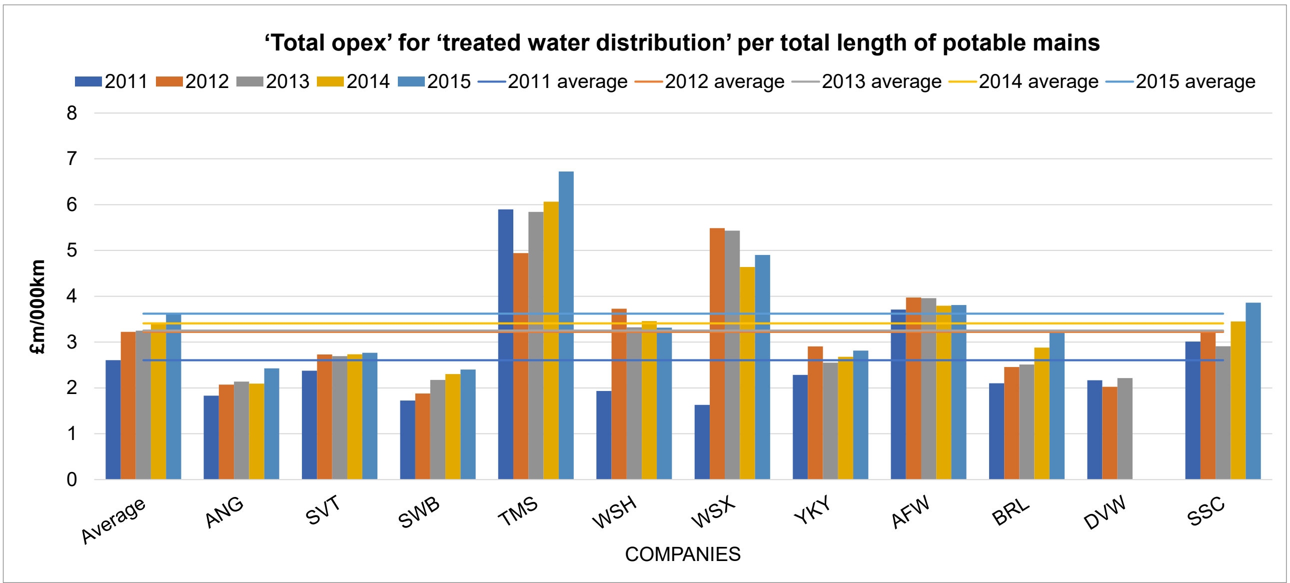
Figure 7.3: Breakdown of capital costs for AMP6



Source: Mott MacDonald analysis of TW AMP6 capital expenditure data

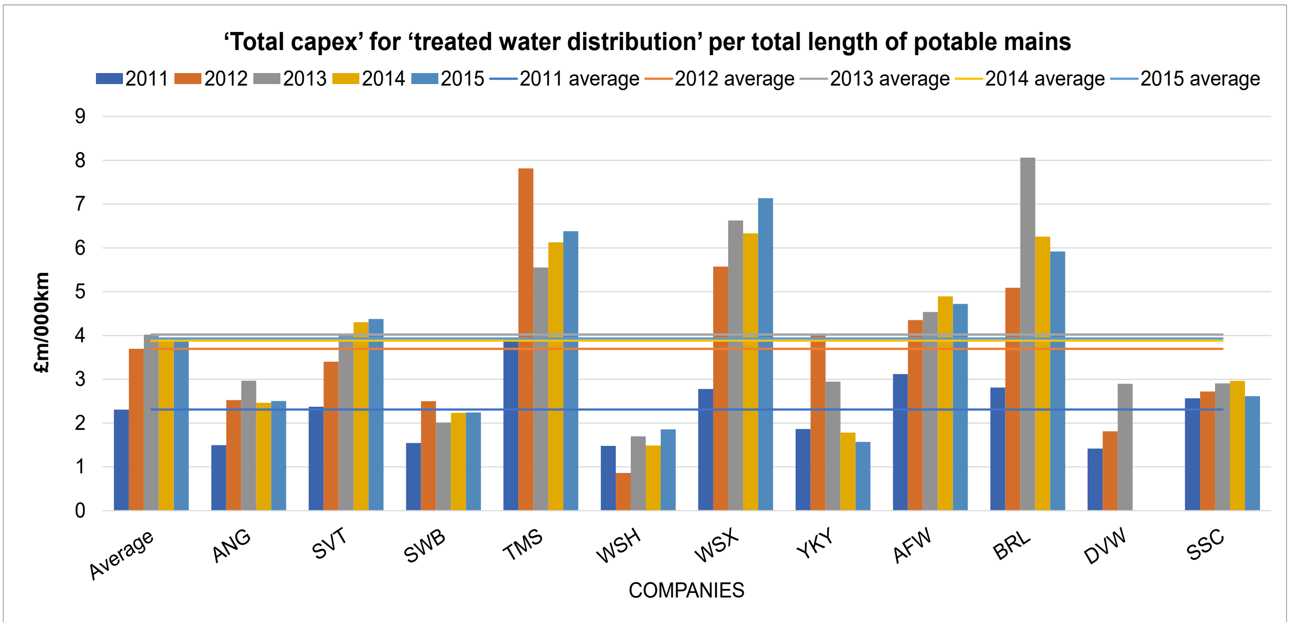
It is clear from Figure 7.3 that 90% of the expenditure was on distribution mains and trunk mains. Apart from higher levels of enhancement expenditure on new mains in growth areas, which would increase costs comparatively, TW incurred unplanned reactive expenditure associated with trunk-main failures, it committed to additional expenditure in the wake of the trunk mains forensic review in 2017 and it spent more bringing leakage under control after failure of targets. In many respects, AMP6 was an atypical period from which to draw conclusions on TW's cost position, so we have prepared similar figures for AMP5, which was a period of stable serviceability and leakage was also stable and below target. Figure 7.4 shows the comparative picture for opex and Figure 7.5 compares capex expenditure, normalised by length of main.

Figure 7.4: Comparative opex for water infrastructure (AMP5)



Source: APR data-tables for 2011/12 to 2015/16 (opex for treated water distribution Table 4J, mains length Table 4P)

Figure 7.5: Comparative capex for water infrastructure (AMP5)



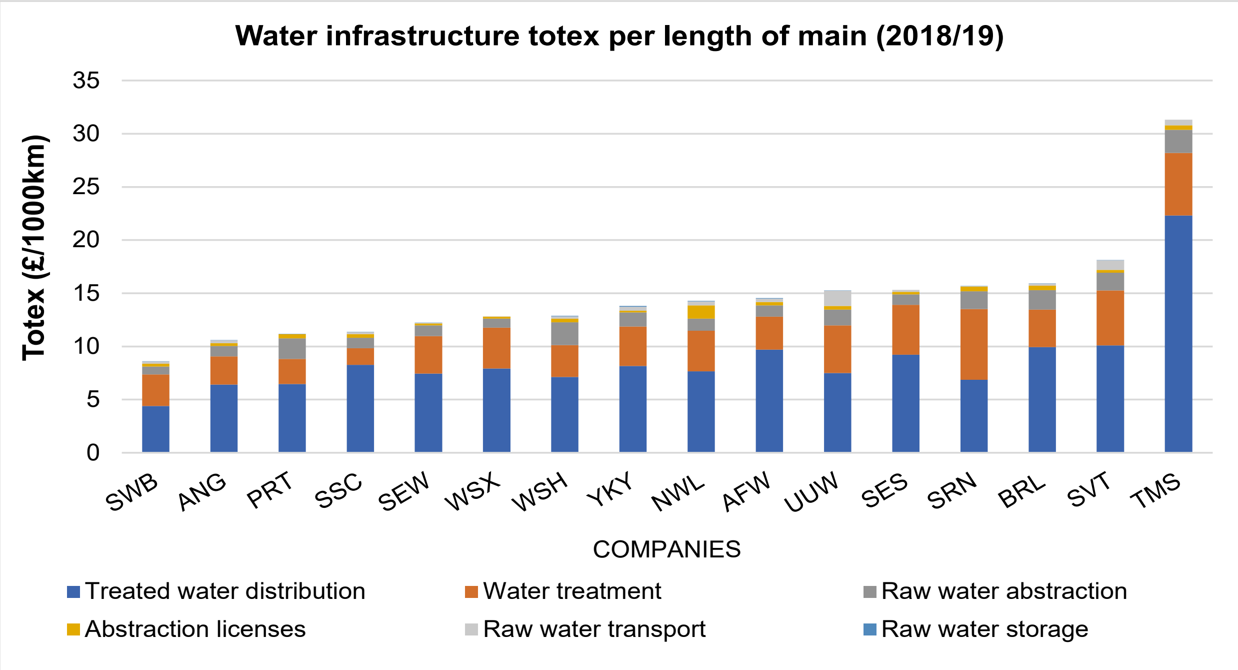
Source: APR data-tables for 2011/12 to 2015/16 (Totex for treated water distribution Table 4J, mains length Table 4P)

Figures 7.4 and 7.5 are missing some companies as we were unable to source all the data for AMP5, but enough remain to confirm that TW's costs in AMP5 were also higher per unit length of pipe than the average of other companies, but not by as much as in AMP6, 80% higher for opex and 70% higher for capex. TW was still an outlier for opex, but other companies also had above average capital costs in AMP5. We believe that AMP5 is a more representative view of the extent to which TW's costs exceed those of other companies.

The conclusion, therefore, is that historically, TW's costs for water infrastructure have always been higher than other companies, both for operational costs and capital costs. AMP6 was an atypical period, requiring excess reactive expenditure and an injection of capital to address performance issues, so AMP5 is in our view a more reliable marker, but the data still shows a cost delta of 70% to 80% compared with industry average, when normalised by mains length.

To illustrate the comparative cost differences another way, Figure 7.6 compares the breakdown of costs across water infrastructure for a single year, 2018/19.

Figure 7.6: Totex comparison for 2018/19



Source: Mott MacDonald, APR data tables 2018/19, Table 4D, Line 21 Totex

Figure 7.6 confirms that TW is spending more than other companies and that its expenditure is dominated by treated water distribution, finding and fixing leaks and maintaining its water mains.

The reasons for the cost difference are that TW spends relatively more on:

- Repairing greater quantities of bursts per unit length of network
- Detecting and repairing more leaks per unit length of network than other companies
- Incurring higher power costs in a largely pumped system
- Replacing pipes to keep pace with higher rates of deterioration
- Incurring higher unit costs in the densely urbanised London environment.

Evidence for the last point is discussed in the next section. The combined effect of these factors means that TW faces higher costs to manage the network than other companies.

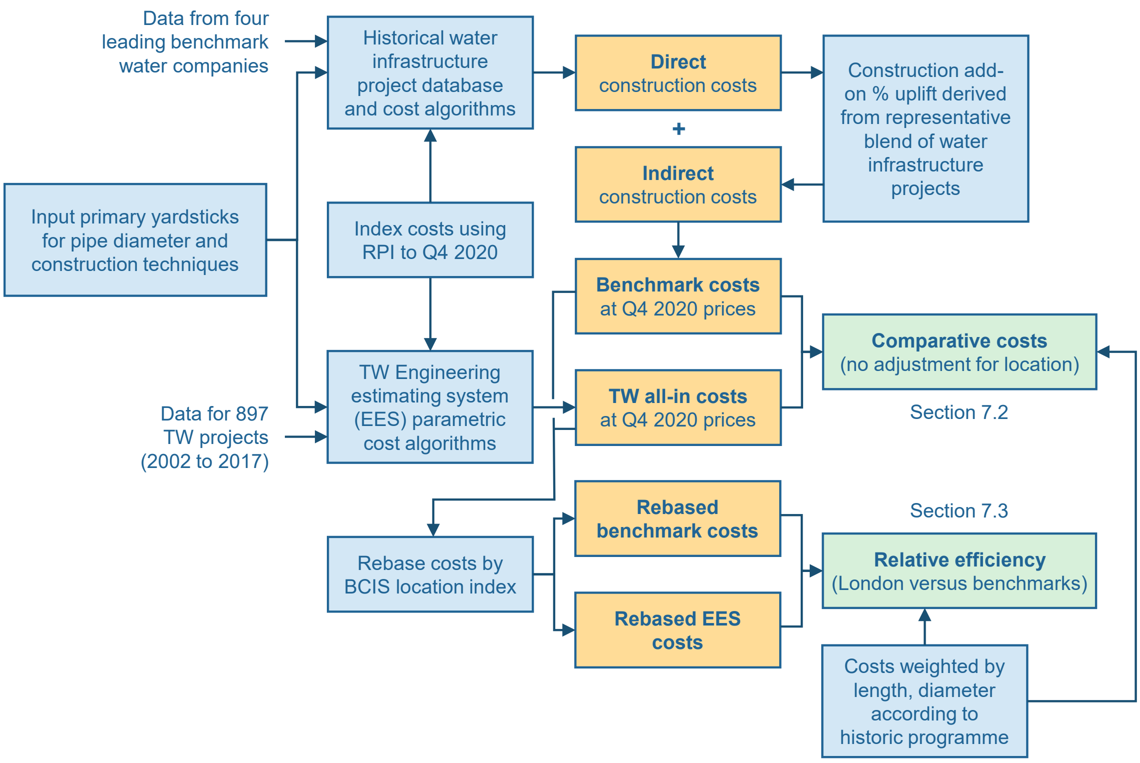
7.2 Comparative analysis of costs

In this section we benchmark the cost of network interventions in London to determine the size of any cost differential. In subsequent sections we consider relative cost efficiency for delivering capital projects and identify the factors driving differences in cost when undertaking work in London. These sections summarise the findings of a separate cost report, which provides more detail on how the benchmarking was undertaken.[26]

7.2.1 Approach adopted

An overview of the approach adopted to benchmark TW's water infrastructure costs and assess relative efficiency is presented in Figure 7.7.

Figure 7.7: Approach to cost benchmarking



The objective of the exercise is to compare TW's costs for selected water infrastructure activities with efficient comparator benchmark costs for the same activities to assess and quantify the cost delta. A second objective is to consider relative efficiency, having first rebased the costs to account for location, as construction costs vary across the country. We then go on to consider the factors that explain the cost delta between TW's costs and the benchmarks.

We have utilised our in-house database to underpin the benchmarking comparison. This contains historical water infrastructure project data sourced from four leading water companies and represents a good geographical coverage of UK cities. The comparator algorithms generate direct construction costs with a primary yardstick quantity used as input. The yardsticks we used were pipe diameter and construction technique (open cut and trenchless) to compare costs for the most significant water infrastructure activity, pipe laying.

[26] Mott MacDonald, London water improvement project - Task J comparative cost analysis of infrastructure mains replacement

Construction add-ons (client and contractor) were retrospectively added to the direct costs from our in-house database using a percentage uplift derived from a representative blend of clean water infrastructure projects. This produced benchmark costs for comparison with TW costs.

We have taken TW costs from TW's engineering estimating system (EES) which is based on information captured from 897 water infrastructure projects undertaken between 2002 and 2017. Using the same yardsticks, we used EES to produce all-in costs (inclusive of contractor and client add-ons) for pipe-laying activity by technique for comparison with benchmark costs.

All costs, both benchmark costs and EES costs, have been indexed to Q4 2020 prices using retail price index (RPI). Our cost report provides more detail on the rationale for choice of RPI.

For each of the selected techniques and disciplines we evaluated TW costs across a representative diameter range and compared them to the median cost of four comparator water companies. When quantifying the cost delta and subsequent TW efficiency, we compared to a benchmark corridor characterised by the lower 25th and upper 75th percentiles of the Industry data. The cost comparisons are presented in section 7.2.3.

To assess relative efficiency, we have rebased both the benchmark costs and TW's costs to account for location using the BCIS (Building cost information service) location indices. This ensures that location is not a factor in the assessment of relative efficiency. Relative efficiency is discussed in section 7.3.2.

Both EES costs and benchmark costs are specific to individual pipe diameters and construction techniques. To enable a comparison of costs at an asset class level, we have made assumptions about the proportional length of each pipe diameter that would be delivered in a typical pipe rehabilitation programme. These assumptions are based on historic diameter ranges and lengths that took place in projects from the TW EES dataset, while also considering the working ranges of the comparator algorithms. The cost comparisons presented here are valid for this historic range of diameters and might differ for future programmes if the diameter mix is significantly different. In addition, we have chosen algorithms from our comparator dataset which represent similar surfaces being excavated. However, we were unable to ensure that inclusions and exclusions were completely aligned in the absence of full cost build-ups. Further limitations of the analysis are given below and in the separate cost report.[27]

7.2.2 Construction add-ons

Construction add-on costs constitute a major component of the total project cost. TW did not provide cost breakdowns for its construction add-ons, but our models are inclusive of:

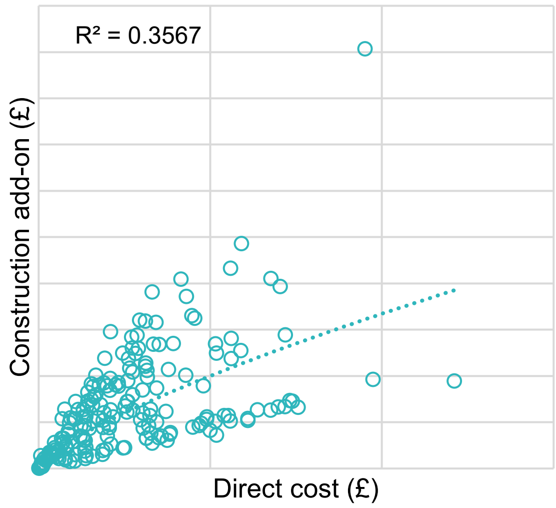
- Overhead and profit
- Design
- Preliminaries
- Construction management (site management and project management)
- Health & safety
- Testing & commissioning
- Risk

The TW add-ons will also capture some of the costs related to unique London factors such as additional administration associated with planning works, traffic management and traffic planning, lane rentals (bus, cycle, and carriageway), and parking bay suspensions.

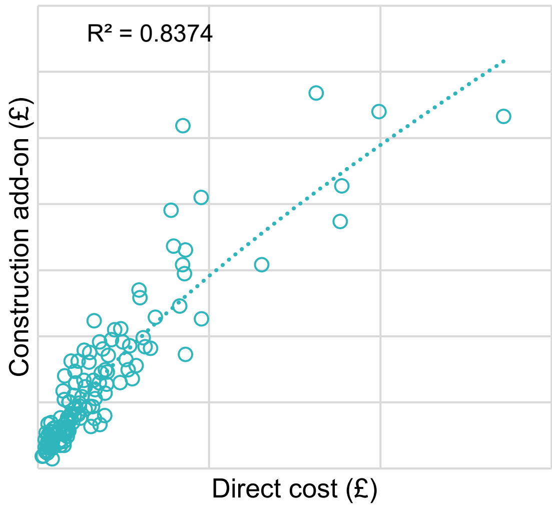
[27] Mott MacDonald, London water improvement project - Task J comparative cost analysis of infrastructure mains replacement

We compared construction add-on costs with direct costs for 193 TW final accounted projects and 435 final accounted industry projects. Figure 7.8 shows the results for TW projects and comparator projects.

Figure 7.8: Direct costs versus construction add-on costs



(a) TW EES projects



(b) Water industry comparator projects

Source: TW EES dataset and MM water sector benchmark database

The regression model for TW projects in (a) shows that there is a strong relationship between project direct cost and construction add-on. The goodness of fit (R^2=71%) shows the TW construction add-ons to be less strongly correlated to direct costs compared to one of our water sector comparators shown in (b). The second model shows that more of the observed variation can be explained by the direct cost variable (R^2=83%). This suggests that there may be more independent variables present within the TW projects.

One explanation for the lower R^2 value in Figure 7.8 (a) is that a wide range of projects are represented. The add-on percentage reported in Table 7.1 is given as the ratio of total construction add-on to total direct cost split by AMP period for TW projects. This shows AMP4 experienced the lowest construction add-on percentage by a significant amount. This is likely because of the larger size of projects undertaken for AMP4, where TW carried out the Victorian Mains Renewal (VMR) programme. AMP4 projects within the dataset represent 1137km of pipe replaced, whereas the combined total of AMP3, AMP5 and AMP6 is 548km, showing the difference in scale of work undertaken. The combination of scale of work and concentration in one area is a likely reason for the lower percentage add-on costs in AMP4.

Table 7.1: Comparison of TW construction add-ons by AMP

Period	Construction add-on
AMP3	93%
AMP4	46%
AMP5	95%
AMP6	149%
TW overall	68%

Source: TW EES dataset

This is an important observation for planning future mains renewal. Smaller projects, perhaps resulting from spot-replacement of pipes in especially poor condition, carry a cost premium in higher construction add-on costs, whereas larger projects involving whole-DMA replacement, such as were undertaken in AMP4, carry lower construction add-on costs as set-up costs are proportionally lower.

Table 7.2 shows that the TW infrastructure final account projects have a 68% average overall construction add-on compared to the industry median of 84%. However, if AMP4 projects are excluded from the calculation owing to the unusual scale and nature of the VMR programme, the add-on percentage for TW infrastructure final account projects rises to 98%. This shows TW to be operating outside the industry benchmark corridor for add-ons for average sized projects, suggesting that London specific factors affect the add-on costs over and beyond their impact on direct costs. We discuss the factors affecting costs in section 7.4.

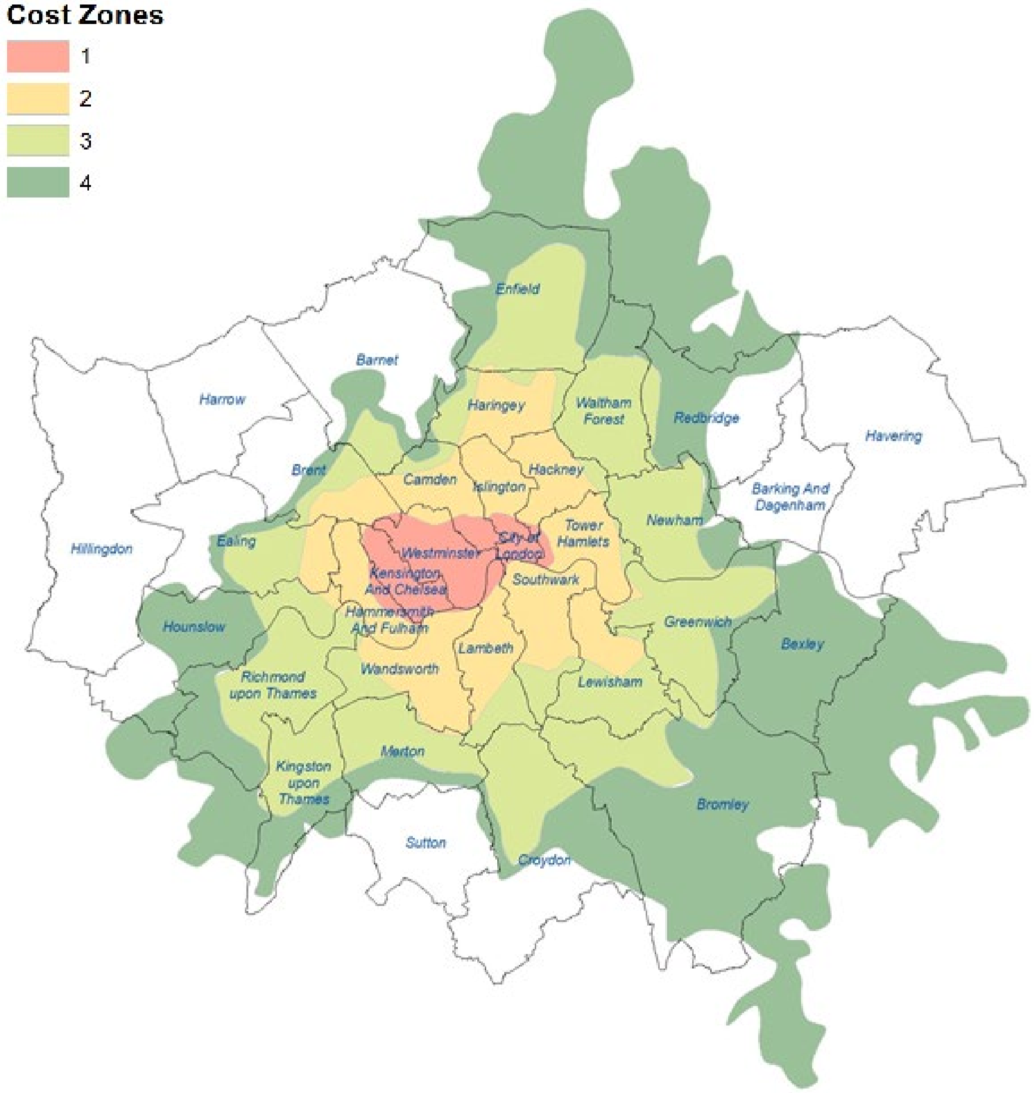
Table 7.2: Comparison of TW construction add-ons to Industry

Period	Construction add-on
TW overall	68%
Industry lower 25^{th} %	73%
Industry median	84%
Industry upper 75^{th} %	97%
TW overall, excluding AMP4 projects	98%

Source: TW EES dataset and MM water sector benchmark database

The variance in construction add-ons in London was further assessed by location. The TW EES dataset contains separate algorithms for generating costs for each London borough and a single algorithm for the Thames Valley. The 33 boroughs of London are further mapped to four zones within London as shown in Figure 7.9.

Figure 7.9: Zonal mapping of council boroughs in London



Source: Thames Water

An analysis of the projects that have been tagged to zones shows that construction add-ons vary by zone, being higher in Zone 1 (inner London) than Zone 2 (outer London) as shown in Table 7.3. However, the data for zones 3 and 4 were limited.

Table 7.3: Client and contractor add-on as a function of London zone

Area	Construction add-on %	Number of projects
London (all FA projects)	68%	193
Zone 1 projects	58%	35
Zone 2 projects	51%	63
Zone 3 projects	45%	12
Zone 4 projects	38%	3

Source: TW EES dataset

The TW project data has been used to generate the construction add-ons within the individual algorithms which are specific to location. The benchmarking that follows uses these algorithms to generate costs by zone, as defined above, for comparison with benchmark costs. This is to explore the cost variance of working in different parts of London. Unfortunately, the add-ons are not specific to technique or discipline. The add-ons thus reflect the average complexity of an average project which might include a range of types of activity and a range of project sizes.

7.2.3 Comparative cost analysis

We have undertaken comparative cost analyses for all the principal areas of pipelaying:

- Open cut pipelaying for distribution mains
- Open cut pipelaying for trunk mains
- Trenchless pipelaying using directional drilling
- Trenchless pipelaying using slip lining

We provide some of the analysis here and a summary of results, but more detail can be found in the separate cost report.

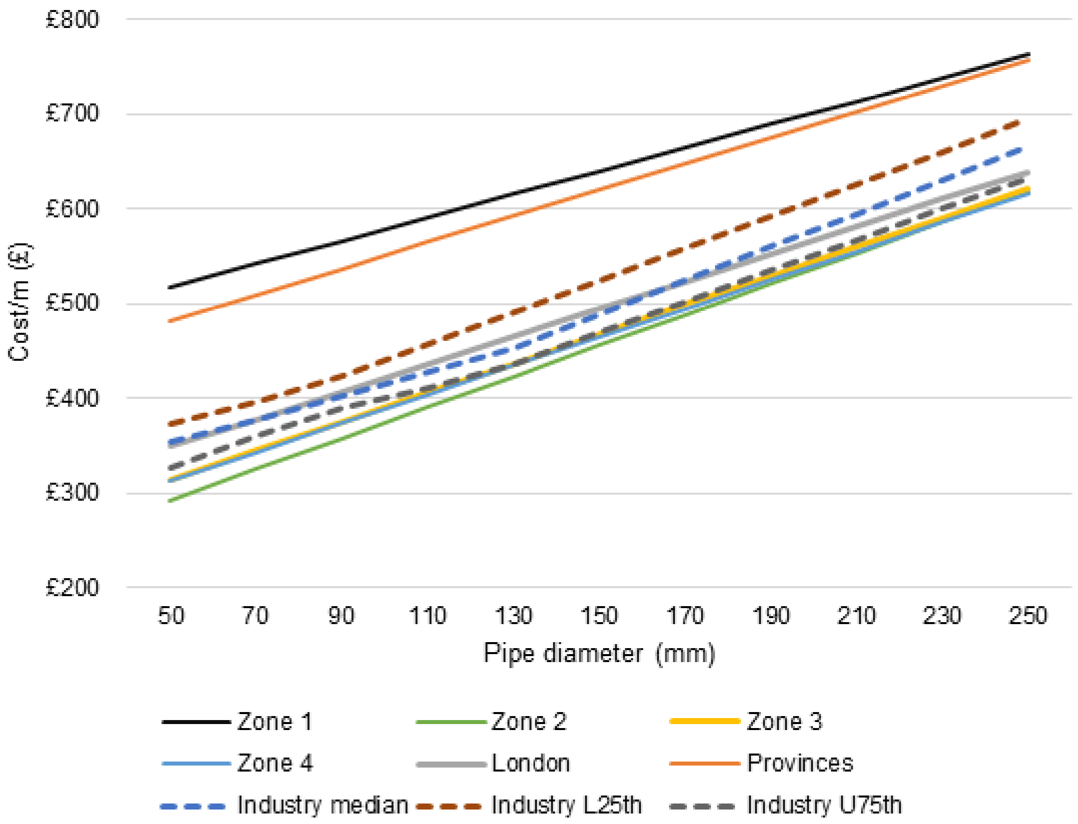
Open cut pipelaying for distribution mains

For open cut distribution mains replacement, we have compared costs over the diameter range 50mm to 250mm. Figure 7.10 shows how the TW EES dataset compares to our benchmarking corridor (as defined by the industry median and upper 75th and lower 25th percentiles).

The London cost curve in Figure 7.10 is based on the average cost from each of the 33 London boroughs and is an average 0.5% below the industry median over the entire comparative diameter range. The average cost was weighted by the length of main tagged in EES to each of the four London zones.

The cost of pipelaying in Zone 1 (inner London) is notably higher than the other zones in London and the benchmarks. Costs in the Thames Valley are also higher than the benchmarks. This is for two related reasons. For comparability with benchmarks, only cost models related to urban ground surfaces were used in the analysis (work in major and minor roads) and in Thames Valley such activity predominantly reflected the costs of pipelaying in city centres such as Reading and Slough not rural locations where costs are lower. TW's experience has been that productivity in cities such as Reading and Slough can be as slow as central London owing to restrictions placed on contractors by the local councils.

Figure 7.10: Open cut - distribution main: cost comparison of London and London zones with the water sector benchmark corridor.



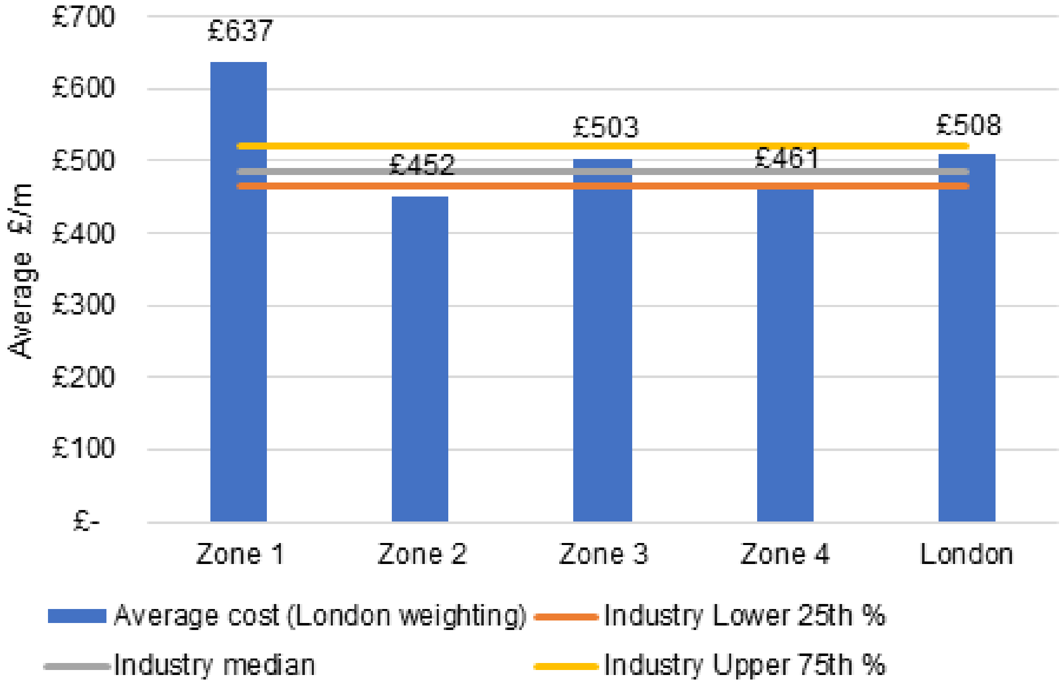
Source: TW EES dataset and MM water sector benchmark DB, costs indexed to Q4 2020

In establishing the average costs shown in Figure 7.11 overleaf, we have evaluated algorithms at diameters where the highest volumes of pipe have been replaced using the open cut method within London, as determined from the split present within the TW EES projects

The cost (per metre) of replacing distribution main (open cut method) in London on average is 5% higher than the industry median (£508 against £486).

As shown in Figure 7.11, the industry benchmarking corridor is notably tight for this pipelaying technique whereas the variation in costs across London is much wider. Average costs for London, however, are within the benchmark corridor. The cost variance within London (Zone 2 being below the lower 25th percentile and Zone 1 well above the 75th percentile) implies the factors affecting productivity in London are highly variable compared with elsewhere in the country, marking London out as different in the challenges that it presents contractors.

Figure 7.11: Open cut – distribution mains: Average cost weighted by historical volumes of pipe diameter replaced in the London area



Source: TW EES project data, costs indexed to Q4 2020.

Noting how costs are sensitive to location, we have assessed how costs vary within the zones by London borough (assumes uniform diameter volume split), with central boroughs having the highest cost (e.g., Westminster). These inner London boroughs will suffer the most significant hits to productivity due to differences in the physical nature of the streets (service density, for example), space restrictions and council constraints. TW contractor productivity data suggests a 16% productivity difference between zone 1 and zone 3 which is reflected in the output costs described above.

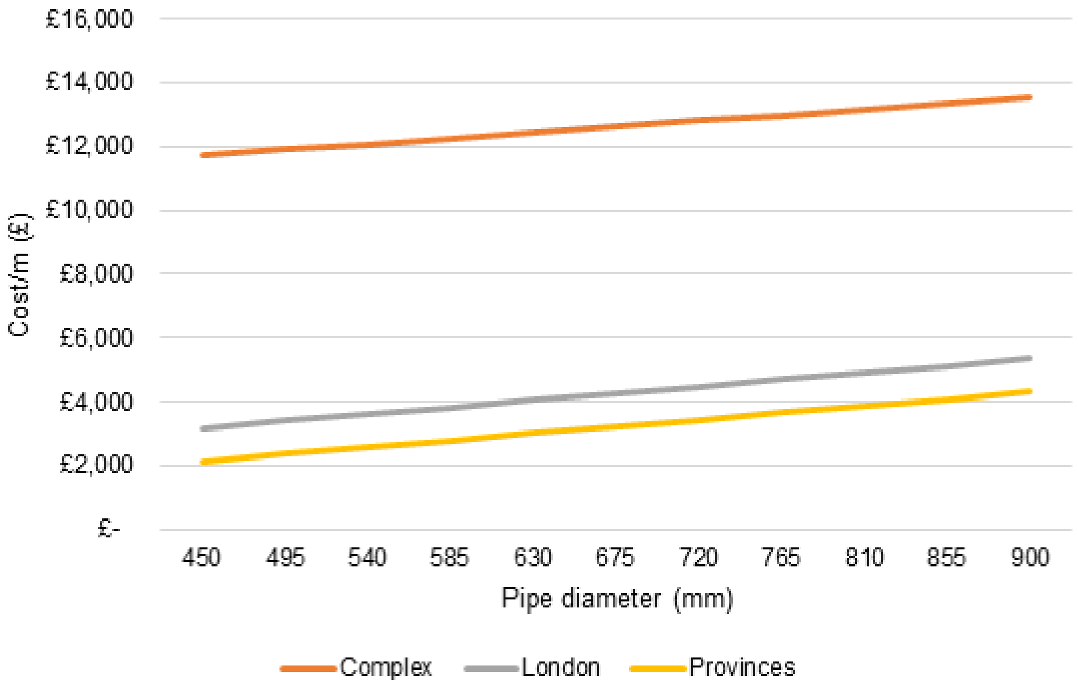
Open cut pipelaying for trunk mains

For Trunk mains replacement (open cut), we used a nominal diameter range of 450-900mm. TW supplied an overall algorithm for laying trunk main (open cut) within London, and no zonal or borough separation was provided. We also evaluated unit rates for replacement of a *complex* Trunk main. The term complex in this context is applied to activities which satisfy two out of three locational cost drivers:

2. Near tube/rail station
3. In an A road (any part of)
4. In congested streets with houses/shops on both sides.

The three algorithms produce cost curves with similar gradients over the comparable pipe diameter range. There are large cost differences between unit costs for laying trunk main in areas tagged as complex, an average of 202% and 306% above London and Thames Valley standard rates respectively for the comparable diameter range. (see Figure 7.12). This shows the sensitivity of costs for larger pipe sizes to local factors and design complexities in a highly urbanised environment.

Figure 7.12: Open cut - trunk main: comparison of TW supply areas

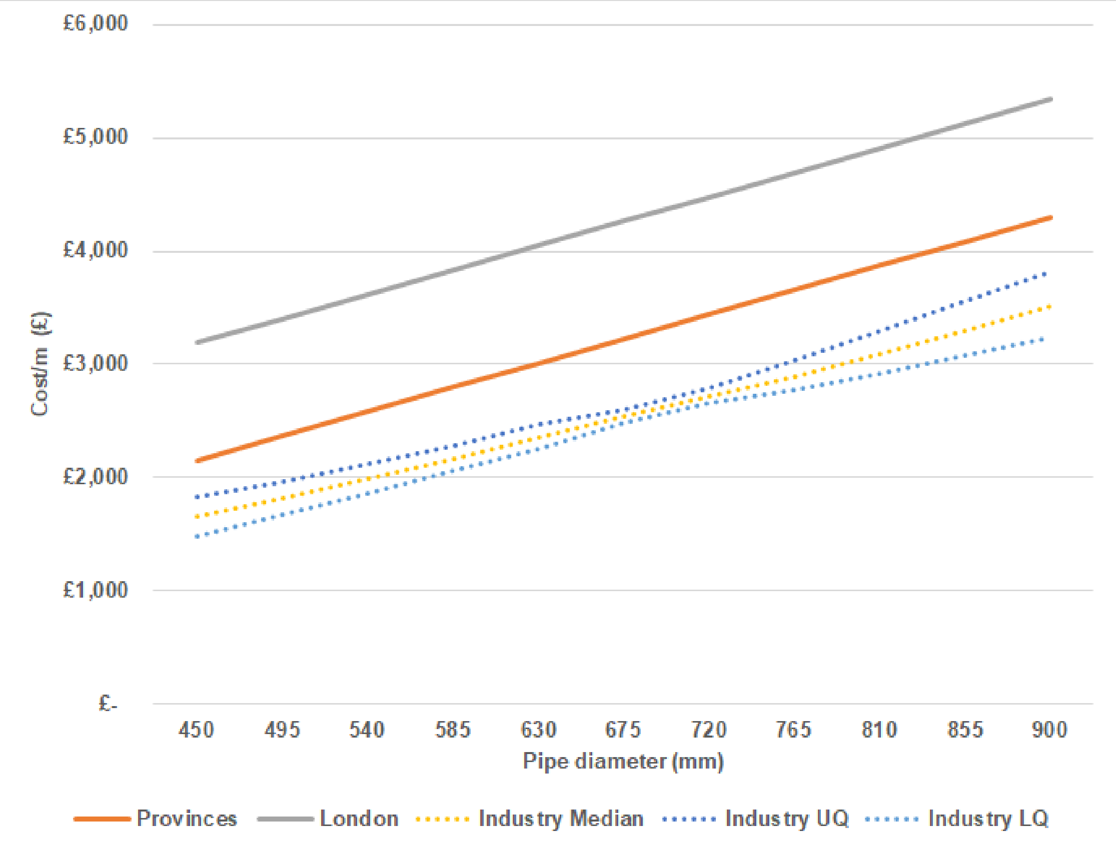


Source: TW EES dataset, costs indexed to Q4 2020.

In Figure 7.13, we compare the TW London and Thames Valley unit rates [for Trunk main replacement] with our industry benchmark corridor. This shows that costs for the Thames Valley are 20% greater than the industry upper 75th percentile and 27% above the industry median. The average cost in London is 68% above the industry median and 58% above the industry upper 75th percentile. The gradients of the cost curves for TW are very similar to the benchmarking corridor.

Compared with the analysis of open cut technique for distribution mains, the cost difference is greater. This may be because some smaller diameter work can take place in smaller roads with fewer services where productivity is better, reinstatement is less and there are fewer atypical factors driving differences in cost with benchmarks. Larger-sized pipes however are more complex, more likely to meet obstacles or need bespoke designs, likely located in bigger roads and the wider construction envelope will cause greater traffic disruption and clash with more services, reducing productivity and increasing costs.

Figure 7.13: Open cut – trunk main: cost comparison of London and the Thames Valley with the water sector benchmark corridor.



Source: TW EES dataset and MM water sector benchmark DB, costs indexed to Q4 2020.

Trenchless techniques – directional drilling and slip lining

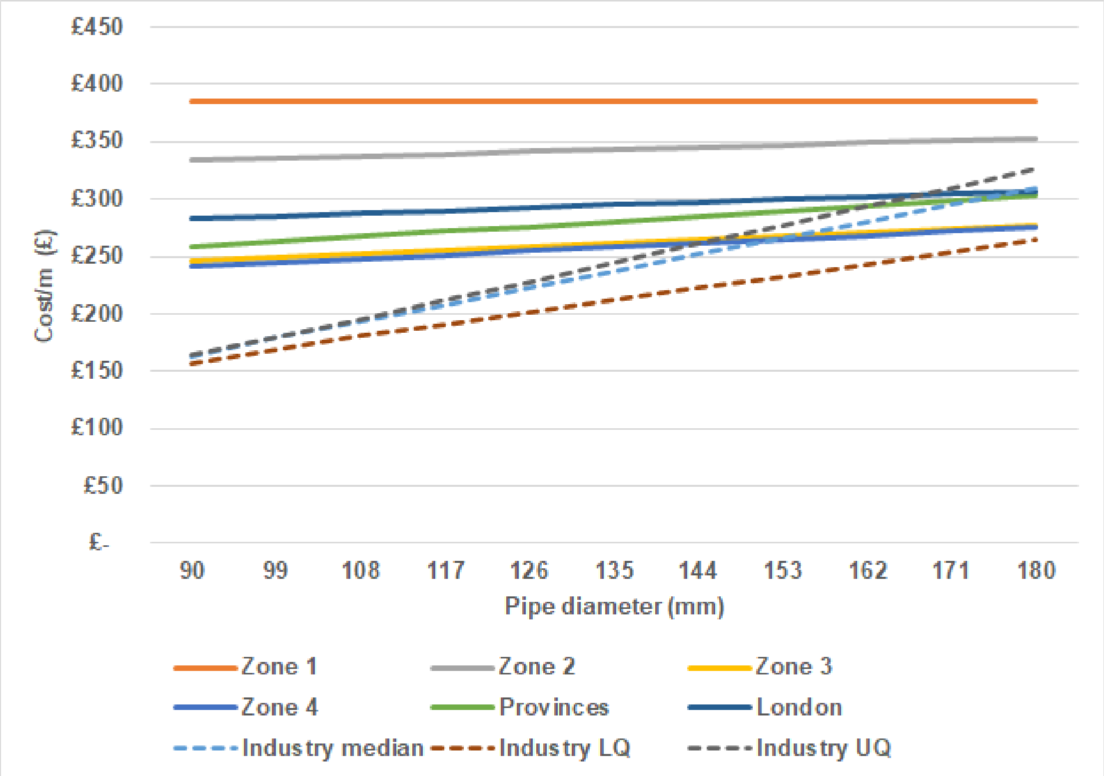
We have considered two types of trenchless pipelaying techniques for which benchmark cost data were available, directional drilling and slip-lining. Both techniques offer cost advantages over open cut in the right circumstances as they cause less disruption with lower reinstatement costs, but their use can be limited in a densely urbanised environment. A high density of house connections means opening the road at frequent intervals to replace communication pipes and service connections. This negates the advantages of trenchless techniques and forces the use of open cut. High housing density therefore limits TW's use of cheaper trenchless techniques and as a result TW does very little slip-lining. Other techniques such as pipe bursting cause too much damage to adjacent utility services.

Directional drilling is not suitable if there are many buried services to avoid but TW does use it for some new mains and to lay pipes across roads to avoid traffic disruption. Slip-lining can be a good option but it requires a small reduction in diameter to be accommodated and TW often finds that it cannot meet fire-flow standards with a reduction in diameter.

For directional drilling we used a 90mm to 180mm pipe diameter range to ensure coverage of historical TW investment while also ensuring comparability with industry data. Figure 7.14 compares costs for directional drilling in this size range with the corridor of benchmark costs. The cost curve gradients for TW have a substantially shallower gradient than the industry benchmarking corridor, being significantly more expensive per metre compared to the median at the lower end of the range (70% more for zone 1). This suggests a high fixed cost component relative to the yardstick variable and is likely linked to the high mobilisation cost within London.

On average, over the volumes within the comparable diameter range, the cost for directional drilling in London is 30% higher than the industry median and 26% higher than the industry upper 75th percentile. The average cost for the Thames Valley is 20% higher than the industry median and 17% above the industry upper 75th percentile but is lower than London Zone 1 and 2 costs.

Figure 7.14: Trenchless technique - directional drilling: cost comparison of London zones and the Thames Valley with the water sector benchmark corridor



Source: TW EES dataset and MM water sector benchmark DB, costs indexed to Q4 2020

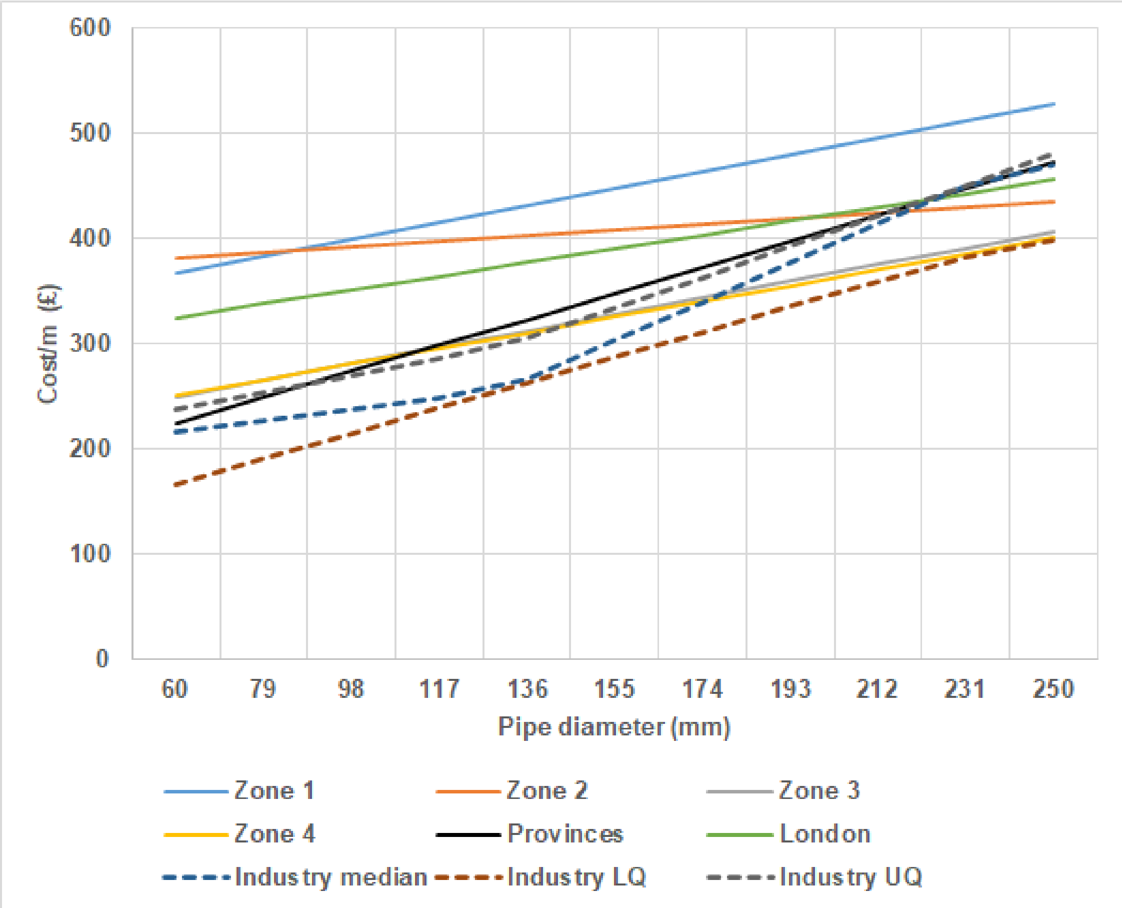
Our comparable pipe diameter range for slip-lining was 60mm to 250mm with significant portions of historical replacement work being performed on pipe diameters of 90mm, 125mm and 180mm.

In Figure 7.15, the lower end of the diameter range shows the largest cost delta for all locations so will drive up the average cost relative to the industry benchmark. With increasing diameter, the cost for the Thames Valley appears to track with the upper 75th percentile of industry data while most London areas cross over to become less expensive than the industry median at larger diameters.

The TW curves appear flatter than the industry benchmark, being another trenchless technique, this is likely resultant from a higher fixed cost associated with mobilisation relative to the cost associated with the yardstick variable. A substantially higher percentage of the overall work for slip-lining is subcontracted out to specialists, which may also affect the balance of costs.

Overall, slip-lining costs for London are 28% higher than the industry median. A stepwise reduction in the average unit rate is observed moving outward by zone, with zones 3 and 4 below the industry upper 75th percentile.

Figure 7.15: Trenchless technique - slip-lining: cost comparison of London and London zones and the water sector benchmark corridor.



Source: TW EES dataset and MM water sector benchmark DB, costs indexed to Q4 2020

Table 7.4 presents a summary of cost comparisons for open cut and trenchless techniques across the London zones and Thames Valley.

Table 7.4: Summary of average cost per metre weighted by historical values of pipe diameter in London and Thames Valley

Area	Distribution main Open cut		Distribution main Directional drill		Distribution main Slip lining		Trunk main Open cut	
Zone 1	637	31%	385	61%	431	49%		
Zone 2	452	-7%	343	44%	402	39%		
Zone 3	503	3%	261	9%	312	8%		
Zone 4	461	-5%	258	8%	310	7%		
London	508	5%	322	35%	383	33%	4263	68%
Industry median	486		239		289		2545	
Industry lower 25th %	466		213		262		2407	
Industry upper 75th %	521		246		317		2705	
Thames Valley	592	28%	277	22%	277	11%	3225	27%
Industry median	462		227		250		2545	
Industry lower 25th %	444		204		218		2407	
Industry upper 75th %	491		233		277		2705	

Source: Mott MacDonald – note %s are differences from industry median

Summarising Table 7.4 we have found that:

- There is high variation in pipe-laying costs according to the location in London that the works are carried out in, with a 40% to 50% difference between the highest and lowest costs depending on technique. This variance is higher than the benchmarks which vary by 10% to 20% (difference between 25% and 75%).
- Inner London (Zone 1) is consistently more expensive than the benchmarks across all techniques and diameters.
- The cost of laying trunk mains in London (450mm to 900mm diameter) is substantially more expensive than benchmark costs (68%), reflecting the impact of the densely urbanised environment.
- The cost of laying smaller diameter distribution mains using open cut techniques is much closer to benchmark costs and in some zones, barring Zone 1, is marginally cheaper. This suggests that the pipelaying environment in outer London for small diameter pipes is similar to that of other cities.
- Pipelaying in the Thames Valley is consistently more expensive than benchmarks, with slip lining being the closest at 11% higher and open cut the most expensive at 28%. The reasons for this are that the costs for Thames Valley predominantly reflect the costs of pipelaying in city centres such as Reading and Slough, not rural locations where costs are lower.
- Open cut for distribution mains is 33% more expensive than slip lining and 58% more expensive than directional drilling, confirming a significant cost advantage for trenchless techniques.
- Benchmark costs for trenchless techniques suggest an even bigger cost advantage over open cut (68% for slip lining and 103% for directional drilling) but we observed that London costs are higher at smaller diameters, owing to higher set-up costs, which reduces the cost advantage.
- Directional drilling is about 20% cheaper than slip-lining for both TW costs and benchmark costs, though the application of directional drilling is restricted in London owing to the presence of more buried services.

7.2.4 Limitations and sensitivities

There are a number of limitations arising from the cost comparisons reported above:

- The analysis has shown the sensitivity of costs to location at a zone level. However, the zonal averages are derived from taking weighted average costs across diameters for average costs across London boroughs within each zone. We have been unable to reliably assign borough tags to the TW EES project data to account for the substantial variation in cost by borough. A £/m benchmark with such a significant locational and size dependence necessitates the use of a locationally weighted average by borough, and this could be considered as the next phase of this work.
- The TW EES dataset is representative of historical projects, with a geographical distribution focused on historical areas of mains renewal such as the VMR programme. It is unlikely that future replacement programmes will have a similar geographic focus, and instead will target areas with high failure rates in other parts of London in boroughs with different cost rates. In interpreting the costs above, it is important to appreciate that future costs for pipelaying in different boroughs will be different.
- Construction add-ons were built into the TW EES algorithms that were available at the start of the project and reflected the additional complexities TW has previously experienced within each of the boroughs and/or zones. The comparator algorithms characterise contractor direct work only. To allow comparison, we added construction add-ons retrospectively based on percentage uplifts derived from averages of the 435 historical clean water infrastructure

projects within our database. The potential for inconsistency in how the add-ons are accounted for limits the quality of insight available. Since undertaking the work, TW has reworked the TW EES algorithms to reflect direct costs only and has new models available for construction add-ons. These would allow a better like-for-like comparison with benchmark costs but reworking our analysis would take some time.

- The construction add-ons used for this analysis reflect historic costs. There is evidence that construction add-ons have increased in AMP7 and not just for TW but for all utilities. The costs presented here are therefore suitable for benchmarking past costs but may not reflect future costs.
- In determining average costs by asset class and technique, we have made assumptions about the proportional length of each pipe diameter based on historic diameter ranges and lengths that took place in projects from the TW EES dataset. The cost comparisons presented here are valid for this historic range of diameters and might differ for future programmes if the diameter mix is significantly different.

7.3 Relative efficiency

7.3.1 Rebasing costs by location

In this section we have rebased the costs presented above to remove the effect of location from the costs to understand the efficiency of TW's costs for London and the Thames Valley compared with the benchmark corridor. We have rebased the costs derived from the EES algorithms with borough specific location factors sourced from BCIS and averaged them by zone. We have also rebased the comparator dataset so that the costs in this section represent costs without location being a factor.

For reference, regional BCIS location factors are given in Table 7.5

Table 7.5: BCIS location indices

Location	BCIS location indices
North East	0.93
North West	0.97
Yorkshire and the Humber	0.94
East Midlands	1.05
West Midlands	0.96
East of England	1.01
London (inner boroughs)	1.28
London (outer boroughs)	1.21
South East	1.08
South West	1.02
Wales	0.94
Scotland	0.91
Northern Ireland	0.56
Islands	1.09

Source: Building Cost Information Service 2021. Based on tender price studies, UK mean = 100

The published location factors summarised in Table 7.5 illustrate a clear price difference between work carried out within the London area and the UK average, 28% and 21% higher for inner and outer boroughs, respectively. Closer inspection at local council granularity reveals that except for Guernsey, the highest 20 council boroughs to build in are London boroughs, with Kensington and Chelsea topping the list at 34% higher than the UK average.

Given the higher BCIS location indices for London compared with elsewhere in the country, the effect of rebasing is to reduce TW's EES costs and to increase benchmark corridor costs.

7.3.2 Relative efficiencies

Table 7.6 presents a summary of cost comparisons for open cut and trenchless techniques across the London zones and Thames Valley after the costs have been adjusted for location using BCIS indices.

Table 7.6: Summary of location-adjusted, average costs per metre weighted by historical values of pipe diameter in London and Thames Valley

Area	Distribution main Open cut		Distribution main Directional drill		Distribution main Slip lining		Trunk main Open cut	
Zone 1	495	2%	299	25%	335	16%		
Zone 2	359	-26%	272	14%	320	11%		
Zone 3	406	-16%	211	-12%	252	-13%		
Zone 4	383	-21%	215	-10%	258	-11%		
London	403	-17%	256	7%	304	5%	3438	35%
Industry median	492		231		304		2567	
Industry lower 25th %	458		204		274		2383	
Industry upper 75th %	532		248		324		2756	
Thames Valley	548	15%	256	17%	257	-4%	2986	17%
Industry median	475		219		268		2567	
Industry lower 25th %	443		195		231		2383	
Industry upper 75th %	506		235		285		2756	

Source: Mott MacDonald – note %s are differences from industry median

Summarising Table 7.6 we have found that:

- TW is relatively efficient for distribution mains open cut in London by about 17%.
- There is still a high variance in costs across London, but most zones are more efficient than the benchmarks for open cut, except for Zone 1.
- Pipelaying in the Thames Valley is about 15% less efficient than the benchmarks for open cut and directional drilling, but is relatively efficient for slip lining.
- Directional drilling and slip lining are relatively inefficient in London compared with the benchmarks by about 5%.
- Trunk mains are relatively inefficient by 35% in London and 17% in the Thames Valley, reflecting the more complex urban environment for large diameter pipe laying in London. Thames Valley costs predominantly reflect city centre costs in cities such as Reading and Slough rather than rural costs, part explaining why they are higher than benchmarks.

7.4 Factors impacting costs

It is evident from the comparative cost analysis in section 7.2.3, that the cost of laying pipes in London varies considerably by zone but that it is generally higher on average than benchmark costs by 5% to 30% depending on the techniques deployed. Costs are much higher in central London and for large diameter pipes such as trunk mains. This is expected given the uniquely urbanised environment in London and congested services, forcing the use of more costly open cut techniques.

When the costs are adjusted for location to test whether TW's costs are efficient, (section 7.3.2) we find that costs for distribution mains in London are broadly efficient across the techniques, excepting central London, but significant cost differences remain for large diameter trunk mains, which we believe relate to the less productive working environment in London rather than inefficiency.

Our separate cost report discusses the factors impacting costs in detail[28] so a summary of our findings is presented here. Building on the work done in 2019 by Nera and Arcadis[29], which examined the impact of the London environment on the costs of all utilities working in London, we summarise our findings on the factors impacting costs as follows:

a. Nature of the streets

The uniquely urbanised streets of London are a primary cause of poor productivity for pipe laying, not only for TW but for other utilities. The following factors have been evidenced:

- There is a greater prevalence of composite road structures with bound concrete layers in London, increasing excavation and reinstatement costs.
- There is a higher density of services and buried utilities, resulting in loss of productivity.
- The higher service density results from London having the highest housing density in the UK leading to high service density in adjoining streets.
- TW data shows that productivity in areas such as Westminster fall owing to trenches having to be hand dug to avoid striking fibreoptic cables and other key services.
- TW data shows productivity reducing as work moves towards inner London. Productivity in metres/gang/week decreases from 57m in Zone 3 to 33m in Zone 2 and 31m in Zone 1.
- Productivity data for other utilities shows the same trend with work in inner London being far slower than outer London which is slower than the East of England.
- Evidence from the gas sector shows a difference of 24% between the cost of pipe replacement work in London compared with the national average[29].

These factors help explain the cost delta revealed by the cost benchmarking in section 7.2.2.

b. Permitting and traffic management

Permitting and traffic management factors are the costs utility companies incur to conduct and plan street works. This can cover a range of costs payable to both TfL and the local borough Highways Authority covering permit costs, parking bay suspensions and lane rentals (carriageways, bus routes and cycle lanes).

- Permitting is more complex and costly in London than other parts of the country, each borough having its own permitting requirements and fees and additional authorisation is also required from TfL. These result in additional client and contractor add-on costs.
- 78% of the population served by TW are covered by parking bay suspension schemes compared with 50% for England and Wales. Parking bay suspensions temporarily transfer the rights to park from the holder to the utility to enable work to be carried out and incurs a fee. Fees for parking bay suspensions vary widely but are much higher for London than other cities.
- Lane rental fees are applied more widely in London than elsewhere in the country. TfL oversees control of London and 56% of its network is covered by a lane rental scheme.
- The costs associated with carriageway suspensions are substantially higher within London than other cities in the UK. For example, a five-day carriageway suspension costs £8,333 in London compared with £1,169 for Birmingham.

[28] Mott MacDonald, London water improvement project - Task J comparative cost analysis of infrastructure mains replacement

[29] Nera and Arcadis, Understanding the Baseline Level of Efficiency in London Prepared for UK Power Networks, Thames Water, Scotia Gas Networks and Cadent Gas, 2019

The impact of the higher permitting and traffic management costs in London is to increase client and contractor add-on costs for pipelaying work compared with other parts of the country.

c. Traffic congestion and charges

Traffic congestion is high in London resulting in lower traffic speeds, affecting the efficient transport of labour and materials to and from site. Average speeds in London are half those in the rest of the country (11mph compared with 25mph) and are even slower in inner London (8mph). In addition, congestion charges add directly to contractors' costs. Until recently these were unique to London, but other cities are now starting to introduce them as well (for example, Birmingham from June 2021).

d. Labour costs

A high proportion of utility company costs are wages, either paid to their own staff or to contractors and their sub-contractors. London is known to have a labour cost premium and the physical nature of the infrastructure assets means that work must be performed in-situ.

The ONS provides data on the median gross earnings in the construction sector for the different regions of the country. This is shown Table 7.7.

Table 7.7: Geographical comparison of median gross earnings for UK construction

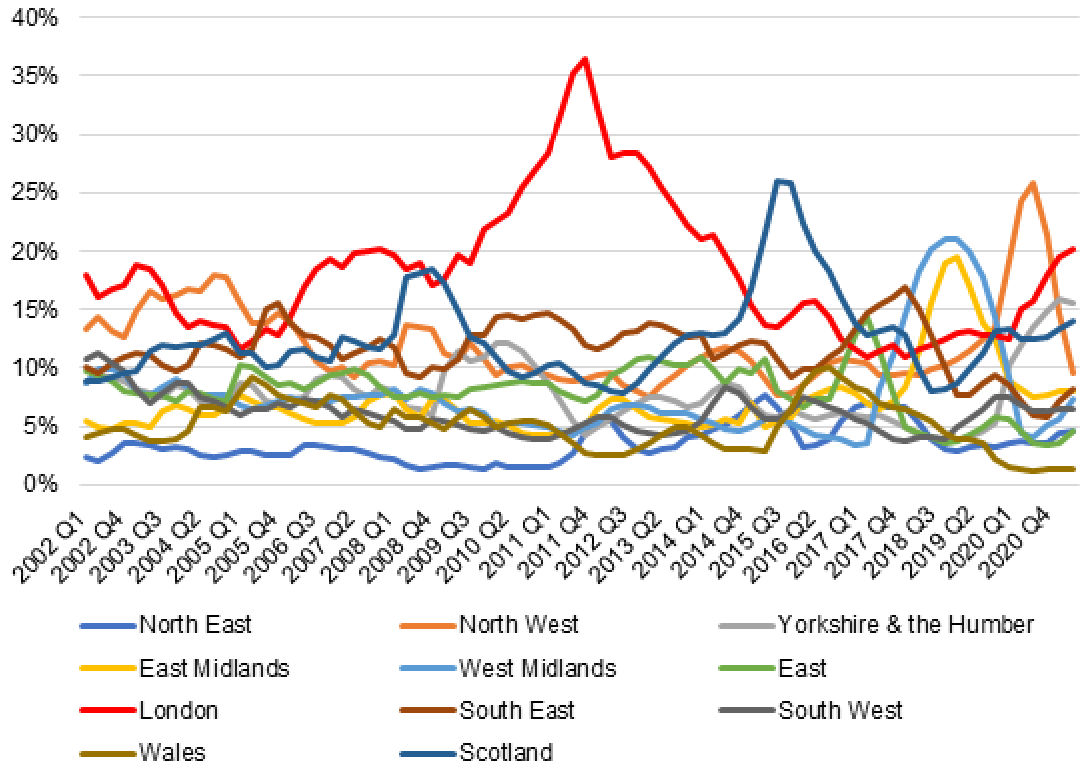
Location	Median Gross Weekly Wage (Construction)	Variance to UK Average (Construction
London	687.8	23.37%
West Midlands	574.9	3.12%
South East	574.9	3.12%
Yorkshire and The Humber	569.6	2.17%
United Kingdom	557.5	0.00%
East Midlands	536.6	-3.75%
East	529.9	-4.95%
North West	515.3	-7.57%
Scotland	512.6	-8.05%
Wales	511.4	-8.27%
South West	504	-9.60%
North East	472.8	-15.19%

Source: (Office for National Statistics)

The table shows that four regions have above national average wages, but only London is significantly above the national average, at 23% more. This will have an obvious effect on the cost to complete a project in London compared with the rest of the country. This also exacerbates any productivity challenges caused by the factors described above, as the main effect of poor productivity is to increase the hours per unit output and therefore the wage bill.

Another factor driving increased labour costs in London is demand for construction workers. London has consistently attracted the greatest share of UK construction work which has increased competition for labour, driving up costs in the area. Figure 7.16 shows how the share of UK construction output has varied by region in the last twenty years, with massive construction developments such as the London Olympics clearly visible.

Figure 7.16: Output in the construction industry



Source: (Office for National Statistics)

All the factors described above ultimately impact TW's productivity and costs; from the additional administrational planning required before breaking ground in London, to the additional level of resource required to break through and reinstate the sublayers of London's streets, the dense utility services slowing productivity and the higher cost of wages all explain the higher costs TW incurs compared with the benchmarks (see Table 7.4).

Some of these additional costs are accounted for when costs are adjusted for location, as the BCIS location indices, being based on tendered prices, indirectly account for some of these factors such as wage effects. This explains why some of TW's location-adjusted pipelaying costs for smaller diameter distribution mains appear comparatively efficient compared with benchmarks. The BCIS location factors, applied at a borough level, effectively capture and largely explain the London factors impacting costs, excepting inner London (see Table 7.6).

This is not the case for trunk mains, where the larger diameter pipes, greater depths and wider construction envelope exacerbate all the factors impacting costs in London leading to higher comparative unit costs overall. The BCIS location factors, being for general building works, are insufficient alone to capture the complexities and site-specific factors impacting deep excavation work in London. In examining TW productivity data, we were unable to identify the specific factors impacting costs for trunk mains or to compare these with similar information associated with benchmarks to quantify the effects. We recommend this as an area for future focus for capturing cost and productivity data.

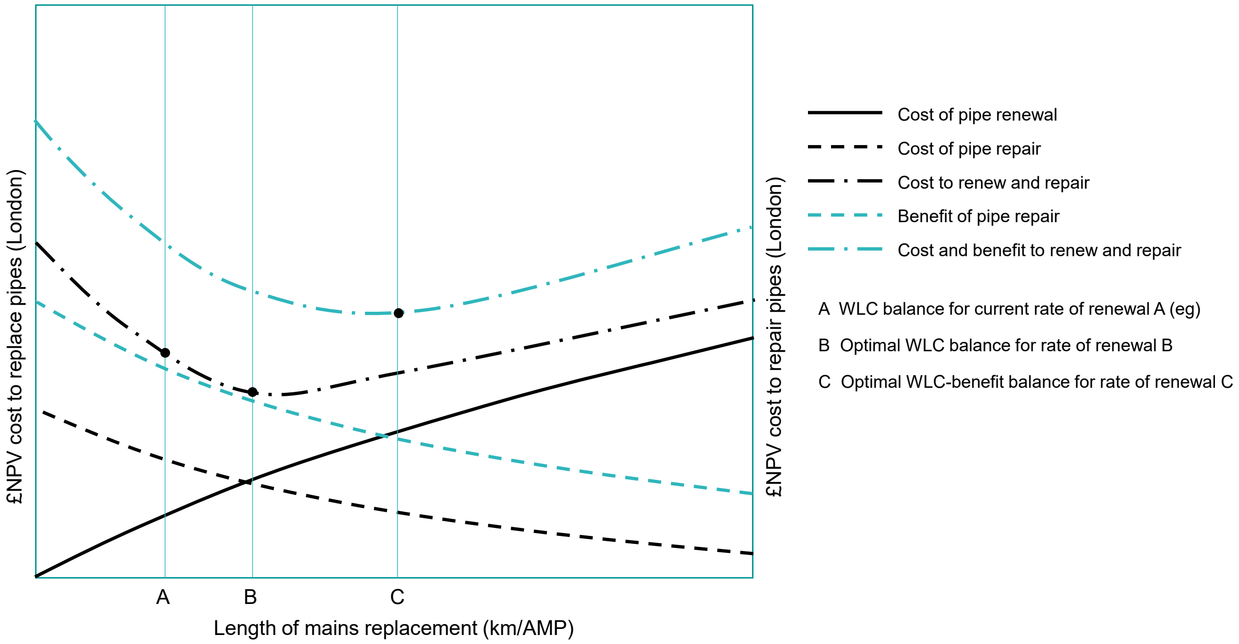
7.5 Achieving efficient whole-life costs

TW is currently spending more Totex on finding and fixing pipes and replacing pipes to control leakage and manage bursts than any other company in England and Wales, as shown in Figure 7.6. This results from the poor condition of the network and higher costs of doing work in

London as shown in section 7.2 and is not the result of inefficiency in the delivery of those tasks as shown in section 7.3. Although there is always room for improvement in efficiency through innovation, there is a wider question about whether the current situation is efficient or sustainable in the long term and whether, from a consideration of whole-life costs, a rebalancing of capital and operational activities would effect an overall reduction in costs and represent better value for customers and TW in the long term.

Figure 7.17 illustrates the options conceptually.

Figure 7.17: Balancing mains replacement and repair: Whole-life cost benefit concepts



Source: Mott MacDonald. For illustrative purposes only. The curves are estimated and not derived from real data.

On the basis that the more pipes in London's water network that are replaced, (the cost of which is represented by the solid black line in Figure 7.17) the more bursts and leakage will reduce (the falling cost of which is represented by the black hatched line), then there is an optimum rate of replacement (B) to minimise overall costs (represented by the black chain-dot line). In addition, if the benefits from improved service, reduced leakage and reduced disruption to London's streets from fixing leaks are accounted for (the blue hatched line) then there is another optimum amount of replacement (C) that minimises costs but maximises benefits. These can be compared with the current balance of replacement rates and costs (say A) to show whether the current situation with London's water network is uneconomic and replacement rates should increase.

The tool that TW uses to undertake this type of analysis is AIM for distribution mains, which accounts for asset deterioration and many of the other factors described in chapter 4. TW has undertaken some analyses using AIM and has made the following initial findings:

- Firstly, the results are sensitive to the time horizon used, with different results shown for a 20 year, 50 year or 100 year timescale.
- The results are also sensitive to whether you consider costs only or whether you include benefits (i.e. the difference between point B and point C in Figure 7.17.
- If you only consider direct costs of repair, then AIM indicates that TW is already replacing too many pipes, but if you include the value of the benefits in terms of reduced leakage and other service benefits, then AIM indicates that TW should be replacing more of its network.

- There is therefore a big difference in replacement rates between a whole-life cost analysis and a whole-life cost-benefit analysis and results are therefore sensitive to the benefit valuations used.
- To illustrate, if you maximise the whole-life cost net benefits, then AIM's optimum solution over a 100-year horizon is to replace the existing distribution mains nearly twice (190%). However, if you minimise whole-life costs and ignore benefits, then AIM only replaces 7.5% of the distribution mains over 100 years.
- If you constrain AIM to hold bursts steady, then AIM's optimum solution is to replace 53% of distribution mains across Thames Water over 100 years. This is equivalent to 150 km/year or 750 km/AMP.
- If you constrain AIM to hold bursts and leakage steady, (a credible baseline scenario) then AIM's optimum solution is to replace 73% of distribution mains over 100 years. This is equivalent to 203 km/year or 1015km per AMP.
- If you replace more distribution mains in the early AMPs than later AMPs and then maximise whole-life cost net benefits within defined length constraints, early AIM results show that more overall benefit can be delivered than the baseline scenario of holding bursts and leakage steady. Further scenario testing is ongoing to determine the best profile of mains replacement to maximise whole-life cost net benefits.

These are indicative results based on an updated AIM model. TW is working with ICS, the authors of AIM, to undertake further scenario modelling to optimise distribution mains replacement to inform its long-term strategy.

To conclude, given the high costs that TW is incurring to manage its water network, there is a case to consider rebalancing its capital replacement of pipes and its find and fix activity on a whole-life cost benefit basis to establish a more sustainable and economic basis to manage network performance and costs in the long-term. Early indications are that mains replacement should increase from the present 650 km per AMP, previously assessed to be sufficient only to offset deterioration. Scenario planning to determine the amount to increase it by to optimise whole-life cost benefits is still ongoing, but early results suggest that it should exceed 1000 km per AMP, especially in the period from now to 2050. Apart from improving the balance of costs and benefits, it will support TW's and industry's commitment to reduce leakage by 50% by 2050.

At the time of writing this report, TW was still working to refine this analysis, but this is a level of mains replacement that triangulates reasonably with other assessments, including analysis of pipe sample data and evaluation of the benefits from the VMR programme (see section 5.2).

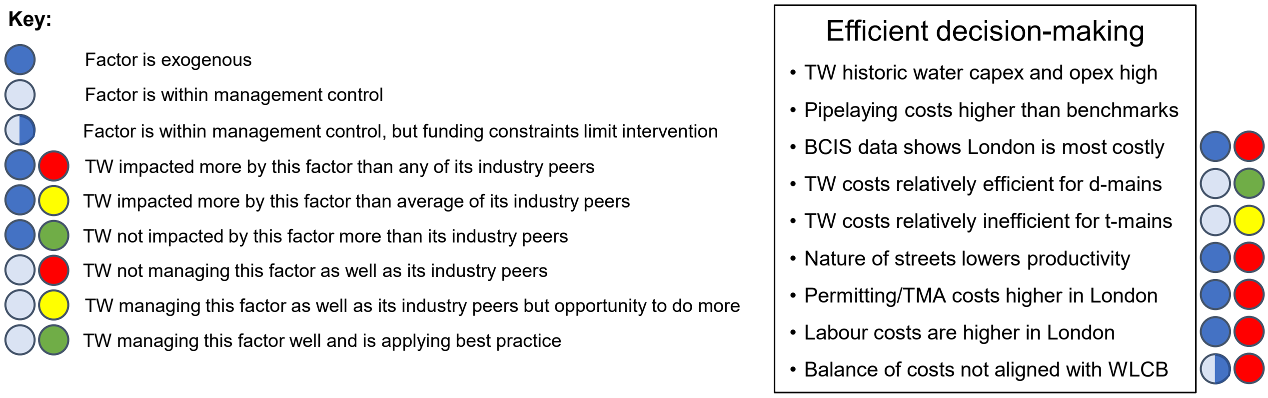
7.6 Conclusions on cost of managing the network

In this section, we draw some conclusions on the cost of managing London's water supply network and the principal reasons why TW's water infrastructure costs are higher than any other water company measured by length of water main. We consider the factors affecting the cost of laying pipes in the London area and we consider how well TW manages to deliver work efficiently compared with benchmark companies, allowing for regional differences in cost. We also make recommendations on improvements in cost capture to inform how best to mitigate upward cost pressures.

1. Factors impacting the cost of managing London's water network

Figure 7.18 summarises the key factors impacting the cost of managing London's water network, the extent to which they are exogenous or within management control and the severity of their impact compared with water industry peers or TW's success in managing them.

Figure 7.18: Key factors impacting cost of managing London's network



Source: Mott MacDonald

The first two points under efficient decision-making are not factors but points of fact. TW's capital and operating costs are higher than its industry peers and one aspect of this that we cover in this chapter is that pipelaying costs are higher in London than industry benchmarks by 5% to 30% for distribution mains and about 70% for trunk mains, though there is high variation in costs across London. The poor comparative health of the network, as described in Chapter 4 requires the highest level of repair activity in the industry to keep leakage under control, leading to higher operational costs.

The main factors impacting the cost of capital works in London are those associated with the highly urbanised environment and the competition for labour in the nation's capital, which we describe in section 7.4. In Figure 7.18 we have summarised these as:

- The nature of the streets, such as the prevalence of concrete bound layers increasing reinstatement costs and the high density of buried services
- The high permitting and traffic management costs, and
- High labour costs in London.

These are exogenous factors impacting the productivity and costs of TW's pipelaying activities and there is evidence to show that their impact is more severe in London than elsewhere in the country. There is also evidence that some of these factors affect inner London more than outer London and that trunk mains with their deeper excavation and wider construction envelope, are more affected by them than smaller diameter distribution mains.

When TW costs and benchmark costs are adjusted for location using the BCIS location indices, (applied by borough), then TW's costs for distribution mains are broadly efficient compared with benchmarks. There is some variation by technique (open cut being more efficient than benchmarks and trenchless techniques being slightly less efficient than benchmarks), and by zone across London, with inner London appearing less efficient than outer London. Trunk mains, however, appear to be inefficient compared with benchmarks by about 35% in London, even after adjustment for location.

Our explanation for this is that for smaller diameter distribution mains, the BCIS location indices, being based on tendered prices, indirectly account for some of the London factors listed above such as the nature of the streets and wage effects. The BCIS location indices effectively capture and largely explain the London factors impacting costs, excepting inner London (see Table 7.6).

This is not the case for trunk mains, where the larger diameter pipes, greater depths and wider construction envelope exacerbate all the factors impacting costs in London leading to higher comparative unit costs overall. The BCIS location factors, being for general building works, are insufficient alone to capture the complexities and site-specific factors impacting deep excavation work in London.

In examining TW productivity data, we were unable to identify the specific factors impacting costs for trunk mains or to compare these with similar information associated with benchmarks to quantify the effects. We recommend this as an area for future focus for capturing cost and productivity data so that TW can better explain its trunk main costs and demonstrate that they are efficient.

Finally, it is clear that TW cannot continue to incur the highest capital and operational costs in the sector to manage London's poor condition network, even if the money is spent efficiently as our analysis shows. If TW could replace more of its deteriorated cast iron network with more resilient PE pipes, then this would both improve service for customers, reduce leakage **and** reduce operating costs to more sustainable levels. However, replacing pipes in London is expensive, as explained above, and although TW has wanted to replace more pipes in the past, it has been constrained by affordability limits and the need to support other investment areas within overall customer bills.

A whole-life cost benefit analysis of London's water network has shown that the current balance of capital and operational costs is uneconomic in the long term and that to reduce operating costs and maximise the benefits from improved service, TW needs to increase the level of mains replacement. Scenario planning to determine the amount to increase it by to optimise whole-life cost benefits is still ongoing, but early results suggest that it should exceed 1,000 km/AMP, especially in the period from now to 2050. This is an increase on the 650 km/AMP that TW has targeted in recent periods to offset deterioration. TW is undertaking further work to refine this analysis.

2. Mitigating the factors impacting the cost of managing London's water network

One cannot change the nature of London's streets or the higher cost of labour in London, but there are measures that can be taken now to limit their effect on costs:

- Analysis of TW costs by technique shows there to be a 33% cost advantage for slip lining over open cut and a 58% cost advantage for directional drilling. A cost-efficient programme of mains rehabilitation needs to maximise opportunities for trenchless techniques where they can be applied, accepting that presence of densely packed services limits the use of directional drilling and pipe-bursting and a high density of house connections can make open cut the only viable option.
- Aim to reduce the length of pipe to be replaced by rationalising the network in the DMAs that TW selects to renew.
- Scale and package the work to reduce construction add-ons. There is evidence that construction add-ons were lower in AMP4 when TW implemented a large programme of renewals, focused on whole-DMA replacement of pipes, whereas construction add-ons for localised replacement work in AMP5 and AMP6 were higher.
- Co-ordinate the work with other utilities to limit the impact on London's traffic by closing off streets once for multiple utility replacement work, rather than undertaking the work sequentially. This also reduces permitting costs. TW has a stakeholder management tool, 'TW Connect' to facilitate this coordination.
- The gas sector has a requirement to replace its cast iron pipes by 2032, after which there will be restrictions on other utilities breaking tarmac in the carriageways that they have just reinstated. Coordination with the gas sector is therefore essential to ensure that TW does not meet such restrictions when it wants to replace its own pipes.

- Engage with the supply chain and keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages

Other measures to mitigate the factors impacting costs in London are to explore cost-effective ways of improving performance without replacing pipes where these give a sustained benefit. These may include:

- Further use of pressure management where opportunities arise, though we acknowledge that future pressure management opportunities will be more limited based on the extent of pressure management already adopted.
- Network calming measures, including improved control of transients.

3. Priority actions for improvements in managing the cost of London's water network

We have identified the following priority actions with respect to managing the cost of London's network:

a. Improving knowledge of costs

- Re-instigate the capture of productivity data and information on the London factors that impact productivity to directly link the factors to cost information.
- Undertake a more in-depth analysis of construction add-on costs to separate client and contractor add-ons and model the effects of project size, locational complexities at a borough level, construction techniques and delivery model.
- Focus attention on the London factors driving the cost of trunk-mains to explain the difference between TW's trunk-main costs and benchmarks and demonstrate efficiency. Better understanding the factors driving cost may also allow them to be better managed.
- Benchmark TW's planned network interventions with consideration of pipe diameter, length of replacement, mix of techniques and location.

b. Achieving inter-generational equity

- To ensure that expensive but essential work to renew water mains are not deferred unduly to become a burden for future generations of customers, assess the optimum blend of capital and operational activities and costs to maximise whole-life-cost benefits (WLCBs) to achieve long term improvements in service and leakage performance. TW has commenced this work, some initial results from which are reported in section 7.5.
- Ensure that rates of renewal in short-term plans are aligned with this WLCB assessment.

c. Mitigating cost pressures

- Ensure that the following cost-mitigating measures for mains rehabilitation are incorporated into the investment delivery process:
  - maximise opportunities for trenchless techniques where feasible
  - minimise the length of pipe to be renovated by rationalising the network in target DMAs
  - scale and package the work to reduce construction add-ons
  - co-ordinate the work with other utilities to minimise disruption and reduce permitting costs
  - Keep emerging technologies under review and where appropriate adopt innovative renovation techniques where these offer resilient solutions at lower whole-life cost.
- Maximise opportunities for cost-effective ways of improving performance without replacing pipes where these give a sustained benefit.

d. Driving innovation

In the future, TW faces a big pipe renovation challenge across London that is not fundable within current historical levels of expenditure unless big changes can be made to the unit costs of replacement. Other companies will face the same challenge, but perhaps TW has reached this point sooner because its network is older, more deteriorated, and further along the bathtub curve. We therefore recommend that TW drives the research agenda to:

- Collaborate with suitable partners to support research into novel forms of condition assessment, pipe repair and pipe renovation that offer potential cost savings in the face of London's particular challenges. These may include in-pipe robotics and novel lining techniques to minimise the requirement for excavation and reinstatement of carriageways.
- Uses its pipe test rig at Kempton as a potential research centre.
- Pilot the efficacy, costs, and benefits of new techniques that will deliver benefits in AMP8 and beyond.

8 Comparisons with global practice

Chapter summary

In this chapter we review global practices with respect to water infrastructure management and compare them with those adopted on London's water network to identify any learning of value to the long-term strategy for London's network. We review data capture, analytical techniques and network design and operation.

Some of the key discussion points presented in this chapter are briefly summarised below:

- Data capture and inspection – TW uses appropriate technologies to inspect its assets. The DMA fingerprinting tool is a significant step towards an integrated approach as it brings together leakage, burst and supply interruptions data with customer contacts data.
- Analytical approaches – The distribution mains AIM tool is mature and well validated, and it is used by TW to optimise investment in the distribution system. The trunk mains AIM tool is newer and is mainly used to identify and quantify risks for each pipe length. TW only updates and runs AIM to support 5-year business plans, which prevents using it for short term planning. With the use of its AIM models, complemented by the DMA fingerprinting tool, TW is well aligned with industry good practice.
- Network design and operational policies – TW's monitoring of trunk mains is seen as industry leading, and it has recently upgraded its SCADA system to an industry standard software, which is now one of the largest of its type in Europe. The design practices for new pipelines are aligned with industry standards, and TW has been open to trialling new technologies with a cautious approach. TW would benefit from simplified DMA arrangements and better understanding of the network through detailed hydraulic models which feed into understanding of risk.
- Risk mitigation for trunk mains – TW uses risk-based asset maintenance planning within the trunk mains AIM model by analysing the probability and the consequence of failure. Its consequence modelling is well advanced and considered industry leading. While probability and deterioration modelling are aligned with industry practices, and is continually improving, TW recognise that the accuracy is not yet sufficient on its own to direct cost-effective investment targeting on a metre by metre basis.

Recommendations

We have identified the following recommendations from our review.

- Data capture and inspection – TW could move towards a more proactive approach for capturing asset data, especially for distribution mains. We also recommend that further work is carried out on integrating databases to increase the efficiency of data processing.
- Analytical approaches – We support TW's plans to increase meter penetration in London. Further to running AIM more frequently, we have made recommendations in previous chapters to assess additional factors causing pipe failures separately.
- Network design and operational policies – We recommend reducing reliance on pumps where possible and reconfiguring DMA to reduce size and complexity. We support TW's plans to update and increase its model coverage in AMP7 and recommend reviewing how hydraulic models can provide live information to Operations. We also recommend increased renewal rates for the next few AMPs to restore the asset base to a condition that will fulfil customer and regulatory expectations.

8.1 Introduction

The purpose of this chapter is to:

1. Review global practice in the management of water infrastructure assets
2. Compare it with practices adopted in the management of London's network
3. Identify any learning of value to this project and the strategy for London's water network.

We have reviewed a range of good practice documents, guidelines, and standards to identify options for continuous improvement. The documents reviewed included manuals published by the American Water Works Association (AWWA); Construction Industry Research and Information Association (CIRIA) guidance notes; HDR's condition assessment and rehabilitation guide, Twort's Water Supply and Water Research Centre (WRc) manuals.

This is by no means an exhaustive review of the global practices; instead, it aims to provide useful suggestions for consideration. It should be noted that some successful practices from around the world will be less applicable for the London water network owing to differences in environmental factors, regulatory context, and available materials, technologies and skill sets in the supply chain.

8.2 Data capture and inspection

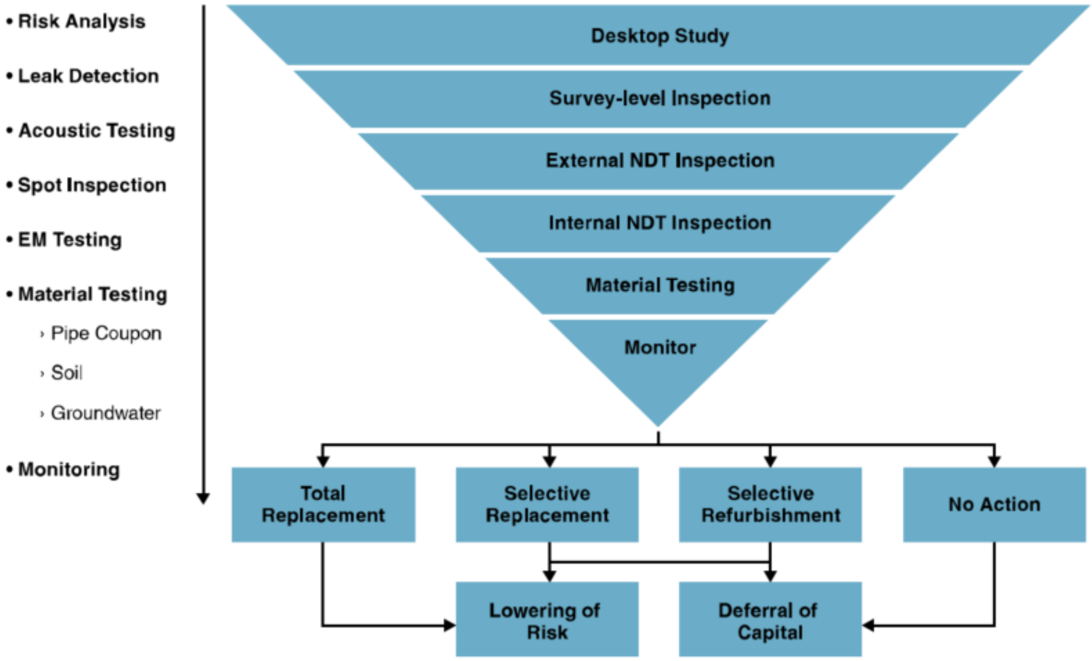
Globally large sections of treated water distribution networks are reaching the end of their serviceable life. To improve operational and financial efficiency and reduce leakage, water companies focus on better understanding and managing the health of their underground assets. Collecting and managing data relating to existing assets, their function, performance, and condition is a major and costly task for any water company.

8.2.1 Capturing asset condition

Condition assessment planning and budgeting is increasingly becoming an integral component of master planning for water companies. To formulate a systematic programme of condition assessment, methods are developed to determine what amount and form of assessment is needed to provide the confidence required to meet the required service levels and to support the capital investment and repair programmes.

One practice in use today is the application of the inverted condition assessment pyramid to make decisions about specific assets or cohorts (see Figure 8.1). The process is aimed at mitigating risk and maximising the value of capital investments. It starts with a desktop study and only continues far enough down the pyramid until sufficient information is obtained for a given asset (it may also not be necessary to follow all the steps after the initial desktop assessment of risks). The available inspection technologies to support this process are listed in Appendix C.1.

Figure 8.1: Progressive condition assessment and resulting actions



Source: Condition Assessment of Water Mains, M77 AWWA Manual

With such an approach, the water company needs to consider whether condition assessment on samples of assets provides sufficient information to enable a cost-effective programme to be developed for the whole population of assets. The linkage between condition assessment and master planning continues to be the subject of additional research to formulate a generalised roadmap for utilities.

In addition to the planned inspections, other opportunities often arise to observe a pipe. Since water mains are usually not easily accessed, these opportunities[30] are usually considered for data capture:

- Repairs – data should be gathered regarding the mode of failure, the properties of materials and the condition of the pipe, including photos and coordinates to be recorded.
- Service taps – when pipes are tapped for new service connections, not only is the pipe observed, but coupon samples are often taken, which can be tested.
- Failure analyses – unexpected or unexplained failures often merit a ‘forensic’ assessment involving laboratory testing of the failed material and a review of the design and construction records of the pipe.
- Service interruptions – pipes that are depressurised and dewatered for repairs, new connections or diversions offer the opportunity for interior inspection.

These opportunistic assessments can cost a fraction of other assessments owing to the advantage of traffic management, excavation, permits and other logistics already being in place. The challenge is to interpret the results with caution (the results may not be representative of a larger cohort due to the localised nature of the assessment and any special conditions that may exist).

[30] Condition Assessment of Water Mains, M77 AWWA Manual

The data collected through the available technologies is used for assessing risk and to support the capital investment and repair programmes; therefore, it is important that it is 'cleaned' and recorded in a structured manner easily available for future use.

Comparison with TW practice

We discuss current practice in the capture of asset health data on pipes and joints in Chapter 4 (sections 4.4 and 4.5).

TW uses several of the available technologies listed in Appendix C:

- Acoustic technologies (Sahara, Syrinix, Hydroguard)
- Ultrasonic method (trunk mains inspections)
- Sampling of pipes (trunk mains inspections and distribution mains up to the end of AMP5)
- Soil corrosivity surveys (trunk mains inspections)
- Magnetic flux leakage – currently not in use as a standard practice, however, the method was used in the past, and TW is re-introducing this method for the trunk mains inspections (to be in use from 2021).

Technologies currently not in use by TW:

- Broadband electromagnetic – the method shows potential for identifying leaks at joints, however it has not been specifically tested for this application. It is recommended that TW trial this technology specifically on leaking joint locations when they have the opportunity at future trunk main inspections (for further information see the Appendix).
- Remote field electromagnetic – only suitable for in-pipe surveys, and requires close contact with the pipe material.
- Petrographic tests of concrete and mortar – generally not relevant for TW's pipe stock.

Compared with the AWWA process in Figure 8.1 we observe that TW relies more on opportunistic inspection methods;

- For the condition of trunk mains, information is collected from planned Sahara surveys targeted at leak detection, opportunistic trunk mains inspections and the pipe repair records (burst mains).
- For the condition of distribution mains, information is collected from pipe repair records (burst mains).

TW records a wealth of information when the opportunity arises. This, complemented by the planned Sahara surveys, helped to build a relatively good understanding of the condition of its most vulnerable and critical trunk mains. However, more could be done to move towards a more proactive approach for capturing asset health data, especially for distribution mains.

Owing to the opportunistic nature of historical pipe sampling for distribution mains, the pipe sample database may be biased towards pipes that are in worse condition. We recommend that a more planned and systematic approach be considered, like that shown in Figure 8.1, for distribution mains. This might be a randomised inspection programme with non-intrusive methods combined with a smaller number of intrusive methods.

TW's asset data is currently recorded in separate databases depending on the source of the information and the purpose for which it is used. We recommend that further work is carried out on cleaning the data and integrating the databases to increase the efficiency of data processing. We also suggest that the data be made available with DMA fingerprinting so that condition and performance can be seen together.

8.2.2 Flow and pressure monitoring

Network flow and pressure measurements provide the data to monitor and control the system to ensure adequate supplies are maintained to consumers and to support leakage and waste detection activities. Data are collected from key monitoring points:

- Flow meters at sources of supply, for district metering, pressure management control and on large consumer connections.
- Customer flow meters for measuring consumption and enabling accurate evaluation of the water balance and leakage measurements.
- Pressure monitors for system management, valve and pump control and for level of service management and reporting. The instrumentation is located at the nearest critical monitoring point (CMP), typically the highest supply point within the DMA or supply zone at which a permanent level of service pressure monitor is installed.

Comparison with TW practice

Consumption metering continues to be challenging area for the UK water industry. According to the Isle benchmarking study undertaken in 2020[31], UK utilities benchmarked averaged approximately 48% customer coverage, whereas other international peers have near 100% metering coverage Thames Water's meter penetration figure was approximately 50%.

Numerous studies have been undertaken to estimate the potential savings with increasing meter penetration, and in summary it has been suggested that metering can achieve at least 7.5% reduction in consumption, as well as a reduction in supply pipe leakage[32]. There is no consensus in the industry on whether universal domestic metering is economically viable.

Consumption data is one of the main areas of information deficit for TW in managing its network. For more detail see Section 5.3 of this report.

8.2.3 Recording performance data

UK water companies are required to record and report performance data against a number of well defined KPIs, including burst rates, leakage rates and supply interruptions.

As a general guide, AWWA recommends collecting performance data through burst records and leaks records. Bursts are expected and tolerated on most water mains; however, for a large transmission main or other critical main, even a single break may be intolerable, and break data may not exist for these pipes. [33]

Comparison with TW practice

Alongside keeping records of all the required KPIs (similar to the other UK water companies), TW has also been keeping records of leakage recurrence, which was found to be a good measure of asset health for distribution mains. TW's approach to investigating recurrence is detailed in section 4.5.3.

TW has separate tools for recording performance data, and it is a complex and labour-intensive task to assess the interconnectivity between the different metrics. We recommend that further work is carried out on integrating the databases to increase the efficiency of data processing. TW would also benefit from more granularity in the data – for example keeping records on regional or FMZ level, as well as separate metrics for distribution and trunk mains.

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[31] Leakage Management Benchmarking - Utility Report - Thames Water 201016

[32] Twort's Water Supply, 7th edition

[33] Condition Assessment of Water Mains, M77 AWWA Manual

TW has introduced the DMA fingerprinting tool, which is a significant step towards an integrated approach as it brings together leakage, burst and supply interruptions performance data with customer contacts data. TW's DMA fingerprinting is a real-time reporting tool, which is a new and innovative development. For more information on the DMA fingerprinting, see section 6.7 of this report.

8.3 Analytical approaches

Water companies use a range of analytical tools to process data to assess performance and the risks associated with the failure of an asset. These tools are often bespoke, developed and configured for the water company's specific needs and there may be overlaps in the databases.

8.3.1 Predicting future performance

Depending on the quantity and quality of asset data, availability of resources (e.g. skill sets, computing power), and digital maturity of a company, a wide range of tools[34] is used to predict future performance and risk of failure of an asset:

- Statistical deterioration modelling, aiming to predict failure rates, pipe bursts, rises in leakage and condition deterioration. The output is an assessment of the condition and potential remaining asset life of each asset and hence need for and timing of an intervention. Deterioration modelling was widely used by the UK water companies in PR14, resulting in more robust evidence-based investment plans. The use of this tool is often hampered by the scarcity of accurate and comprehensive performance and failure data, which is a challenge for many water companies. In TW's case, it has a lot of pipe repair data with which to support statistical modelling, the only advantage of managing a poorly performing network.
- Semi-automated analyses, increasingly available due to advances in the quality of data and data processing speeds.
- Management information systems (MIS) and graphical information systems (GIS), combining data from hydraulic modelling software and deterioration models.

The analysis needs to take into account both the practical operational risk and consequences, and regulatory and reputational business risk and consequences of failure (or conversely, the benefit of preventing failure). The operational risk is often included, but cost-benefit assessments generally do not include for business risk, and engineering and operational judgement is required to complement modelling. Recent developments in data processing and improved data quality allow for more efficient and auditable processes.

8.3.2 Developing an investment plan

The output from the performance analysis is a schedule of interventions over the planning period to address the identified risks with defined costs and benefits. However, due to the financial constraints, an affordable shorter list of needs and solutions needs to be developed from the list of identified interventions, balancing the conflicting drivers of maximising benefit to customers while minimising costs and operational and business risk.

This challenge is normally achieved through use of optimisation to balance the optimum blend of interventions and their costs and benefits to achieve defined performance criteria within defined constraints.

The tool widely used for this purpose is an Asset Investment Manager (AIM) tool[35] which uses statistical models to perform the optimisation, which identifies an optimum set of integrated interventions that deliver best value based on the pre-set constraints such as minimising the risk

[34] Based on Twort's Water Supply, 7th edition
[35] Twort's Water Supply, 7th edition

of interruptions, limits on capital expenditure or target numbers of customer complaints. The model inputs include data on pipe material, wall thickness, class, age, jointing system, pressure, soil type and ground conditions, traffic loading and pipe failure and customer complaints history. Data on other factors such as lining and coating systems and condition may be included if available. The analysis is repeated periodically to support Business Plans. Annual updates of the analysis can be run using the previous year's performance data, but it is time consuming and may suit only small utilities.

Comparison with TW practice

We discuss TW's analytical approaches and capabilities in sections 5.3 and 5.4.

TW uses two AIM tools – one for distribution mains and the other for trunk mains.

- The distribution mains AIM tool is mature and well validated, and it is used by TW to optimise investment in the distribution system.
- The trunk mains AIM tool is newer, and is mainly used to identify and quantify risks for each pipe length. The output, in combination with operational knowledge – is used to plan interventions to mitigate these risks, which usually involve pipe repairs rather than replacement which may be unaffordable for large trunk mains.

The AIM tools take time to set up and run, especially with a large asset base. As a result, TW only updates them to support 5-year business plans. However, improvements to the base data, analysis tools and computing power may allow for more regular updates, and TW has an aspiration to run AIM more frequently, perhaps annually, to inform short-term planning.

With the use of its AIM models, complemented by the DMA fingerprinting tool, TW is well aligned with the industry good practice. For further improvement, the integration of models and drivers across the different analytical tools should be considered. We have also made recommendations in previous chapters to assess additional factors causing pipe failures separately, overlayed with the AIM results.

8.4 Network design and operational policies

8.4.1 System design

The layout of a system is selected based on the geographic characteristics of an area. An interconnected looped layout provides the maximum flexibility, and most urban systems tend to be subdivided into hydraulically discrete areas, which are looped networks. Dendritic layouts are more common for trunk mains and local distribution mains in rural areas.

The most economical layout is a gravity network fed from a local service reservoir, located as near as technically feasible to the service area it supplies, ideally close to the centre of demand. If the reservoir cannot be located close to its service area, best practice dictates that at least two major supply pipes connect the reservoir to the area, forming a ring main to provide redundancy and resilience in the network.[36] Some companies adopt standards that specify a maximum number of properties that can be supplied from a single distribution main without an alternative supply (generally in the range of 100 to 200 properties).

In many cases it is not viable to design such an ideal gravity network. There are several network elements that can be used as an economical alternative to address peaks in demand. Booster pumping stations can be used in a network to provide a fixed extra flow; to provide a fixed extra pressure; and to maintain a given pressure irrespective of the flow. The use of balancing storage (e.g. balancing tank or water tower) along with a booster arrangement may be used to

[36] Twort's Water Supply, 7th edition

provide sufficient pressure in the network in flat areas if land and planning permission can be obtained to build water towers.[37]

It is good practice to have a dedicated pumped transmission main to the reservoir (top entry inlet) with no customers connected to it and a dedicated distribution main out of the reservoir (bottom exit) which can have customers connected to it on gravity supply from the reservoir. The top entry, bottom exit arrangement ensures good turnover in the reservoir, which protects water quality. The other advantages are that customers experience a calmer network and if the transmission main fails, there is no immediate interruption to supply.

It is also possible to pump directly into distribution (thus avoiding a need for elevated storage). This option requires considerably less capital investment; however, it has significant disadvantages when compared to elevated storage solutions, requires a higher level of technical maintenance, incurs higher annual ongoing operational expenditure and creates more turbulence in the distribution system, even if variable speed pumps are used.

Comparison with TW practice

TW has the highest installed capacity in kW per Km of watermain in the UK, which reflects a high level of pumping in the network. In section 4.7 we investigated the impact of this on increasing the risk of transients and other hydraulic stresses. As described above, reducing the proportion of the network which is directly supplied from pumps could have a beneficial impact on the whole-life management of the network and could reduce interruptions to supply. We recommend that this option is considered when and where the opportunity arises to reconfigure the network.

There is a lack of redundancy in some parts of the London trunk main network – especially in the North East and South East regions which are not supplied by the Ring Main. This means that failure of some of these trunk mains and pumping assets would be high-consequence events, possibly cutting off thousands of customers with no alternative supply. TW is developing options to improve resilience in these areas.

For new mains, TW’s asset standards require a combination of isolation valves and hydrants to enable the isolation of sections of the main, with a spacing to achieve an isolation of a maximum of 1000 properties for trunk mains and 200 properties for distribution mains.[38]

8.4.2 Hydraulic modelling

Most hydraulic analysis software can incorporate/import data from GIS based databases used by water companies to manage their assets, although none has yet resolved the problem of repeatability or updating only where there are changes in the data sets.

Calibrated models should be validated periodically to confirm that they are still ‘fit for purpose’ within acceptable tolerances. Modellers have conflicting views on the frequency of re-validating a model, whether to undertake a full or partial model rebuild and whether to carry out a calibration field test. Unless there is strong evidence that the model is still performing within its specified tolerances of flows and pressures over the diurnal period, the model should be reviewed. Its performance should be validated against field measurements, using flow and pressure data at key locations derived from telemetry or a small field test. In high growth areas, such as east London, there are likely to be significant changes to the network and model recalibration should occur more frequently.

Comparison with TW practice

We discuss TW’s hydraulic modelling approach and capabilities in section 4.7 of this report.

[37] Twort’s Water Supply, 7th edition

[38] Thames Water Asset Standard AM-DES-WN&T-WN02-Water Mains Design-SEC1of1

In summary, TW is constrained in its understanding of its network by a lack of up-to-date calibrated hydraulic models (only 35% coverage). TW has plans to update and increase its model coverage in AMP7, covering the whole of the London network by the end of the AMP, and to operationalise its hydraulic models so that it can provide live model information to Operations. This will compliment TW's System Risk Visualisation tool which visualises information on current pressures and flows from SCADA data. Operationalising hydraulic models for all parts of the system will provide interactive capabilities for operational planning and alarms to highlight hydraulic anomalies. When these plans are implemented, TW will be applying industry leading practices in this regard.

8.4.3 Design of new pipelines

Pipes used in water supply systems are generally cast iron, ductile iron (DI), steel, polyethylene (PE), PVC (polyvinyl chloride), GRP (glass reinforced plastic), prestressed concrete, cylinder or non-cylinder (PSC), and reinforced concrete cylinder (RC).

Asbestos cement (AC) and lead pipes are no longer produced in the UK due to the health risks they pose (e.g. lung disease, cancer, and lead poisoning). Water companies still operate pipes of these materials though and are slowly replacing them with modern materials.

Pipe materials are chosen based on technical considerations, price (cost of material and installation, plus running costs if there are differences in hydraulic performance), local experience and skills, ground conditions, and standardisation.

For the smaller pipe sizes in water distribution systems (DN 51 to 300), in the UK over 80% of new pipes are plastic (about 10% PE 100, 50% PE 80 and over 20% PVC-U and MOPVC) and over 15% DI. Plastic pipes are advantageous at smaller diameters as they can be joined above ground and then snaked into narrow trenches reducing time and social and environmental impact during construction. This advantage reduces with increasing diameter and pressure class, and in hot climates where temperature derating is necessary.

For larger diameters, DI or steel is predominantly used, depending on pressure rating, the need for welded joints (e.g. to avoid the need for thrust blocks in congested urban areas), and the availability of skilled welders.

In some countries, prestressed concrete, concrete cylinder or GRP pipes are used as alternatives because of various circumstances such as local preference and practice, price competitiveness, tied funding, in-country manufacture, aggressive ground conditions, or where a greater margin of safety is required against rough handling and backfilling (in the case of concrete pipes).

Design of horizontal and vertical alignments follow similar considerations around the globe.

- The horizonal alignment of a pipeline follows an available corridor, minimising cost whilst adhering to local constraints. Where possible, laying a pipeline along a highway beneath the road surface is usually avoided due to the cost and disruption to traffic.
- The vertical alignment of a pipeline is usually determined to minimise the depth of the excavation while maintaining the required pipe cover (driven by structural considerations and depth of frost) and providing the required gradients for drainage and air release purposes.

The structural design of pipelines to withstand internal hydrostatic pressure, external loads from soil, surcharge and traffic is well researched and standardised, sharing the same principles globally. While local requirements and guidance may vary, this has limited impact on the effectiveness and efficiency in network operation and maintenance.

Comparison with TW practice

Although TW owns pipes of a wide range of materials, the TW design standards clearly identify the preferred materials for use in new water supply pipes (PE, DI and steel), which it has found to be the most resilient options for the specific needs of its network. [39]

TW's asset standards also specify the minimum depths of cover for pipes (900mm for distribution mains and trunk mains in minor roads; 1.2m for trunk mains in heavily trafficked roads) and provide clear requirements for pipe bedding design and detailing. This approach ensures that new pipes are protected from frost and the impact of traffic loading, though there is evidence that some existing pipes do not comply with these standards.

We find that TW's design practices for new pipelines are aligned with industry good practice.

8.4.4 Operational policies – monitoring of the network

It is standard practice for water companies to use telemetry, remote sensing and control and central or regional operational control centres to manage their networks. From here, pumping stations, reservoir levels, and control valves can be monitored and controlled.[40]

Comparison with TW practice

Thames Water recently upgraded its system controlling London's water supplies, moving from the 25-year-old RTAP system to the new ClearSCADA platform. This is one of the largest of its type in Europe[41], and monitors output from the five big treatment works as well as more than 200 service reservoirs, pumping stations and boreholes, many of which are unmanned and need to be operated remotely.

We discuss TW's trunk main monitoring practices in section 4.5.2. Monitoring is a notoriously difficult and expensive task for any water company, but especially under London's busy streets. TW combines fixed monitoring (using Syrinix and Hydroguard units), targeted surveys (including proactive Sahara surveys on high-risk mains) and opportunistic inspections (including NDT) to understand asset health. In our view, TW's monitoring of trunk main assets is industry leading.

8.4.5 Operational policies – active leakage control

As opposed to passive leakage control policies, which only deal with unacceptable visible leaks as they occur, an active leakage control policy monitors the distribution system closely for signs of leakage, including leaks that are unseen and have no significant local impacts, and providing the resources needed to detect and repair leaks, to maintain leakage at acceptable levels.

Active leakage control relies on district metering to identify areas of the network where leakage is greatest. The leaks are then located and repaired, and the effectiveness of the interventions assessed using the district meters.

Once leakage has been reduced to the acceptable level within an area, repair activities can be suspended. If the continued monitoring indicates that leakage has risen above a certain threshold again, it may be necessary to re-enter the area and repeat the process. The threshold level of intervention is determined based on several factors including the unit cost of water compared with the unit cost of reducing water losses in that area; resources available, and whether other areas should take priority.

[39] Thames Water Asset Standard AM-DES-WN&T-WN02-Water Mains Design-SEC1of1

[40] Twort's Water Supply, 7th edition

[41] London water system IT upgrade | Newsroom | Thames Water

8.4.6 Operational policies – district metering

Good practice dictates that the most effective method of monitoring is to divide the system into varying levels of control[42]:

- Zones of 10,000 – 25,000 connections.
  - Typically too coarse for targeting and efficient intervention; however can be the first stage monitoring for water companies starting to address leakage.
  - Permanent flow meters are installed on the feed mains to zones. Historically, a venturi meter or a 'Dall tube' was installed; but these types of meters are no longer used because of their high cost. Instead, electromagnetic and ultrasonic flow meters are now preferred.
- DMAs of typically 500 – 3,000 connections[43].
  - Provides sufficient detail to be able to target interventions effectively to individual DMAs. Monitoring at DMA level is the most common method.
  - Permanent flow meters are installed on the feed mains to DMAs. Preferably there should be a single feed main for each DMA as DMAs fed by more than three meters are generally difficult to monitor and the flow analyses can be unreliable.
- Waste districts of a few hundred connections.
  - Generally, too small for efficient permanent monitoring, but they are effective subdivisions for detecting and locating leaks within a DMA.

Data from zone and DMA flow and pressure measurement can be transferred to the operational control centre to be processed, stored and monitored using an integrated telemetry system, hard wired, by radio or GPS technology. This provides an opportunity to monitor daily demand and minimum night flows. Alternatively, the data can be stored in on-site data loggers that are interrogated periodically, and their data transferred to the flow monitoring database for analysis. The data from on-site loggers is typically downloaded on a 28-day cycle, implying an inevitable delay before the information can be processed.

Comparison with TW practice

We discuss TW's district metering practices in section 6.6.

TW has an average 2,800 properties per DMA in London, compared to most other UK companies where the average DMA size is 1,000-1,500 properties. TW's DMAs are also complex with multiple metering points on the boundaries, owing to the complexities of the London network.

TW recognises that the design of its DMAs could be improved to reduce their size and simplify metering arrangements and has implemented the DMA excellence programme targeting DMAs with long standing operability issues for improvement.

8.4.7 Operational policies – leak detection and repair

Visible leaks are often reported first by the public. District inspectors can also find more visible leaks by looking for damp patches, trickles of running water and extra vegetation growth close to pipes, valves or fire hydrants, or above ferrules or stop taps.

Unreported, invisible leaks are usually located by a stepped approach. Once a 'leaky' area is identified through district metering, it can be narrowed down by waste metering or step-testing, and further investigations undertaken to locate possible leaks.

[42] Twort's Water Supply, 7th edition

[43] Based on the Water UK LPI data set (2003 to 2014), the majority of UK water companies have an average DMA size of 1,000-1,500 properties.

Locating leaks by sound is the basis of the majority of leak detection techniques and electronic equipment currently available (a short description of the available technologies is included in Appendix C.2).

More sophisticated techniques are required for detecting and locating leaks in trunk mains and large critical mains, which cannot be isolated for testing. These mains are often constructed of different materials, are not readily accessible and include only limited numbers of valves and other fittings to which sensors can be attached.

Pipeline integrity management systems use continuously monitored flow and pressure data linked to hydraulic modelling software to provide on-line active leak detection on a pipeline. The technology is suitable for critical assets such as trunk mains where pipe failure would need immediate, automatic shutdown of a section. The equipment is expensive to install and maintain but cost effective in terms of the consequential damage that might otherwise occur if a large pipeline were to fail.

A short description of the other available technologies is included in Appendix C.3 and Appendix C.4.

Comparison with TW practice

Apart from addressing visible leaks throughout its network, TW takes a proactive approach to locating leaks by implementing a programme of Sahara surveys targeting high-consequence mains (mainly trunk mains, but occasionally including distribution mains). Visible and active leaks are all recorded and prioritised dynamically on an ongoing basis.

TW's asset standards dictate that when a fracture or damage is small and around the circumference of the pipe, a localised repair is carried out using a clamp fitted onto the pipe, which may be done under positive pressure. If this is not possible, depressurisation is implemented and the whole length of the pipe is replaced. [44]

We have noted in section 6.4 that the prevalence of clay and hard surfaces in the London area means that leaks do not surface as readily as in non-clay or open soil environments. This results in TW having to detect a greater proportion of leaks than other companies. However, despite high urbanisation, TW is keeping pace with the industry on speed of repair.

8.4.8 Operational policies – pressure management

Pressure management is aimed at reducing the operating pressure in a network. The quantity of water lost through a leak or burst is proportional to the operational pressure of the system; therefore, reducing pressure will have a significant impact on leakage. Lower and more consistent pressures can extend the asset life of the network assets by reducing continuous high and transient pressures. In addition, reduced operating pressures can also result in water savings by consumers through reducing flow rates from showers, taps and toilets.

Pressure management is generally achieved by installing pressure-reducing valves (PRVs) on the inlet pipework supplying a DMA or PMA. These PRVs require periodic maintenance which increases network operating costs.

Energy recovery turbines may be used to generate electricity from the surplus energy that would otherwise be dissipated through a PRV; however, these are expensive, require high levels of maintenance and may not be economically viable in many situations.

[44] Thames Water Asset Standard AM-PRO-WN&T-WN43-Mains Repair-SEC2of4

Comparison with TW practice

TW has a relatively mature pressure management programme and has a high penetration of remote-controlled PRVs compared to its UK and global peers (see Section 4.7). There are limited options to expand its programme; however, advances in technologies may open new opportunities in future.

8.4.9 Asset renewal

Asset renewal is intended to target those pipes which are more vulnerable to bursts (visible leaks) or leaks (unreported leaks) or whose condition presents a risk to water quality.

An asset maintenance and replacement plan is developed based on an analysis of the network's physical and operational performance (e.g. using deterioration modelling). This plan may include short and longer-term measures.

Short-term measures include the rezoning of supply areas, repairing visible leaks, active leakage control, as well as valve maintenance and mains flushing to resolve water quality problems. A short description of available pipe cleaning technologies is included in Appendix C.5.

Longer term measures include mains rehabilitation or replacement. Rehabilitation techniques can comprise non-aggressive and aggressive cleaning methods or use of non-structural and structural linings (for further information, see Appendix C.6), while pipe replacement may utilise open-cut or trenchless techniques (for further information, see Appendix C.7).

Comparison with TW practice

For pipes identified for renewal, TW asset standards encourage the use of trenchless technologies to reduce environmental impact, disruption and to provide economic alternatives to open cut methods. The TW standard is mainly based on principles set out in CIRIA SP147 Trenchless Techniques – Planning and Selection. It makes use of most available technologies for linings (slip-lining, close-fit lining, rolldown, Swage lining), on-line replacement (pipe bursting, pipe splitting and pipe pulling) and for new installations (horizontal directional drilling, microtunnelling, impact moling, pipe ramming and auger boring).[45]

We observe that with regard to applying new technologies, TW has been taking a cautious approach. Recognising the practical challenges and cost implications of renewal and replacement, TW has been prioritising the use of HPPE both in structural linings as well as replacement as this material has proven to be the most resilient option, especially beneficial in corrosive soils.

TW's historical renewal rates are relatively low compared to others, particularly in AMPs 1-3. The increase in renewals through the VMR programme in AMP4 helped deliver a step improvement in leakage and asset health. Post the VMR programme, TW identified and delivered improvements using a range of asset management and engineering processes. [46]

We have noted in section 4.10 that the improvements in performance and reductions in cost that are required in future AMPs cannot be achieved without significantly increasing mains renewal rates above those delivered in recent AMPs to offset deterioration (650 km/AMP). Increased renewal rates are required for the next few AMPs to restore the asset base to a condition that will fulfil customer and regulatory expectations and meet performance targets in an effective and sustainable way.

[45] TW Asset Standard AM-DES-WN&T-WN04-Mains Renovation-SEC1of1

[46] Isle Leakage Management - Best Practices Workshop Asset Management (Mains Renewals)

8.5 Risk mitigation for trunk mains

Trunk mains are notoriously difficult and expensive to renew in longer sections. Therefore, water companies usually deploy a risk-based approach to replace critical sections of trunk mains.

TW uses risk-based asset maintenance planning within the trunk mains AIM model by analysing the probability and the consequence of failure.

- The model provides a consequence score for every 100m for all 3,200km of trunk mains, describing the impact of flooding on third party assets, and the downstream level of interruptions to supply to customers. The higher consequences targeted are interruptions to supply and public safety from flooding following the HSE guidance.
- Probability and deterioration are modelled based on available asset health and performance data such as burst history and data from fixed monitoring points (Hydroguard and Syrinix TrunkMinder).

TW's consequence modelling is well advanced and considered industry leading. While probability and deterioration modelling is aligned with industry practices, and is continually improving, TW recognise that the accuracy is not yet suitable enough to direct cost effective investment targeting on a metre by metre basis. Therefore, TW uses the consequence of failure to guide intervention planning. For low consequence pipes, an operational response is used, whilst planned maintenance is targeted at high consequence pipes. [47]

8.6 Comparison and recommendations

Conclusions

Summarising our review, we conclude the following on how TW compares with industry good practice.

Data capture and inspection:

- TW uses most of the available technologies where appropriate to capture asset condition data, however it generally relies more on opportunistic inspection methods than on a proactive inspection regime.
- Using opportunistic inspections complemented by the planned Sahara surveys, TW developed a relatively good understanding of the condition of their most vulnerable and critical trunk mains. However, more could be done to move towards a more proactive approach for capturing asset data, especially for distribution mains.
- TW's asset data is currently recorded in separate databases depending on the source of the information and the purpose for which it is used.
- Consumption data is one of the main areas of information deficit for TW in managing its network.
- Aligned with all UK water companies TW records all the required performance KPIs. Additional TW has also been keeping records of leakage recurrence, which was found to be a good measure of asset health for distribution mains.
- TW has separate tools for recording performance data, and it is a complex and labour-intensive task to assess the interconnectivity between the different metrics.
- The DMA fingerprinting tool is a significant step towards an integrated approach as it brings together leakage, burst and supply interruptions performance data with customer contacts data. TW's DMA fingerprinting is a real-time reporting tool, which is a new and innovative development.

[47] London water network resilience – Response to Ofwat's letters

Analytical approaches:

- The distribution mains AIM tool is mature and well validated, and it is used by TW to optimise investment in the distribution system.
- The trunk mains AIM tool is newer and is mainly used to identify and quantify risks for each pipe length. The output, in combination with operational knowledge – is used to plan interventions to mitigate these risks, which usually involve pipe repairs rather than replacement which may not be viable for large trunk mains.
- The AIM tools take time to set up and run, especially with a large asset base. As a result, TW only updates and runs them to support 5-year business plans. However, improvements to the base data, analysis tools and computing power may allow for more regular updates, and TW has an aspiration to run AIM more frequently, perhaps annually, to inform short-term planning.
- With the use of its AIM models, complemented by the DMA fingerprinting tool, TW is well aligned with the industry good practice.

Network design and operational policies:

- TW has the highest installed capacity in kW per Km of watermain in the UK, which reflects a high level of pumping in the network, which may have an impact on increasing the risk of transients and other hydraulic stresses.
- There is a lack of redundancy in some parts of the London trunk main network – especially in the North East and South East regions which are not supplied by the Ring Main. This means that failure of some of these trunk mains and pumping assets would be high-consequence events, possibly cutting off thousands of customers with no alternative supply.
- TW is constrained in its understanding of its network by a lack of up-to-date calibrated hydraulic models (only 35% coverage), but is implementing a plan to update and increase its model coverage in AMP7. TW is also planning to operationalise its hydraulic models so that they can provide live information to Operations on modelled pressures and flows in all parts of the system. This will compliment TW's System Risk Visualisation tool which visualises pressure and flow data from SCADA. Operationalised hydraulic models will provide interactive capabilities for operational planning and alarms to highlight hydraulic anomalies. When these plans are implemented, TW will be applying industry leading practices in this regard.
- TW's design practices for new pipelines are aligned with industry good practice.
- TW has recently upgraded its SCADA system to an industry standard software, which is now one of the largest of its type in Europe.
- TW combines fixed monitoring (using Syrinix and Hydroguard units), targeted surveys (including proactive Sahara surveys on high-risk mains) and opportunistic inspections (including NDT) to understanding asset health. In our view, TW's monitoring of trunk main asset health is industry leading.
- TW has an average 2,800 properties per DMA in London, compared to most other UK companies where the average DMA size is 1,000-1,500 properties. TW's DMAs are also complex with multiple metering points on the boundaries, owing to the complexities of the London network. The design of its DMAs could be improved to reduce their size and simplify metering arrangements and TW has implemented the DMA excellence programme targeting DMAs with long standing operability issues for improvement.
- TW takes a proactive approach to locating leaks by implementing a programme of Sahara surveys targeting high-consequence mains (mainly trunk mains, but occasionally including distribution mains).
- The prevalence of clay and hard surfaces in the London area means that leaks do not surface as readily as in non-clay or open soil environments. This results in TW having to

detect a greater proportion of leaks than other companies. However, despite high urbanisation, TW is keeping pace with the industry on speed of repair.

- TW has a relatively mature pressure management programme and has a high penetration of remote-controlled PRVs compared to its UK and global peers. There are limited options to expand its programme; however, advances in technologies may open new opportunities in the near future.
- TW asset standards encourage the use of trenchless technologies to reduce environmental impact, disruption and to provide economic alternatives to open cut methods for pipe renewal. TW makes use of most available technologies for linings, on-line replacement and for new installations as well.
- With regard to applying new technologies, TW has been taking a cautious approach. Recognising the practical challenges and cost implications of renewal and replacement, TW has been prioritising the use of HPPE both in structural linings as well as replacement, as this material has proven to be the most resilient option, especially beneficial in corrosive soils.
- TW's historical renewal rates are relatively low compared to others, particularly in AMPs 1-3. The increase in renewals through the VMR programme in AMP4 helped deliver a step improvement in leakage and asset health. Post the VMR programme, TW identified and delivered improvements using a range of asset management and engineering processes.

Risk mitigation for trunk mains

- TW uses risk-based asset maintenance planning within the trunk mains AIM model by analysing the probability and the consequence of failure. Its consequence modelling is well advanced and considered industry leading.
- Whilst probability and deterioration modelling is aligned with industry practices, and is continually improving, TW recognise that the accuracy is not yet suitable enough to direct cost effective investment targeting on a metre by metre basis.

Recommendations

We have identified the following recommendations from our review.

Data capture and inspection:

- TW could do more to move towards a more proactive approach for capturing asset data, especially for distribution mains. We recommend that a more unbiased data collection approach is considered for the distribution mains.
- We recommend that further work is carried out on cleaning the data and integrating the databases to increase the efficiency of data processing.

Analytical approaches:

- We support TW's plans to increase meter penetration in London, which will lead to reduced consumption, reduced supply pipe leakage and an improved understanding of leakage in the network.
- TW has an aspiration to run AIM more frequently, perhaps annually, to inform short-term planning. In addition to this, we have made recommendations in previous chapters to assess additional factors causing pipe failures separately, overlayed with the AIM results.

Network design and operational policies:

- Reducing the proportion of the network which is directly supplied from pumps could have a beneficial impact on the whole-life management of the network. We recommend that this option is considered when and where the opportunity arises to reconfigure the network.

- A long-term strategy needs to be developed to address supply sufficiency and resilience in London. This is addressed as part of a separate workstream.
- We support TW's plans to update and increase its model coverage in AMP7, covering the whole of the London network by the end of the AMP, and to operationalise its hydraulic models so that it can provide live model information to Operations. This will supplement data on actual pressures and flows visualised in TW's SRV (system risk visualisation) tool and enable interactive capabilities for operational planning and alarms to highlight hydraulic anomalies.
- More work could be done to improve DMAs to reduce their size and simplify metering arrangements and TW has implemented the DMA excellence programme targeting DMAs with long standing operability issues for improvement.
- We recommended increased renewal rates for the next few AMPs to restore the asset base to a condition that will fulfil customer and regulatory expectations and meet performance targets in an effective and sustainable way.

9 Summary findings

Chapter summary

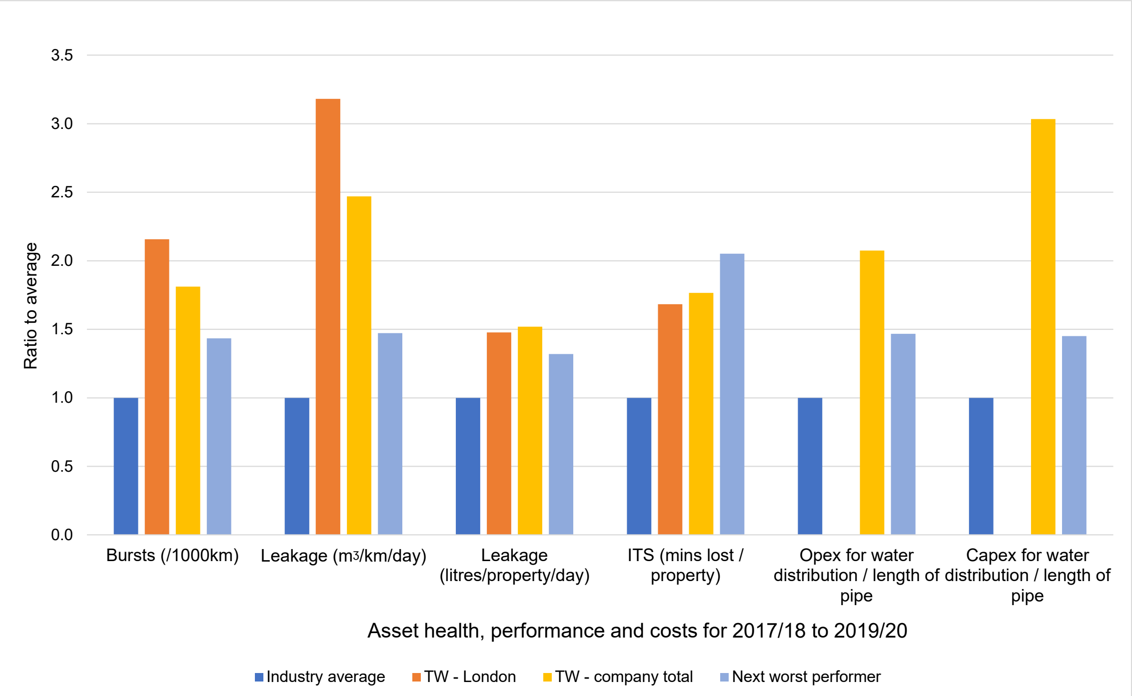
This chapter summarises the findings from the previous chapters on the factors driving performance and costs in London's water network. It compares the factors with those impacting networks in other parts of the country, assesses management control over them and ways to mitigate them going forward as well as ways to improve asset management to meet future challenges.

As this chapter of the report is a summary of the findings from previous chapters, this chapter summary table is purposefully limited so as not to repeat the information which is presented below.

9.1 Factors impacting performance and costs

Chapter 4 presented evidence that London's water network is in poor asset health and Chapter 7: Cost of managing the network showed that TW's capital and operational costs are much higher, when normalised by length, than the rest of the industry. This is shown in Figure 9.1

Figure 9.1: Comparative asset health and costs



Source: Mott MacDonald analysis of APR data

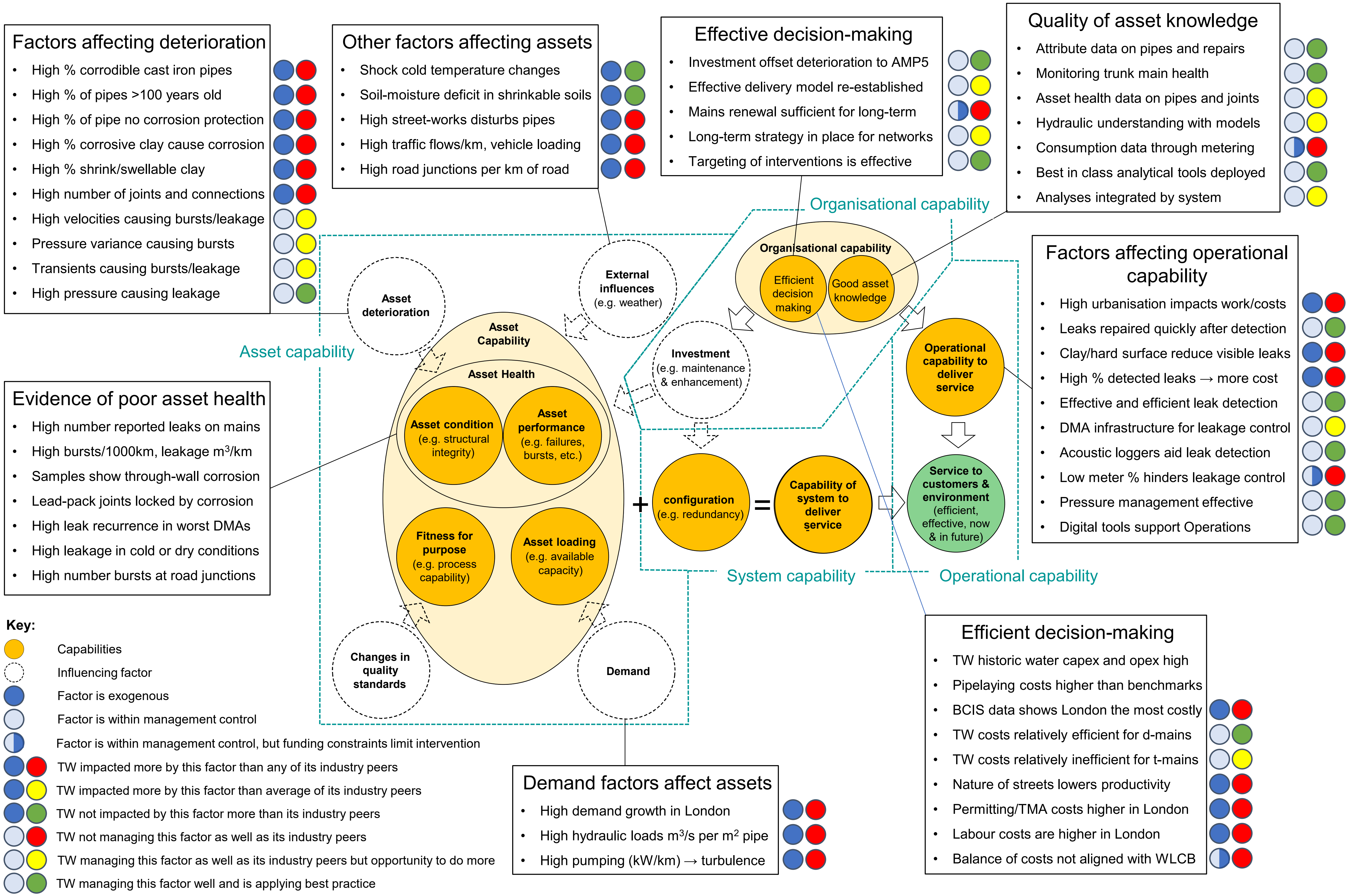
Figure 9.1 compares performance and costs with industry averages and the next worst performing company for the years 2017/18 to 2019/20. This shows that London's water network is a performance outlier for bursts and leakage but not interruptions to supply, (though performance is worse than average). The poor asset performance is partly responsible for high levels of expenditure, both operationally in repairing the asset base and in capital maintenance.

Other bottom-up evidence that London’s water mains are in poor health, as described Chapter 4, are that:

- There is a high number of reported (visible) leaks on mains compared with other companies.
- Pipe samples show heavy corrosion with through-wall corrosion in many cases.
- Locked joints on corroded cast iron pipes are vulnerable to fracture from temperature drops.
- High leakage recurrence in poor performing DMAs indicates that pipes are in poor condition.
- The network responds poorly to periods of cold or dry conditions, with leakage outbreaks.
- There are high numbers of repairs at road junctions, suggesting vulnerability to traffic loading.
- There were a high number of high-profile trunk-main failures in AMP6.

The key factors affecting the capabilities that drive performance and cost in London’s water network, as summarised from the preceding chapters, are shown in Figure 9.2. We provide a short summary against each of the key areas, noting the chapters where more detail is given.

Figure 9.2: Key factors affecting the capabilities that drive performance and cost



Source: Mott MacDonald

Factors affecting deterioration (chapter 4)

One of the reasons for the poor health of London's water network is the deterioration of cast iron pipes caused by a large number of exogenous factors as shown in Figure 9.2. The combined effect of corrodible materials and very old pipe of variable manufacture with no corrosion protection in contact with corrosive and plastic clay soils for so long has resulted in through-wall corrosion and propensity to burst and leak. Other factors, as listed below, also impact deterioration and likelihood of failure, but many of these are secondary factors that are significant because of the age profile and corroded state of the pipes. They are important, however, as they help identify the pipes that are the most vulnerable to failure.

Other factors affecting deterioration include:

- The high number of pipe joints and connections in London's dense urban environment, all of which are potential points of weakness for leaks to occur
- Pipe wall thickness, which means that large diameter pipes fail less frequently
- High and low pipe velocities in water mains which is associated with higher failure rates
- Diurnal pressure variance exceeding 25m which model data shows causes higher failure rates in distribution mains (not trunk mains)
- Occurrence of transients in the network during normal operation, such as pump switching
- Pressure which affects leakage. Uncontrolled, this could have a negative impact on leakage but in practice, TW manages pressure well.

The number of joints and connections and pipe wall thickness are exogenous, but the other factors listed above are within management control. We have shown three of these as 'yellow', meaning that TW manages these as well as others, but there is more it could do.

Other factors affecting asset capabilities (chapter 4)

Other factors impacting the performance of the assets relate to the weather and London's highly urbanised environment. Some of these factors would not affect pipes in good condition.

- Sudden drops in water temperature during cold weather causing London's corroded cast iron pipes to fail leading to outbreaks of leakage. This failure mechanism makes the network vulnerable to freeze-thaw events such as that seen in 2018.
- Changes in soil-moisture deficit in clay soils lead to soil movement through shrink or swell effects, resulting in pipe rupture. This can lead to outbreaks of leakage during dry weather.
- The high density of utilities in London's streets results in a high level of street-works activity which can disturb the ground adjacent to water mains, sometimes causing leakage.
- London's streets experience the highest traffic flows in the country, and this results in high vehicle loads where water mains are within 1m of the surface.
- London has the highest road junctions per km of road in the UK and this is where vehicle loading is most acute through acceleration and braking forces. Analysis shows that pipes are 40% more likely to fail at road junctions than in the roads between junctions.

Demand factors affecting asset capabilities (chapter 4)

London is a growing city and demand growth has an impact on the performance of pipe networks. We have listed three demand-related factors impacting London's network:

- High demand growth leading to high velocities and hydraulic stresses in existing water mains

- Higher hydraulic load (expressed in m^3/s per m^2 of pipe) than any other water company, creating the potential for higher hydraulic stress in the network.
- High level of pumping and the highest installed pumping capacity per length of main (kW/km) owing to the flat topography. Pumping leads to turbulence in the network, even with good controls, and this can affect the performance of the system.

The effect of these hydraulic stresses is reflected in the factors causing deterioration, namely high velocities, diurnal pressure variations and impacts from transients.

The factors affecting asset capability have been considered individually in Chapter 4. To prioritise investment, TW needs to understand the combination of factors that best explain localised performance. TW's AIM model for water distribution mains does this statistically for some of the key factors driving performance such as pipe material, diameter, age and soil conditions but not for all the factors analysed in this report. It would be valuable to undertake some follow-on statistical analysis to examine the compounding effect of the full basket of factors identified in this report. This could be done through multi-regression analysis and machine learning, building on the analysis developed for this project in PowerBI.

Effective decision-making (chapter 5)

We have identified five factors under effective decision-making, all within management control.

- TW's decisions on a blend of interventions, including mains renewal, to offset deterioration and achieve stable serviceability were effective up to the end of AMP5.
- TW's decisions were less effective in AMP6 and it had to intervene to modify the alliance models it set up to deliver service objectives and leakage targets, to bring capability back in-house. AMP6 targets were eventually recovered and the intelligent client model that it now has in place is more effective but is not yet mature. It therefore has a yellow designation.
- TW has not renewed as much of its network as other companies or as much as it would have liked owing to affordability constraints. This is shown as red, but funding constrained.
- TW does not have a long-term strategy in place for networks, in common with many companies, but is in the process of developing one. This has a yellow designation.
- TW has effective processes for targeting interventions at assets that pose the highest risk to service or public safety.

Quality of asset knowledge (chapter 5)

The quality of TW's asset knowledge is good with some areas of leading practice and some areas for improvement. TW's monitoring of trunk main health through on-line monitors is excellent and it has some best-in-class analytical tools such as AIM and DMA fingerprinting. It could do more systematic capture of asset health data on its pipes and pipe joints and it could extend the use of hydraulic model data into needs identification as well as solution design. It does need to extend its detailed model coverage, which it is doing in AMP7. TW suffers a lack of accurate consumption data owing to low meter penetration compared with some companies, but this is improving in AMP7 as the smart metering programme is rolled out. We have shown this as funding constrained in Figure 9.2 because TW had proposed a metering programme in AMP5. We recommend that more is done to bring together all the insights from TW's different modelling tools into integrated hydraulic system plans. TW has a long-term objective to do this.

Factors affecting operational capabilities (chapter 6)

The factors impacting TW's operational capability are largely within management control, but in London's urbanised environment, some are exogenous, as shown in Figure 9.2.

Firstly, London is the most densely urbanised environment in the UK, which has an impact on the cost of working on London's water network and the time it takes to do it. Despite this, TW has managed to reduce the time to repair pipes once leaks are found to below industry average and we conclude that TW is managing speed of repair well despite the challenges.

However, the combined effect of hard surfaces through high urbanisation and the clay subsoils means that a greater proportion of leakage is invisible below the surface in London than elsewhere in the country. This means that TW must detect and repair 50% more invisible leaks for each visible leak than the industry average, which increases TW's leak detection volumes and costs compared with others.

TW's leakage technicians are effective and efficient at leak detection and TW has installed 27,000 acoustic loggers to aid leak detection efforts which are delivering leakage savings. However, TW's DMA infrastructure, although improved, still has relatively low operability which effects TW's ability to accurately measure leakage and target detection efforts effectively. TW is implementing a DMA excellence programme to gradually improve operability.

TW has comparatively low meter penetration which limits the availability of good consumption data but roll-out of its smart metering programme is improving understanding of consumption. TW has also been installing and operating pressure management schemes since AMP3 and has extensive coverage of London's network with pressure managed areas.

TW has a good set of smart digital tools to support Operations, detect anomalies and enable rapid response. They are, by their nature, tactical and rely on current performance data and recent history. There may be opportunity to increase their value by integrating them more with asset management forecasting tools.

Efficient decision-making (Chapter 7: Cost of managing the network)

The main factors impacting the cost of capital works in London are those associated with the highly urbanised environment and the competition for labour in the nation's capital. In Figure 9.2 we have summarised these as: the nature of the streets, such as the prevalence of concrete bound layers increasing reinstatement costs and the high density of buried services, the high permitting and traffic management costs, and high labour costs in London. These are exogenous factors impacting the productivity and costs of TW's pipelaying activities and their impact is more severe in London than elsewhere in the country.

When TW costs and benchmark costs are adjusted for location using the BCIS location indices, then TW's costs for distribution mains are broadly efficient compared with benchmarks. Trunk mains, however, appear to be inefficient compared with benchmarks by about 35% in London, even after adjustment for location. Our explanation for this is that whereas the BCIS location indices largely explain the London impact on costs for distribution mains, they are insufficient alone to capture the complexities and site-specific factors impacting deep excavation work associated with trunk mains in London. Unfortunately, we were unable to identify the specific factors impacting costs for trunk mains from TW productivity data or to compare these with similar information for benchmarks to quantify the effects. This as an area for future focus.

Finally, a whole-life cost benefit analysis of London's water network has shown that the current balance of capital and operational costs is uneconomic in the long term and that to reduce operating costs and maximise the benefits from improved service, TW needs to increase the level of mains replacement. We have shown this as red, but funding constrained in Figure 9.2.

Key challenges

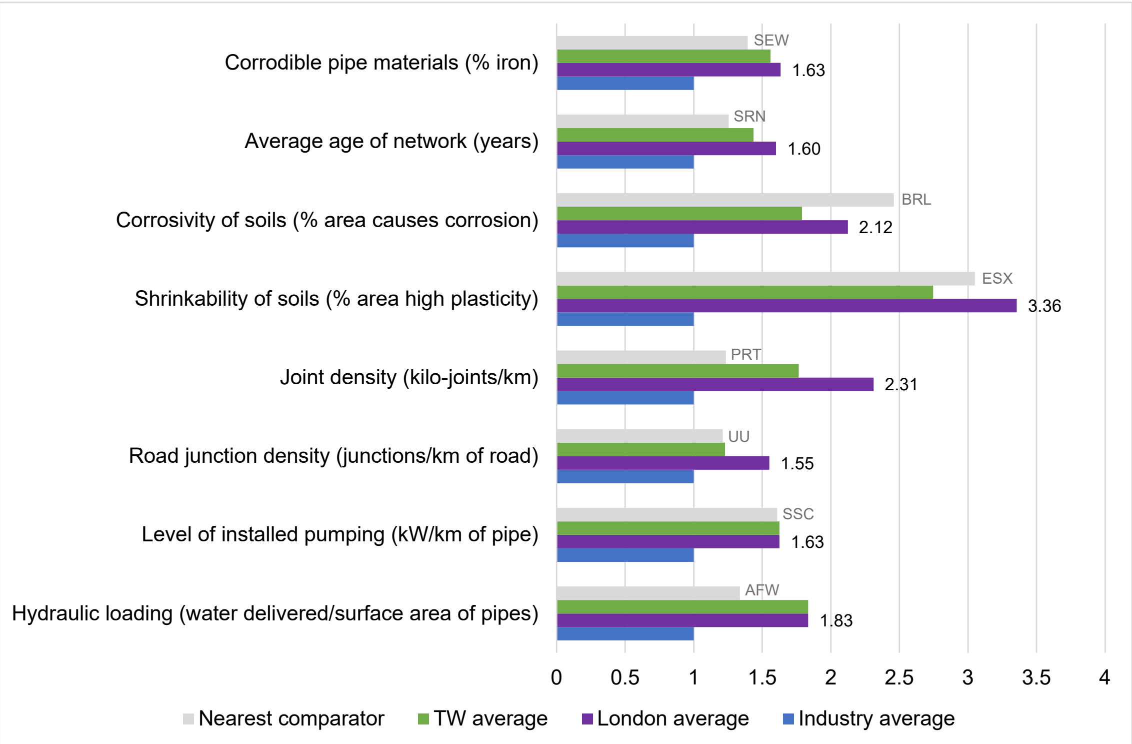
The key challenges for TW from Figure 9.2 are:

- Managing very old, predominantly cast-iron pipes in poor health and in corrosive clay soils to achieve acceptable levels of service for customers at an affordable cost.
- Managing growth in demand and the effects of pumping in a fragile network.
- Containing the effects of weather events on the network and the urban impacts from high traffic volumes and high numbers of road junctions.
- Controlling costs in London's highly urbanised environment where high reinstatement, labour and permitting costs make it the costliest place in the country to do construction work.
- Managing leakage in London where the effect of hard surfaces and clay soils means fewer visible leaks appear on the surface and TW must find more leakage through detection.
- Knowing enough about the health of its buried infrastructure to pinpoint the key vulnerabilities in the network.
- Knowing enough about customer consumption and leakage to know where best to target leak detection efforts.
- Changing the balance of costs and performance affordably.

9.2 Comparative analysis of factors impacting performance and costs

Figure 9.3 shows how London's water network is affected by these factors more than others by comparing London and Thames Water with the industry average and nearest comparator values for a selection of the factors listed in Figure 9.2. It shows that all the factors impacting the performance of TW's network are more severe for London and TW than the average for England and Wales and that in all but one case the factors for London are more severe than the nearest comparator.

Figure 9.3: Comparison of factors impacting asset capability



Source: Source: Mott MacDonald analysis, data based on various data sources listed in Table 4.10

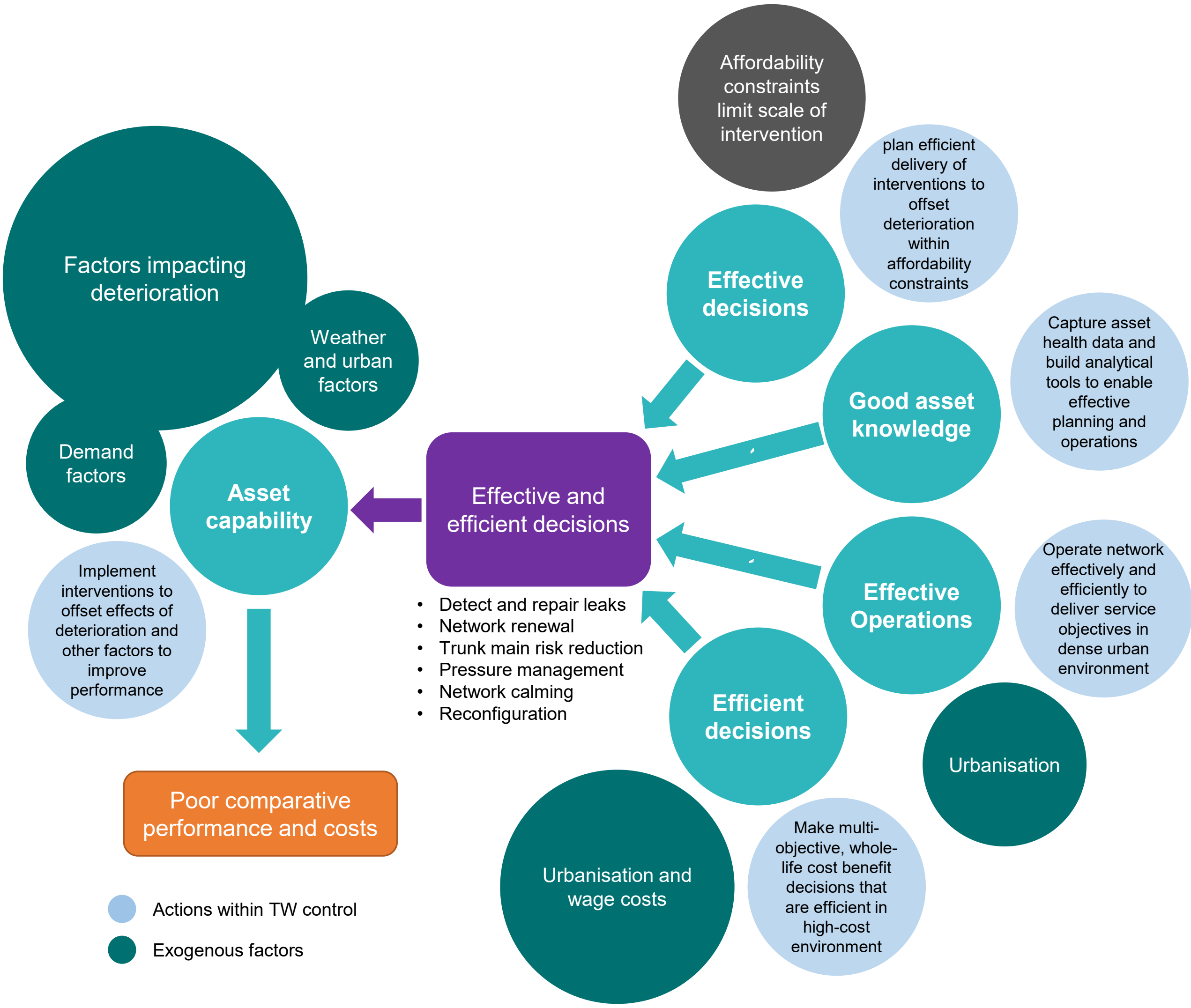
The main exceptional and foundational issue is the material and age profile of the asset base, the scale and age of which marks London out from other networks. This is compounded by the various situational factors, which themselves are more extensive and severe than other parts of the country such as the aggressive soils, various exceptional urban environment related factors and hydraulic factors. This has manifested as exceptionally poor asset health, poor performance and high risk (for example sensitivity to weather shock and high-profile catastrophic failures and major incidents) as clearly evidenced over many years making TW an industry outlier in terms of performance and public perception. This situation is likely to deteriorate as the assets age further and increased customer expectations and demands are placed upon them.

Note that the nearest comparator company is different for each factor, so there is no other company facing a similar combination of challenges.

9.3 Management control over the factors impacting performance and costs

TW has sought to control the factors impacting the performance of London's water network in a positive way within the constraints that it operates. In Figure 9.4 we have shown how the actions that TW takes to control and improve performance interact with the exogenous factors that are causing the network to deteriorate, or which pose a challenge to cost efficiency.

Figure 9.4: TW control over factors impacting performance and costs



Source: Mott MacDonald

Firstly, we show how the exogenous factors causing the deterioration of the network or otherwise negatively affecting its performance are countered by the interventions that TW takes both operationally and through capital investment. The decisions on which interventions to make and when are determined by the four capabilities of: effective decisions, good asset knowledge, effective operations, and efficient decisions. Good asset knowledge is important in making effective decisions, but the scale of intervention has been constrained historically within affordability limits. Operations is effective but affected by urbanisation, both in the costs of repair and leak detection. Decisions can also be efficient but are affected by urbanisation and the high cost of doing construction work in London.

The management actions that TW has taken to date (shown in the pale blue circles) have been successful historically in maintaining service but at a relatively high cost compared with other companies. This is not because TW is inefficient. Benchmarking shows TW's pipelaying costs to be efficient. The cost impacts of urbanisation and wages in London plus the unique combination of a high proportion of cast iron pipes of exceptional age sitting in corrosive soils means that TW must expend more effort and cost than other companies to maintain service.

To improve service and reduce leakage, TW needs to increase its efforts to renew and repair its pipes but is constrained from doing so by affordability constraints and the high cost of doing work in London. But the only way to change the current situation is to renew or renovate more of the cast iron pipes in its network with high failure and leakage rates and to do so as efficiently as possible over an extended period to make it affordable and deliverable.

9.4 Mitigating the factors impacting performance and costs

TW's capabilities for managing the factors within its control shown in Figure 9.2 generally compare well with its industry peers (designated green) but there are some capabilities where more could be done (designated yellow) that would support better decisions and benefit the balance shown in Figure 9.4. We have summarised the improvements and other actions to mitigate the factors impacting performance and costs in Figure 9.5.

The mitigation measures listed in Figure 9.5 have been summarised from chapters 4 to 7 and address the factors affecting performance while minimising the upward pressure on costs from working in London. The measures listed against asset capability include many of those that TW already implements, such as find and fix and mains renewal, but gives some additional attention to pipes at road junctions, especially those found to be shallow compared with TW's asset standards and also reconfiguration options to reduce the impact of pumping by creating greater separation between transmission and distribution.

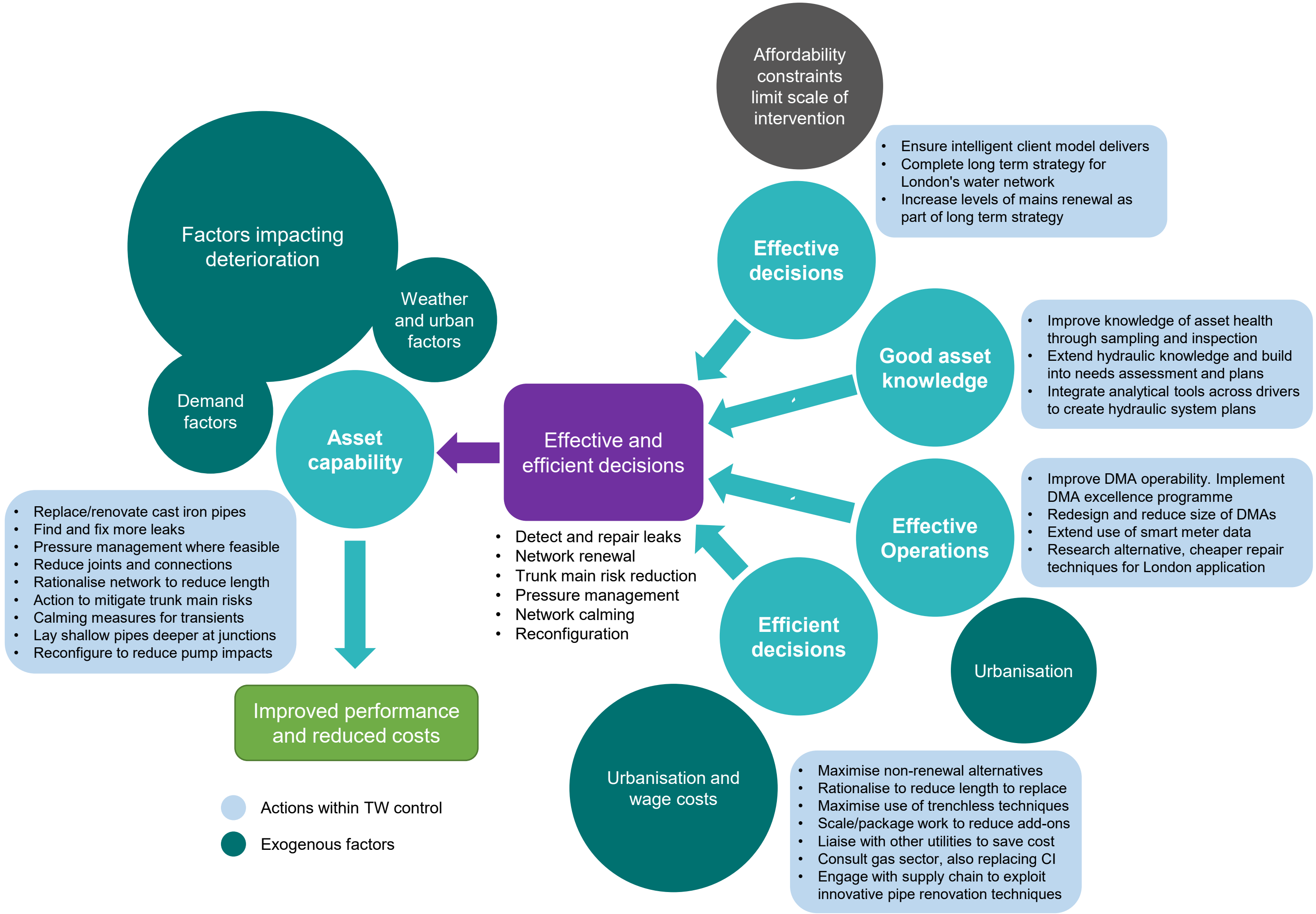
For effective decisions, it is important that the new intelligent client model delivers schemes quickly and efficiently, taking the targeting work from asset management, packaging it appropriately, briefing and appointing contractors and ensuring that the expected benefits are realised. We have also noted a need for a long-term strategy for London's water network, which TW is developing and as part of that, a need to increase the level of mains renewal to improve asset health and resilience. The strategy still needs to consider affordability and the wider investment needs of the business.

Against good asset knowledge, we have noted a need to continue to improve knowledge of asset health with in-the-field sampling, monitoring and inspection to supplement the data that TW already has. We have also identified a need for TW to extend its understanding of the hydraulic behaviour of the network (by increasing model coverage of its network) and to use that knowledge in helping to identify needs as well as for designing solutions. We also feel that the analytical tools that TW has could be integrated to develop hydraulic system plans to consider investment needs and solutions across multiple drivers.

For effective operations, we have focused on improving DMA operability and DMA design to reduce the size of some of London's DMAs. TW already has plans in hand for this as well as making more use of smart meter data when it is available. We have also suggested supporting research into innovative repair techniques to try to reduce the cost and disruption of repairs.

Against efficient decisions, we have listed a number of measures to reduce cost. These focus on prioritising cheaper options where available and rationalising the network to reduce the length of main to renew, given the high cost of construction in London. We have also suggested packaging the work to reduce construction add-on costs (given evidence from AMP4 that whole-DMA replacement of pipes attracted lower construction add-ons than spot replacement work) and we have recommended liaising with other utilities to coordinate work and reduce permitting costs. We have suggested consulting with the gas sector in particular as it needs to replace its cast iron gas pipes by 2032 and therefore represents a good opportunity to share road-space and permitting costs. Finally, we have recommended that TW engage with the supply-chain to consider innovative pipe renovation techniques where they offer resilient solutions at lower cost.

Figure 9.5: Mitigating the factors impacting performance and costs



Source: Mott MacDonald

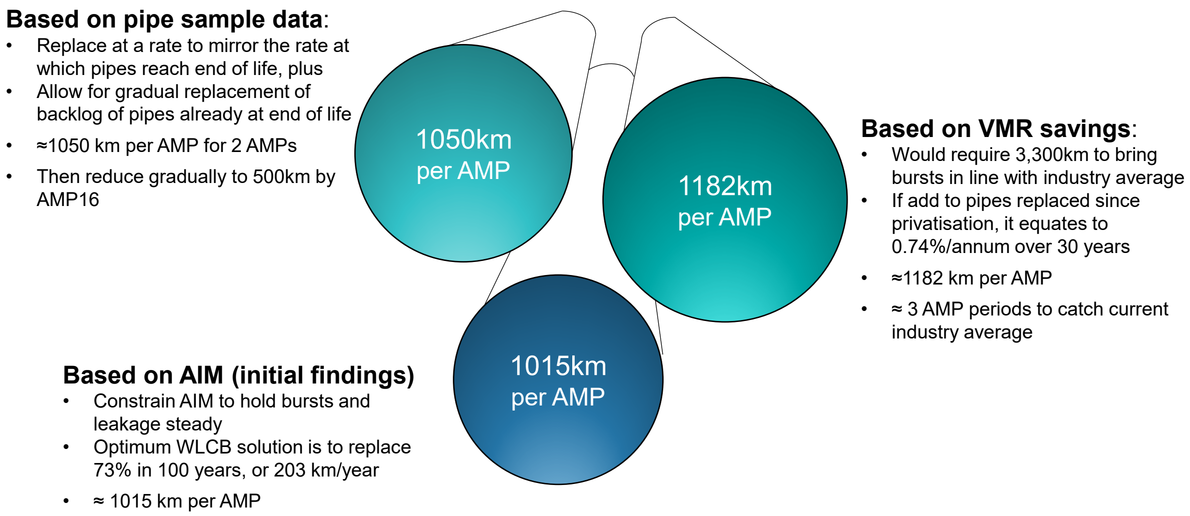
Sustainable level of mains renewal

A key requirement going forward is to increase the rate of renewal of cast-iron water mains to reduce leakage and bursts and improve asset health and resilience. The question is what is the sustainable rate of renewal that optimises the balance of costs and benefits for the long-term?

In Figure 9.6 we have considered this question at a high level from three perspectives:

- Evidence from pipe samples and pit-depth analysis (section 4.1)
- Evidence from the benefits delivered by the VMR programme (section 5.2)
- Evidence from early analysis using TW's AIM model for distribution mains (section 7.5)

Figure 9.6: Sustainable levels of mains replacement for TW



Source: Mott MacDonald

The three sets of analyses for the whole of Thames Water presented in Figure 9.6 are approximate and approach the problem from different angles arriving at similar answers (1000 to 1200 km per AMP).

The pipe sample analysis sets the rate of renewal based on renewing pipes when corrosion has reduced pipe wall thickness to minimum levels. As the rate also allows for the gradual replacement of pipes that have already reached this point (the backlog), it will affect an improvement in performance. The analysis using savings achieved by the VMR programme considers what rate of renewal would have been required to achieve industry average rates of bursts by 2020. The answer suggests that at that rate (1182 km/AMP) it would take nearly three AMP periods to catch up with industry average burst rates.

Finally, initial AIM model results using PR19 costs and benefit values suggests an optimum replacement rate of 1015 km/AMP to hold bursts and leakage steady over the next 100 years. A higher renewal rate is inferred to affect an improvement in performance. These are early results and TW is undertaking further AIM modelling to determine the best profile of investment to maximise whole-life cost net benefits within affordable limits.

These are high-level estimates, and we are not necessarily recommending any of them as the definitive long-term renewal rate, but they are indicative of the order of magnitude of renewals required, higher than previously estimated to offset deterioration (650 km/AMP) but less than that delivered for the VMR programme (2074 km/AMP). TW continues to assess the optimum long-term whole-life-cost-benefit rate of renewal to support its long-term strategy.

9.5 Improving asset management to meet future challenges

In investigating the factors impacting performance and cost of London’s water network, several asset management improvement themes have emerged:

- Developing and embedding a long-term strategy for managing the health of London’s water network that dovetails with long-term plans for water resources and resilience and is adaptive to account for uncertainty.
- Having a process to ensure that short term (1 to 3 year) and medium term (5 to 10 year) plans are aligned with the strategy.
- Improving knowledge of asset health based on more systematic sampling and inspection (rather than relying overly on opportunistic inspections), tied into wider reporting of asset health metrics as part of TW’s asset information strategy.
- Driving innovation to improve and lower the costs of internal pipe inspection and develop novel forms of pipe renovation and repair techniques that can be applied in London’s urbanised environment to renew the network at lower cost.
- Adopting an optimum whole-life cost-benefit (WLCB) approach across multiple objectives to drive long-term investment decisions to ensure intergenerational equity. Ensuring that short and medium-term plans are aligned with this.
- Developing a deeper understanding of hydraulics and incorporating it into targeting decisions and eventually developing a hydraulic ‘digital twin’ by linking calibrated models to telemetry.
- Developing integrated hydraulic system plans that account for growth, asset integrity, leakage, water quality, operational efficiency, and other water network service objectives.
- Capturing productivity data linked to cost drivers to better understand and manage costs.
- Improving the capture of benefits from intervention, the sustainability of those benefits and how they compare with expectations at the planning stage.

Many of these themes align with the findings from Ofwat’s asset management maturity assessment (AMMA) report[48] which TW is considering in developing its strategic asset management plan.

The improved asset management capabilities above will enable water infrastructure planning and the management of asset health and resilience to be more strategically driven and less reactive and be better informed with systematically captured asset health data. The whole-life cost benefit approach will also enable improved service at lower costs for customers in the long-term and a hydraulic digital twin will enable a more agile operational response to events in the network which will be spotted earlier (relying less on customers to call problems in). The focus on productivity data, benefit realisation and research into renovation and repair techniques will address the fundamental challenge that London is the costliest place in the country to do construction work and TW needs to find cheaper ways to replace its aging pipe network.

It is recognised that not all the asset management improvements above are achievable in the same timeframe. Developing a long-term strategy is an immediate priority but developing a hydraulic digital twin and hydraulic system plans will take years and researching new pipe renovation techniques to the point of adoption will likely take longer.

[48] Ofwat, Asset management maturity assessment – insights and recommendations, September 2021

10 Recommendations for strategy

Chapter summary

In this chapter we draw together the recommendations from the earlier chapters for strategic actions to improve the performance of London's water network and reduce costs. We have grouped these into ten categories, and note the chapters where more detail can be found.

These categories are:

- Tactical interventions
- Long-term strategy
- Network policies
- Improving asset knowledge
- Targeting investment
- Achieving inter-generational equity
- Improving hydraulic efficiency
- Calming the network
- Mitigating cost pressures
- Priority actions

As this chapter of the report is a summary of the recommendations from previous chapters, this chapter summary table is purposefully limited so as not to repeat the information which is presented below.

In the sections that follow, we have given each recommendation one of three priority designations: I (immediate - next year), M (medium-term - AMP7), and L (long-term - AMP8 and beyond). We then discuss the priorities in the last section which are summarised in Table 10.1. Some of the recommendations are already being actioned by TW or are planned to be and these are highlighted in blue font in Table 10.1.

10.1 Tactical interventions

We have identified the following tactical interventions from Chapters 4 and 6.

- Set triggers for high-frequency same location repairs (M)

Our analysis of repair frequencies at road junctions revealed that at some junctions, many repairs were undertaken in the same location over a short period of time. A whole-life cost benefit analysis would probably support replacement over continued repair at some of these locations. We recommend that triggers be set to alert asset planners to this so that a decision can be taken on the best course of action. Replacement of short lengths of distribution main could be delivered under DMC (directly managed capital).

- Improve DMA operability through delivery of the DMA excellence programme (M)

Continued improvement in DMA operability is required to improve understanding and targeting of leakage. TW's DMA excellence programme aims to achieve this in AMP7.

- Divide the largest DMAs to improve leakage targeting (L)

Some of TW's DMAs are large and over-complex which is sub-optimal for targeting leakage. Reconfiguring the network to enable them to be divided into smaller ones is not straightforward and will take time to deliver.

- Increase the coverage of acoustic loggers and other leak detection technology (M)

TW has had early success with the 27,000 acoustic loggers that it has installed. They have already enabled the saving of 12 Ml/d of leakage in 2021 by supporting more effective leak detection and location. This recommendation is to consider extending the use of such loggers to other parts of the network and to consider other emerging forms of leak detection technology.

10.2 Long-term strategy

TW's investment plans for water infrastructure, in common with other companies, have been driven by five-year cycles and the lack of a long-term strategy has proved a hindrance in transitioning from maintaining stable serviceability in AMP5 to improving service on a competitive basis in AMP6 and beyond. It is also important to understand how long-term changes in water resources will impact the water network. TW is developing a 50-year strategy for its water network to address these gaps. Recommendations from chapters 4 and 5 are to:

- Set a long-term strategy for distribution mains with an uplift in the rate of renewal to meet long-term objectives for asset health, resilience, and service provision. Ensure that short-term and medium-term plans align with the strategy (I).
- Set a long-term strategy for trunk mains and the ring main to manage risks to service and public safety, accounting for growth, the water resource strategy, and improvements in resilience with adaptive pathways to account for uncertainty. Ensure that short-term and medium-term plans align with the strategy (I).
- As part of the long-term strategy for trunk mains, set a strategy to improve the asset health of the 42" and 48" cast iron trunk mains whose age and condition means that they fail more frequently than desirable for such critical conveyors (I).

10.3 Network policies

Network policies and asset standards govern how water networks are configured and designed to deliver service for the long-term. If large parts of the older and less reliable parts of the system are to be renewed, now is a good time for TW to review its network policies and standards to shape the network it wants to operate in the future, rather than just renew the network it has. From our analysis in chapter 4 we recommend that TW:

- Reviews its network policy on the number of customers to be supplied directly by pumping as opposed to gravity-supplied from a service reservoir. Can the network be reconfigured affordably to create greater separation between transmission and distribution? (I)
- Reviews its network policies and asset standards more generally prior to network replacement to cover requirements for growth, water quality, hydraulic efficiency, and other drivers (I).
- Assesses the implications of any policy changes for legacy assets, not just new assets and address them in the strategy (I)

10.4 Improving asset knowledge

TW has comparatively good information on its assets, but there is room for improvement as identified in Chapter 5.

- Improve records for abandoned and renovated pipes (I)

GIS records focus on operational assets (understandably) but insights into historical performance and trends could be improved if records of abandoned pipes and pipes before they were renovated (and their repair records) were better documented.

- Improve knowledge of asset health of pipes and joints through sampling and inspection (M)

We recommend recommencing pipe sampling of distribution mains and inspection of trunk mains on a systematic basis, (not to rely only on opportunistic inspection), to build up the bottom-up evidence on asset health to validate statistical models and provide confidence in investment proposals.

- Investigate causes of failure at road junctions (M)

We recommend investigating the causes of failure at road junctions, starting with those with the highest failure frequencies, to assess if there are any quick wins and to expand knowledge of the failure mechanisms in highly trafficked areas.

- Improve use of hydraulic models and coverage (I), (M), (L)

We recommend expanding the use of existing hydraulic models to aid identification of needs as well as the design of solutions, expanding the coverage of the network with calibrated hydraulic models (which TW is progressing) and operationalising hydraulic models to make simulated pressure, flow and other data available to Operations (which TW also plans to do).

- Improve systems/data for surge protection and network calming assets (M)

There is currently no dedicated system or single point of access to information on surge protection assets which bridge above-ground and below-ground assets. We recommend creating an information system for such assets as well as creating an asset group so that investment in these assets, including maintenance, can be more visibly managed.

- Improve capture of benefits and their sustainability (I)

We developed a PBI tool to investigate the benefits from past investment (reported in chapter 5) but this is not routinely done and actual benefits delivered are not routinely compared against the expected benefits at the planning stage. TW's DMA fingerprint tool, being near-live, holds promise in being able to do this going forward. As well as monitoring immediate benefits, it is important to continue tracking the benefits to determine how long they are sustained. There is evidence that the benefits from some interventions (e.g. spot-replacement) are eroded over time, whereas other interventions (whole-DMA replacement) are sustained into the long term. It is important to capture this so that it can be accounted for in evaluating differences in whole-life cost-benefits of different types of intervention when setting the long-term strategy.

- Capture of productivity data linked to cost drivers (M)

TW has some productivity data for pipe-laying activities in London, but it is limited and not linked to the cost drivers that affect productivity, such as the impacts of buried services (e.g. enforced hand-dig near fibre-optic cables), traffic management and parking bay suspensions. In the case of trunk mains, where at face value TW's costs appear inefficient relative to benchmarks, there was insufficient productivity data available to support the anecdotal reasons why the costs were higher. Capturing this information in future will be important for a) demonstrating efficiency and b) understanding and managing the cost drivers where they can be controlled.

10.5 Targeting investment

Although TW has a good set of tools for identifying risks and needs and targeting investment, our investigations have identified other factors worthy of consideration in targeting investment. These are reported in Chapter 4.

- Undertake statistical analysis to examine the compounding effect of factors to aid targeting

To prioritise investment, TW needs to understand the combination of factors that best explain localised performance. Notwithstanding that TW's AIM model for water distribution mains does some of this already, we recommend undertaking a follow-on statistical analysis to examine the compounding effect of the full basket of factors identified in this report. This could be done through multi-regression analysis and machine learning.

Undertake statistical analysis to examine the compounding effect of the basket of factors identified in this report to aid targeting

- Refine investment targeting to account for pipe failures at road junctions (I)

Our investigations show that pipes are 40% more likely to fail in London at road junctions than in the roads between. There are many possible reasons for this, including traffic loading and we have recommended that TW investigate the causes (see above), but this may indicate that localised intervention could yield significant benefits in reduced repairs and leakage.

- Use leakage recurrence in targeting decisions (M)

We have found that DMA leakage recurrence is a good indicator of asset health and operational efficiency (high recurrence = poor asset health = poor efficiency) where the data are reliable enough to derive values with confidence. We recommend tracking leakage recurrence as an asset health metric for targeting investment and as an added means of quantifying the benefits from improving asset health in DMAs.

- Identify high and low velocity pipes in identifying needs (I)

For the modelled area we investigated, we found a strong correlation between pipe velocity and frequency of repair with both high velocities (>1.2 m/s) and low velocities (<0.3 m/s) attracting higher failure rates. We consider that an understanding of velocities in the network would aid the identification of vulnerable pipes in the system.

- Take greater account of hydraulic effects (I), (M), (L)

We recommend that more account is taken of hydraulic effects in general, both in the short-term using existing models and in the long-term when on-line models will be available. There is some evidence that high diurnal pressure variance (>25m) can affect the failure of smaller diameter pipes and that tuberculated pipes with high head losses also fail more frequently. This is likely because the pipes are already weakened through corrosion and the additional hydraulic stresses are sufficient to weaken them further to the point of failure.

- Keep under review pressure management opportunities (M), (L)

We note that TW has already implemented pressure management and that opportunities for further pressure management may be limited. We recommend keeping this under review as valve technology evolves (perhaps enabling further benefit from existing PMAs) and reconfiguration of the network creates new opportunities potentially.

- Implement a blend of whole-DMA and targeted mains replacement (M), (L)

The report notes the success of the VMR programme and the sustained benefits and reduced costs achieved from whole-DMA replacement. Equally, it finds that where there are hot-spots of pipe failures at road junctions or high head-loss pipes, then localised renewal may be the best course of action. Overall, we recommend a blend of both approaches where they are supported by whole-life cost benefit analysis.

10.6 Achieving inter-generational equity

We recommended in Chapter 7: Cost of managing the network that whole-life cost-benefit principles are applied when optimising best value investments for improving asset health and service in the long term to ensure inter-generational equity. Affordability constraints can lead to asset planners focusing on short-term measures and leaving poor performing but hard to reach, expensive parts of the network for later. This can place a cost burden on future generations when the short-term measures run out. In many respects, TW is already approaching that point as the most significant opportunities for pressure management, for example, have already been exploited (the same could be said for other water companies).

- Use analysis of optimum whole-life cost benefits (WLCB) to determine the best mix of interventions in the long term (I).
- Align short-term plans to the WLCB profile (I).

10.7 Improving hydraulic efficiency

In chapter 4 we noted that the poor asset health of London's water network affects its hydraulic efficiency (head losses in the system) as well as its performance in terms of leakage and bursts and as significant parts of the system are pumped, this has implications for costs. We recommend that TW:

- Assesses opportunities to improve hydraulic efficiency, especially pumped systems with tuberculated mains (I)

Existing models could be used for this in the short term and improvements in efficiency assessed as part of the design of DMAs targeted for intervention.

- Develop hydraulic system plans that integrate hydraulic efficiency, asset integrity, growth, water quality and operational efficiency and are aligned with the WRMP and plans to improve resilience (M), (L)

This requires the integration of TW's analytical tools to take a holistic view of investment needs at a system level. This is a medium to long-term ambition, i.e. some system plans will be developed in AMP7 with the rest completed in AMP8.

- In the future, aim to operationalise hydraulic models (L)

TW is focusing on extending the coverage of hydraulic network models in AMP7 but has ambitions to operationalise these so that simulated pressures and flows can be used by Operations to optimise the network and receive early warning of anomalies.

10.8 Calming the network

As reported in chapter 4, TW has an identified programme of network calming measures for AMP7, predominantly located in south east London. This is a recommendation to continue that programme into other areas of London where transients occur.

- Continue to explore opportunities to calm the network through transient controls (I), (M)

Calming measures have been shown to deliver immediate reductions in bursts and leakage and may extend the life of corroded pipelines, deferring the need for replacement. TW therefore needs to explore the potential for calming measures before deciding to renew distribution mains. Calming may not always be the best whole-life cost solution however, especially in parts of the network with badly corroded pipes in aggressive soils where the benefits of calming might be short-lived. Calming should at least be considered, however, in determining the best whole-life cost benefit solution.

10.9 Mitigating cost pressures

The following recommendations are documented in Chapter 7: Cost of managing the network and are aimed at mitigating the high cost of construction work in London. These are therefore immediate priorities for the conditional allowance.

- Explore the potential for and cost-benefit case for pressure management and/or network calming before embarking on pipe renewal. (I)
- Maximise trenchless techniques to limit the use of more expensive open cut where the advantages of trenchless techniques can be fully exploited (I)

It is recognised that in many parts of London with high connection density, open cut may still be the most viable and feasible pipe laying technique, but opportunities for trenchless techniques should also be explored.

- Rationalise the network to reduce length to renew (I)
- Scale and package the work to reduce construction add-ons (I)

The construction add-ons for AMP4 and the VMR programme were lower than subsequent work, suggesting a relationship with the scale of work and concentration in specific areas.

- Co-ordinate with other utilities and engage with stakeholders (I)

TW has had success with its TW Connect tool in co-ordinating work with other utilities to share workspace and save on permitting costs. There is also a need to engage with stakeholders such as TfL, highways authorities and borough councils to ensure smooth progress.

- Keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages (M), (L)

This is a general recommendation to remain open to new pipe renovation techniques if they deliver a resilient solution at a lower cost, but equally not to rush into something that may not deliver the long-term benefits of HPPE, for example. New techniques should really be piloted first (see below).

10.10 Driving innovation

In future, TW faces a big pipe renovation challenge across London that is not fundable within historical levels of expenditure unless big changes can be made to the unit costs of replacement. We therefore recommend that TW drives the research agenda by:

- Adopting a pipe renewal procurement strategy that incentivises innovation and efficiency (I)
- Continuing research into inspection techniques to improve knowledge of pipe/joint health (M)
- Supporting research into novel forms of pipe renovation and repair that offer cost savings in the London environment (M), (L)
- Piloting the efficacy, costs and benefits to support plans for AMP8 and beyond (M), (L).

10.11 Priority Actions

We recognise that not all the recommendations in this chapter can be taken forward immediately and some will take time to deliver. In Table 10.1 we have listed the recommendations in the priority order that we have assigned them above. Those in the immediate category will benefit AMP7 and conditional allowance decisions, those in the medium-term category will benefit PR24 and AMP8 decisions and those in the long-term category will benefit decisions in AMP8 and beyond. Some of the recommendations are already being actioned by TW or are planned to be and these are highlighted in blue font in Table 10.1.

Table 10.1: Priority actions

Category	Immediate priorities (next year)	Medium-term priorities (AMP7)	Long-term priorities (AMP8 and beyond)
Tactical interventions	-	- Set triggers for high-frequency same location repairs to alert asset planners - Improve DMA operability through delivery of the DMA excellence programme - Increase the coverage of acoustic loggers and other leak detection technology	- Divide the largest DMAs to improve leakage targeting
Long-term strategy	- Set a long-term strategy for distribution mains with an uplift in the rate of renewal - Set a long-term strategy for trunk mains and the ring main - set a strategy to improve the asset health of the 42" and 48" cast iron trunk mains	-	-
Network policies	- Review policy on the number of customers to be supplied directly by pumping - Review network policies and asset standards more generally prior to renewal design - Assess implications of policy changes for legacy assets and address in the strategy	-	-
Improving asset knowledge	- Improve use of existing hydraulic models - Improve capture of benefits and their sustainability - Improve records for abandoned and renovated pipes	- Investigate causes of failure at road junctions - Capture productivity data linked to cost drivers - Improve knowledge of asset health of pipes and joints through sampling and inspection - Improve use of hydraulic models and coverage - Improve systems/data for surge protection and network calming assets	- Improve use of hydraulic models in Operations
Targeting investment	- Undertake statistical analysis to examine the compounding effect of the basket of factors identified in this report to aid targeting - Refine investment targeting to account for pipe failures at road junctions - Identify high and low velocity pipes in identifying needs - Take greater account of hydraulic effects in identifying investment needs	- Use leakage recurrence in targeting decisions - Take greater account of hydraulic effects - Keep under review pressure management opportunities - Implement a blend of whole-DMA and targeted replacement of distribution mains, where supported by whole-life cost benefit analysis	- Take greater account of hydraulic effects - Keep under review pressure management opportunities - Implement a blend of whole-DMA and targeted replacement of distribution mains, where supported by whole-life cost benefit analysis

Category	Immediate priorities (next year)	Medium-term priorities (AMP7)	Long-term priorities (AMP8 and beyond)
Achieving intergenerational equity	- Use analysis of optimum whole-life cost benefits (WLCB) to determine the best mix of interventions in the long term - Align short-term plans to the WLCB profile	-	-
Improving hydraulic efficiency	- Assess opportunities to improve hydraulic efficiency, especially in pumped systems	- Develop hydraulic system plans that integrate interventions across drivers at a system level	- Develop hydraulic system plans that integrate interventions across drivers at a system level - operationalise hydraulic models
Calming the network	- Continue to explore opportunities to calm the network through transient controls	- Continue to explore opportunities to calm the network through transient controls	-
Mitigating cost pressures	- Explore potential for and cost-benefit case for pressure management and network calming before pipe renewal - Maximise trenchless techniques to limit the use of more expensive open cut where the advantages of trenchless techniques can be fully exploited - Rationalise the network to reduce length of pipe to renew - Scale and package the work to reduce construction add-ons - Co-ordinate with other utilities and engage with stakeholders	- Keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages	- Keep emerging technologies under review and where appropriate adopt innovative pipe renovation techniques where they provide a resilient solution and cost advantages
Driving innovation	- Adopt a procurement strategy for pipe renovation work that incentivises innovation and cost savings	- Continue research into pipe inspection techniques to enhance knowledge of pipe and joint health - Support research into novel forms of pipe renovation and repair that offer cost savings in the London environment - Pilot the efficacy, costs, and benefits of these to support plans for AMP8 and beyond	- Support research into novel forms of pipe renovation and repair that offer cost savings in the London environment - Pilot the efficacy, costs, and benefits of these to support plans for AMP8 and beyond

Source: Mott MacDonald

These recommendations are already being actioned by TW or included in planned work

Appendices

A. Data sources

Title	Author / Published by	Published	File name	Received from	Short description	Type of data
APR Industry Datashare 2017			APR Industry Datashare 2017 v4 (no macro)	Aly Hawkins	Annual return data, years 2-5 of AMP6	Spreadsheet
APR Industry Datashare 2018			APR Industry Datashare 2018 V4	Aly Hawkins	Annual return data, years 2-5 of AMP6	Spreadsheet
APR Industry Datashare 2019			APR Industry Datashare 2019 Final v2.1 no macro	Aly Hawkins	Annual return data, years 2-5 of AMP6	Spreadsheet
Network Breakage and DMA Fingerprinting, Executive Summary	Thames Water	Jul-19	Network Breakage Exec Summary report July 2019 v3	Steve Roberts (TW)	DMA fingerprinting	Report
The Impact of Burst-Driven Mains Renewals on Network Leakage Performance (Report Ref. No. 18/WM/08/67)	UKWIR	2018	UKWIR impact of burst driven mains renewals	Steve Roberts (TW)	Kilo-joint concept	Report
Mains repairs database	Thames Water		MainsRepairs.gdb	Richard Tull (TW)	Output of the mains repair data - GIS file - SAP data	GDP
A Report for Thames Water - Transient Pressure Analysis	ICS Consulting	Jun-20	20200619 THAM Transient Pressure v0.98	Richard Tull (TW)	Report on surge/bursts correlation (weak link)	Report
Clean Water Asset Data (GIS)	Thames Water		CleanWaterNetwork.gdb	Richard Tull (TW)	TW GIS data - CW asset data	GDP
Distribution mains AIM model	Thames Water		200320113155_AIM Distribution Mains	Richard Tull (TW)	AIM data (distribution mains)	CSV
Thames Water Mains Replacement Programme Independent Review	Black & Veatch	10-May-12	TWMRPIR Findings and Recommendations Report v 1 2	Anthony Owen	Mains Replacement Independent Review	Report
Thames Water Mains Replacement Programme Independent Review - Phase 1	Black & Veatch	19-Sep-11	MRPIR Phase 1 Draft Second Issue RevB	Anthony Owen	Mains Replacement Independent Review	Report
Long Term Distribution Mains Deterioration Rate Analysis – Phase 1 – Literature Review and Available Data	GL Industrial ServicesUK Ltd	15-Jun-12	T0489 Deterioration rate - Stage 1 report [Final] GL June2012	Steve Roberts (TW)	Deterioration rates study	Report

Title	Author / Published by	Published	File name	Received from	Short description	Type of data
Long Term Distribution Mains Deterioration Rate Analysis - Phase 3 - Sample programme and rehabilitation rate curves	GL Industrial ServicesUK Ltd	11-Jul-13	T0490 Deterioration rate - Stage 3 report V1 2 FINAL	Steve Roberts (TW)	Deterioration rates study	Report
Review of GL project for Thames Water - Long Term Distribution Mains Deterioration Rate Analysis	Wellington Associates	14-May-13	T0491 Material Deterioration Review of GL Project for Thames Water v2	Steve Roberts (TW)	Deterioration rates study	Report
Evidence - connections left after terraced houses replaced by large flats	Thames Water		Evidence - connections left after terraced houses replaced by large flats	Anthony Owen	Abandoned connections	Report (ppt)
Long term trends in London fractures - Business Summary	Thames Water	25-Aug-98	IR11-Long term trends in London fractures, business strategy.980825	Anthony Owen	Assessment of yearly increase in fracture rates based on repair data (1920-1997)	Report
Condition Analysis of Fractured Pipes - Winter Leakage Event 2001_2	Thames Water	Jan-03	VMR - IR12-Condition Analysis of Fractured Pipes - Winter Leakage Event 2001_2	Steve Roberts (TW)	Victorian Mains Replacement VMR	Report
Condition Analysis of Thames Water's Water Distribution Mains	Thames Water	Jan-03	VMR - IR13-Condition Analysis of Thames Water's Water Distribution Mains	Steve Roberts (TW)	Victorian Mains Replacement VMR	Report
Understanding Pipe Condition and Performance - Street Exhumations SUH7	Thames Water	Jul-04	VMR - IR5a-Understanding Pipe Condition and Performance - Street Exhumations SUH07	Steve Roberts (TW)	Two streets project Phase 2, Victorian Mains Replacement VMR	Report
Failures in steel and cast-iron mains and provisions for their protection	Eric Field Reid, M.A., Assoc. M. INST. C.E. (ICE)		Research - Failures in steel and cast iron mains (paid)	Steve Roberts (TW)		Report

Title	Author / Published by	Published	File name	Received from	Short description	Type of data
			Research - Historical Cast Iron Water Mains London	Steve Roberts (TW)		Spreadsheet
BGS geohazard layers for large urban areas in England (GIS file)	BGS		Thames Water BGS data 29-04-21	Rick Crowhurst (Landmark)	BGS geohazard layers for large urban areas in England (GIS file)	GIS file
Trunk mains inspection database	Thames Water		TW_Data_Export 30 03 2021	Tim Evans (TW)	Trunk mains opportunistic inspection data	MS Access database
FA1367 Trunk Mains NDT Testing Hydrosave Final Agreement			FA1367 Trunk Mains NDT Testing Hydrosave Final Agreement_tech spec only	Tim Evans (TW)	New trunk mains NDT spec for Hydrosave (technical specification only)	Framework agreement
Mains repair schema			Mains Repairs SCHEMA UPDATE April 2021	Richard Tull (TW)	Explanation of the mains repair database fields	Spreadsheet
Network pumps database	Thames Water	-	Pump Data.zip	Richard Tull (TW)	Pump curve database	Various files
London Zonal Performance Reports			London Zonal Performance Reports	Richard Tull (TW)	London Zonal Performance Reports for 27 FMZs	Reports
Barrow Hill and Shootup Hill FMZ hydraulic model			Barrow Hill and Shootup Hill FMZ hydraulic model	Richard Tull (TW)	Flow, velocity, and pressure results.	Model
Review of bend strength analysis to assess pipe condition	Thames Water	31-Mar-03	Two Streets phase 1 - Final report and appendices	Tim Evans (TW)	Two streets project Phase 1, Victorian Mains Replacement VMR	
Condition analysis of clean water mains from the Finsbury Park 10 DMA	Thames Water	Jun-03	Two Streets phase 2 - Final report and appendices	Tim Evans (TW)	Two streets project Phase 2, Victorian Mains Replacement VMR	
Isle Leakage Management - Best Practices Workshop Asset Management (Mains Renewals)	Thames Water	Sep-20	Isle Asset Management - Final	Steve Roberts (TW)	Isle Mains Renewal Best Practices workshop (presentation) • Statistics on pipe stock, growth rate, why London is different • mains renewal journey from AMP1 to AMP6 • appraisal of the VMR programme • Recommendations from Independent review of	ppt

Title	Author / Published by	Published	File name	Received from	Short description	Type of data
					mains replacement • Brief plans for AMP7, DMA Fingerprinting, Calm networks	
Isle Leakage Management Benchmarking - Industry Summary Report	Isle	16-Oct-20	201030 Leakage Management Benchmarking - Industry Summary Report	Steve Roberts (TW)	Isle Leakage Management Benchmarking Program (Oct 2020) • Benchmarking exercise to capture an objective basis of performance evidence towards reducing Non-Revenue Water • participants: from UK, Australia, Brazil • Key metrics and industry observations for NRW, leakage pillars (pressure management, active leakage control, speed and quality of repairs, asset management), recommendations	Report
Isle Leakage Management Benchmarking - Utility Report - Thames Water	Isle	30-Oct-20	201016 Leakage Management Benchmarking - Utility Report - Thames Water 201016	Steve Roberts (TW)	As above + detailed Thames Water information (Oct 2020)	Report
Network valves database	Thames Water		ValvePounds_Final_TV_v1	Richard Tull (TW)	valve database	
Estimating DMA Recurrence	Richard Cocks / Thames Water	Aug-20	DMA Recurrence presentation 1	Richard Cocks (TW)	presentation on visible bursts, that shows how we estimate an approx. 45% reduction due to VMR	
Estimating DMA Recurrence	Richard Cocks / Thames Water	Aug-20	DMA recurrence table	Richard Cocks (TW)	DMA recurrence presentation that illustrates how we are looking at recurrence, and has plenty of examples	
Modelling Thames Water's Visible Bursts, including the impact of VMR	Richard Cocks / Thames Water	07-Jun-21	Modelling Visible Bursts, including the impat of VMR	Richard Cocks (TW)	results table from the DMA recurrence work – for each DMA two values are generated for each year, and compared. I'm afraid inscrutable SAP is preventing inclusion of any data beyond Dec 2019 at the moment.	
Estimating Savings per Repair, and Recurrence	Richard Cocks / Thames Water	09-Jun-20	Savings per repair and recurrence v5	Richard Cocks (TW)	pack because slides 11, 17 and 18 provide a whole-company perspective on recurrence	

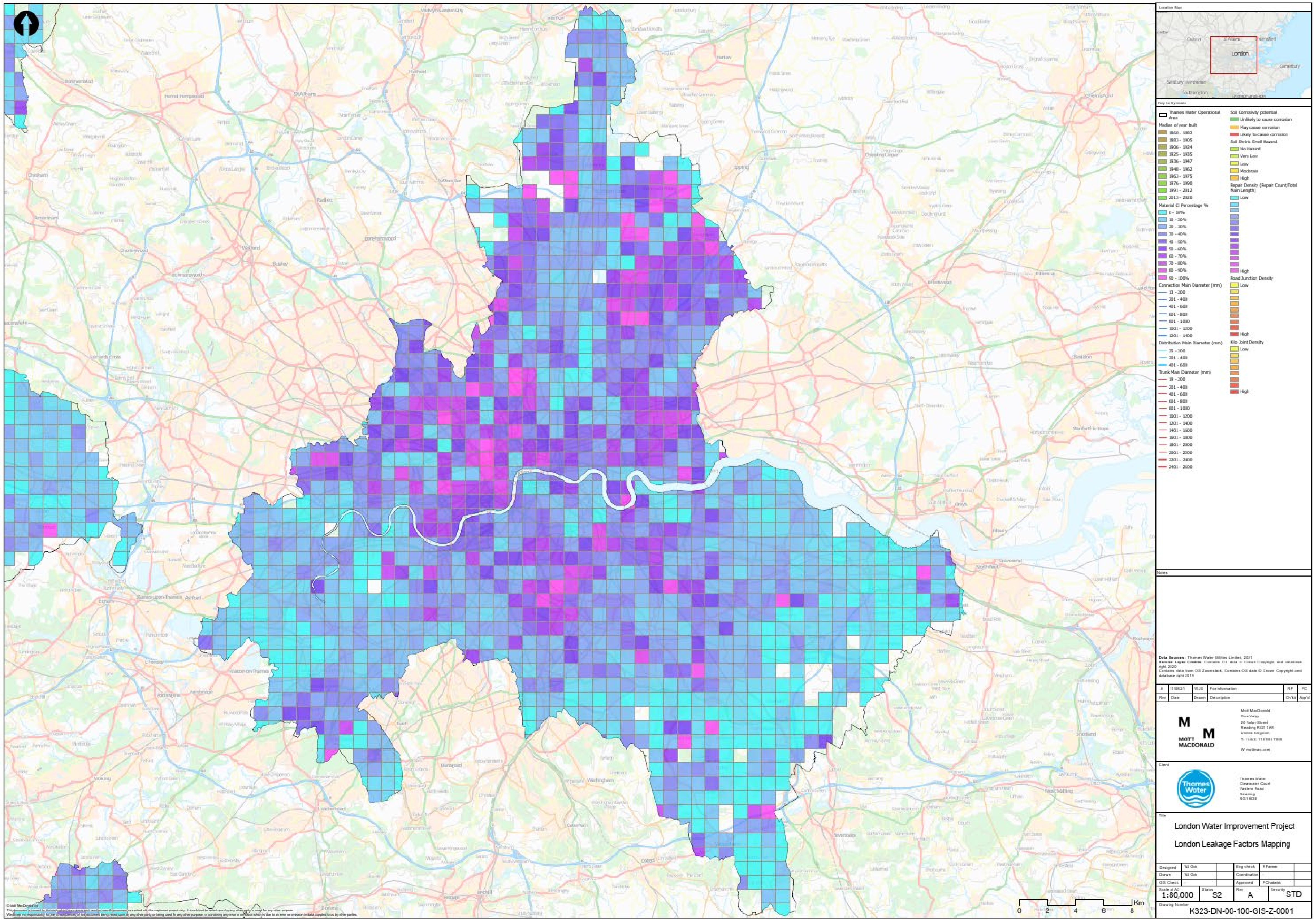
Title	Author / Published by	Published	File name	Received from	Short description	Type of data
Isle Leakage Management - Best Practices Workshop Asset Management (Mains Renewals)	Thames Water	Sep-20	Isle Asset Management - Final_ISSUED	Steve Roberts (TW)	Isle Mains Renewal Best Practices workshop (presentation) • Statistics on pipe stock, growth rate, why London is different • mains renewal journey from AMP1 to AMP6 • appraisal of the VMR programme • Recommendations from Independent review of mains replacement • Brief plans for AMP7, DMA Fingerprinting, Calm networks	ppt
London water network resilience – Response to Ofwat's letters	Thames Water	24-Mar-17	Response to Ofwat letters_Final clean_	Steve Roberts (TW)	2017 report on London water network resilience – response to Ofwat • In response to concerns raised by Ofwat with regard to the trunk mains bursts between Oct 2016 - Jan 2017 • Description of TW's internal programme to investigate and ameliorate this issue, including the Forensic Review and the Strategic Review, commitment of £77M + £20M additional funds • Assessment of the mains replacement programmes over AMP4, AMP5 and AMP6 and plans to improve	Report
Isle Leakage Management - Best Practices Workshop - Speed and quality of repairs	Thames Water	Sep-20	Speed and Quality of Repairs - Isle Utilities Best Practice Workshop_ISSUED	Steve Roberts (TW)	Isle Speed and Quality of Repairs Best Practices workshop (presentation) • Statistics on pipe stock, growth rate, why London is different • Operating environment (site access, traffic management, planning constraints, stakeholder engagement) • Types of repair, quality assurance and cycle times	ppt
Victorian Mains Replacement - 1603-1903km - the case for more activity in AMP4	Thames Water	Mar-08	VMR - 1603-1903km Case for more activity in AMP4 - Final report 270308	Steve Roberts (TW)	2008 report on VMR, the case for an additional 300km of mains replacement activity in 2009-10.	Report
Water Networks Baseline Opex Activities	Thames Water	09-Mar-18	Water Networks Baseline Opex Activities - 09.03.18	Steve Roberts (TW)	Estimated opex costs for different activities (spreadsheet). This is the spreadsheet Steve shared during the meeting. As discussed in our call, these are average costs, used to build budgets.	spreadsheet

Title	Author / Published by	Published	File name	Received from	Short description	Type of data
All MRP,VMR and DMR Data from EES (Mains Replacement)	Thames Water		All MRP,VMR and DMR Data from EES (Mains Replacement)	Paul Smith (TW)	All MRP,VMR and DMR Data from EES (Mains Replacement)	
Effect of Region and Pipe Material on size of Mains Leaks	Richard Cocks / Thames Water	14-Jun-21	Effect of Region and Pipe Material on leak size	Richard Cocks (TW)	Average mains leak size (as measured by repair saving) by region and by material	
Leakage in Mains Repair Backlogs	Richard Cocks / Thames Water	22-Jun-21	Leakage in Mains repair backlogs	Richard Cocks (TW)	Ml/d value of mains leaks found but not yet repaired, by week, by region	
Leakage in Mains Repair Backlogs	Richard Cocks / Thames Water	25-Jun-21	Leakage in Mains repair backlogs v2	Richard Cocks (TW)	Ml/d value of mains leaks found but not yet repaired, by week, by region. Updated with visible leaks data	
20210630 IBP2B WN totex and activity summary			20210630 IBP2B WN totex and activity summary	Kyle Robins (TW)	March 2021 opex and capex forecast for Water Networks broken down by activity and taken from our strategic model.	
Book1 MJUBB			Book1 MJUBB	Kyle Robins (TW)	File received from finance breaking down repair costs by region.	
FY21-22 v7.0 (Q1RF) Orderbook			FY21-22 v7.0 (Q1RF) Orderbook	Kyle Robins (TW)	Latest orderbook revised by Operations, to recover leakage performance (which was behind our plan at the end of FY21). It builds up activities by region for each of the operational leakage workstreams.	
Strategic Business Plan – April 2004, Part A – The Company Strategy	Thames Water	Apr-04	PR04 - Final Business Plan - Part A_Redacted	Lana Kraine (TW)	PR04 business plan, redacted	
Final Business Plan Submission for the 2009 Price Review, Part A – The Company Strategy	Thames Water	Apr-09	TW FBP Apr 09 Part A Adj _Redacted	Lana Kraine (TW)	PR09 business plan, redacted	
Thames Water PR19 Cost Efficiency Challenge Report - A study into comparative efficiency of Thames Water's PR19 Business Plan Wholesale Capex	Mott MacDonald	04-Feb-19	PR19 Cost Efficiency Challenge (Issue 2, Draft) PDF	Will Betts (TW	A high level analysis of the efficiency and sufficiency of TW's PR19 overall business plan costs based on a comparison with other company planned costs at the time.	

B. Geospatial mapping of external factors

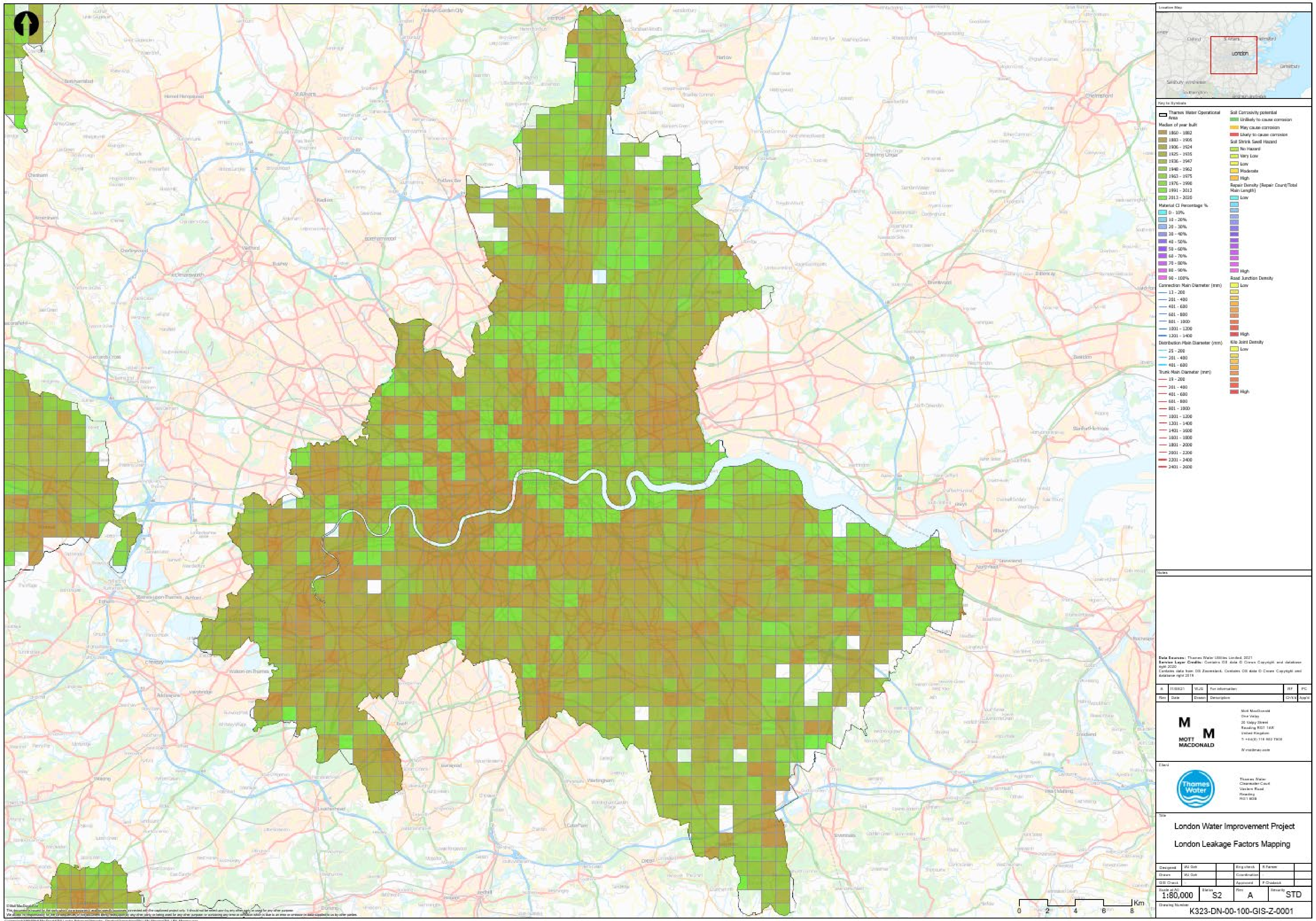
Interactive PDF to be inserted in final issue to improve resolution of small text.

Figure B.1: Repair density (repair count/total main length)



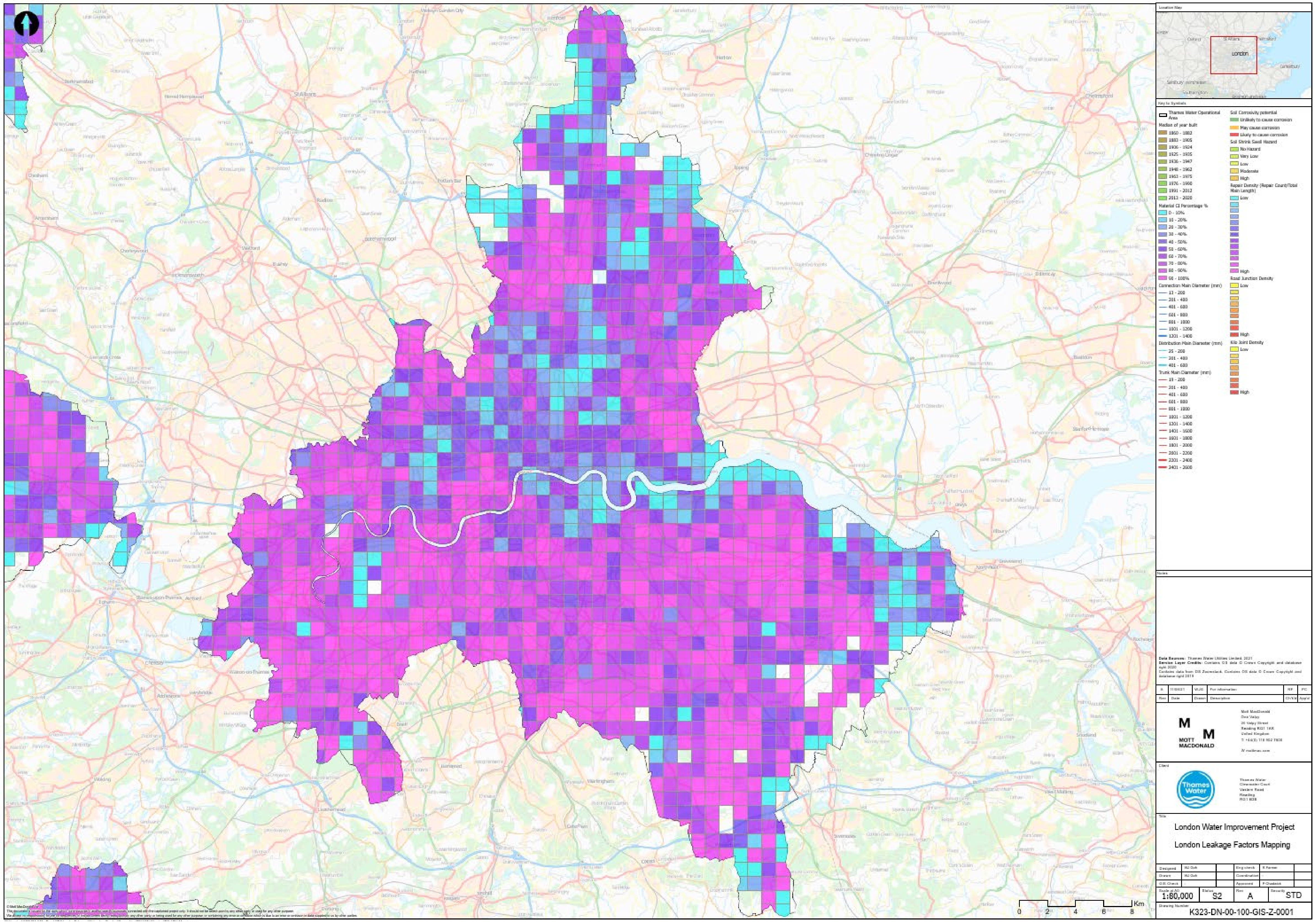
Source: Mott MacDonald

Figure B.2: Median age of pipe



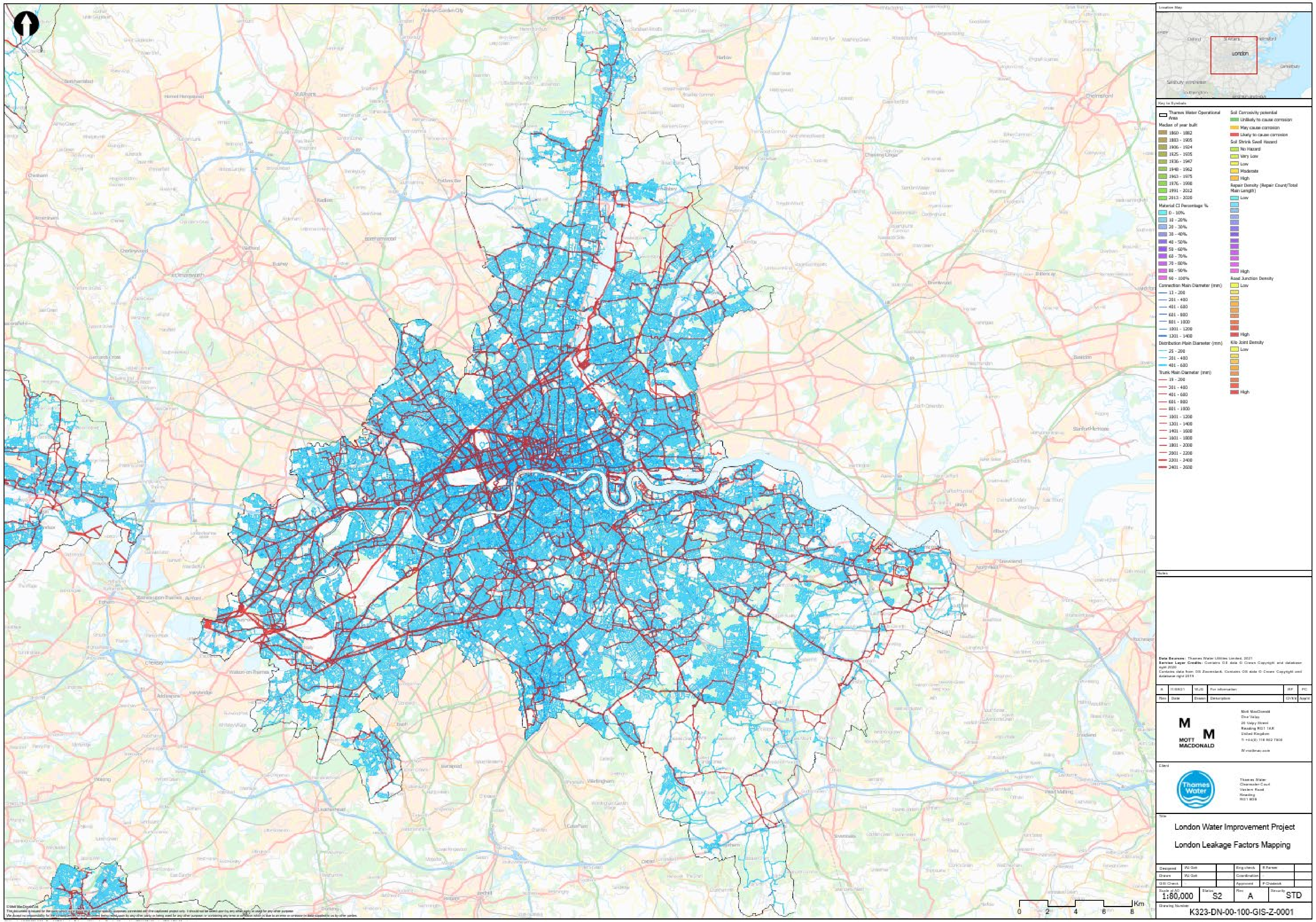
Source: Mott MacDonald

Figure B.3: Material CI percentage



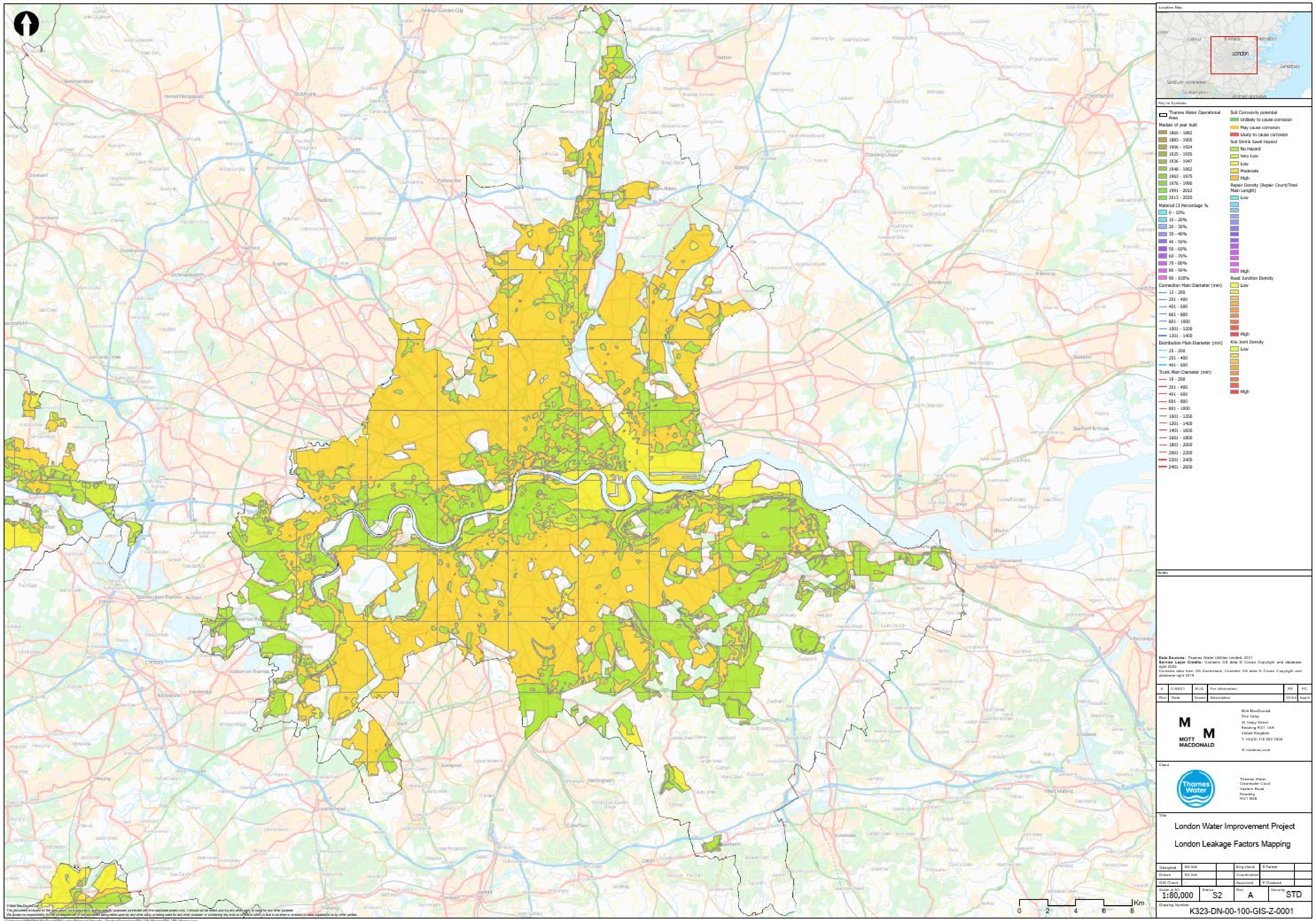
Source: Mott MacDonald

Figure B.4: CW Mains Diameter (mm)



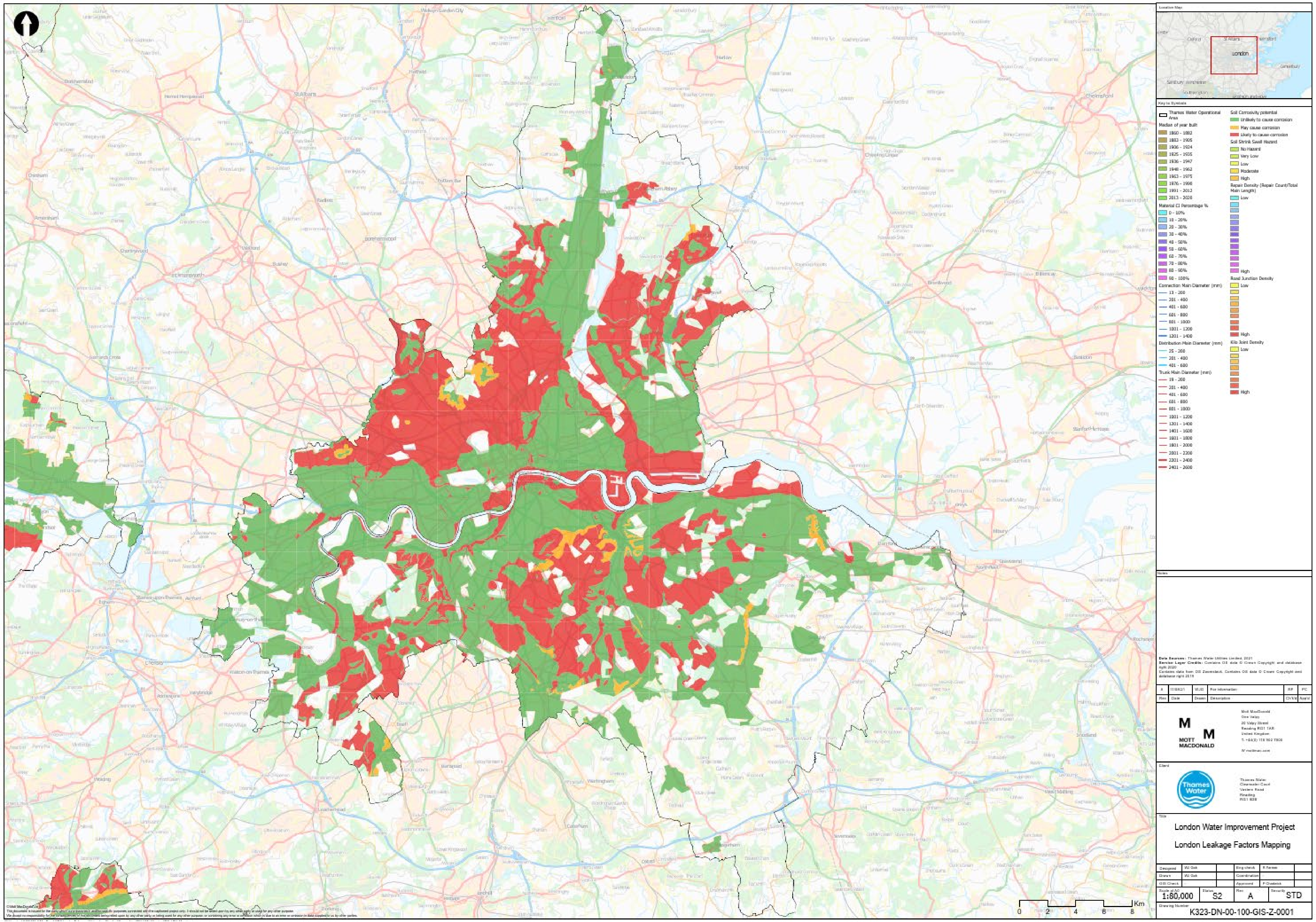
Source: Mott MacDonald

Figure B.5: Shrink swell hazard



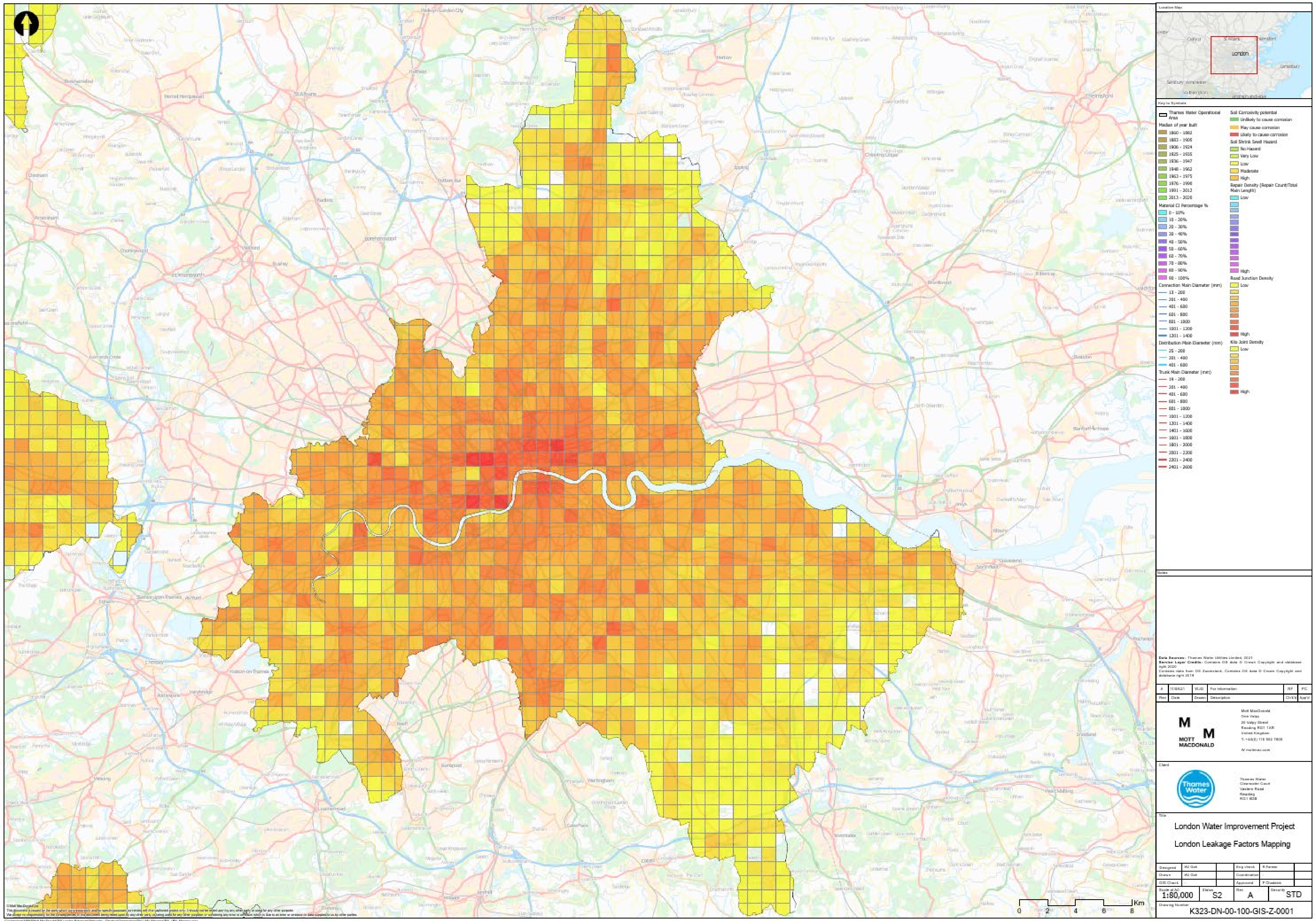
Source: Mott MacDonald

Figure B.6: Soil corrosivity potential



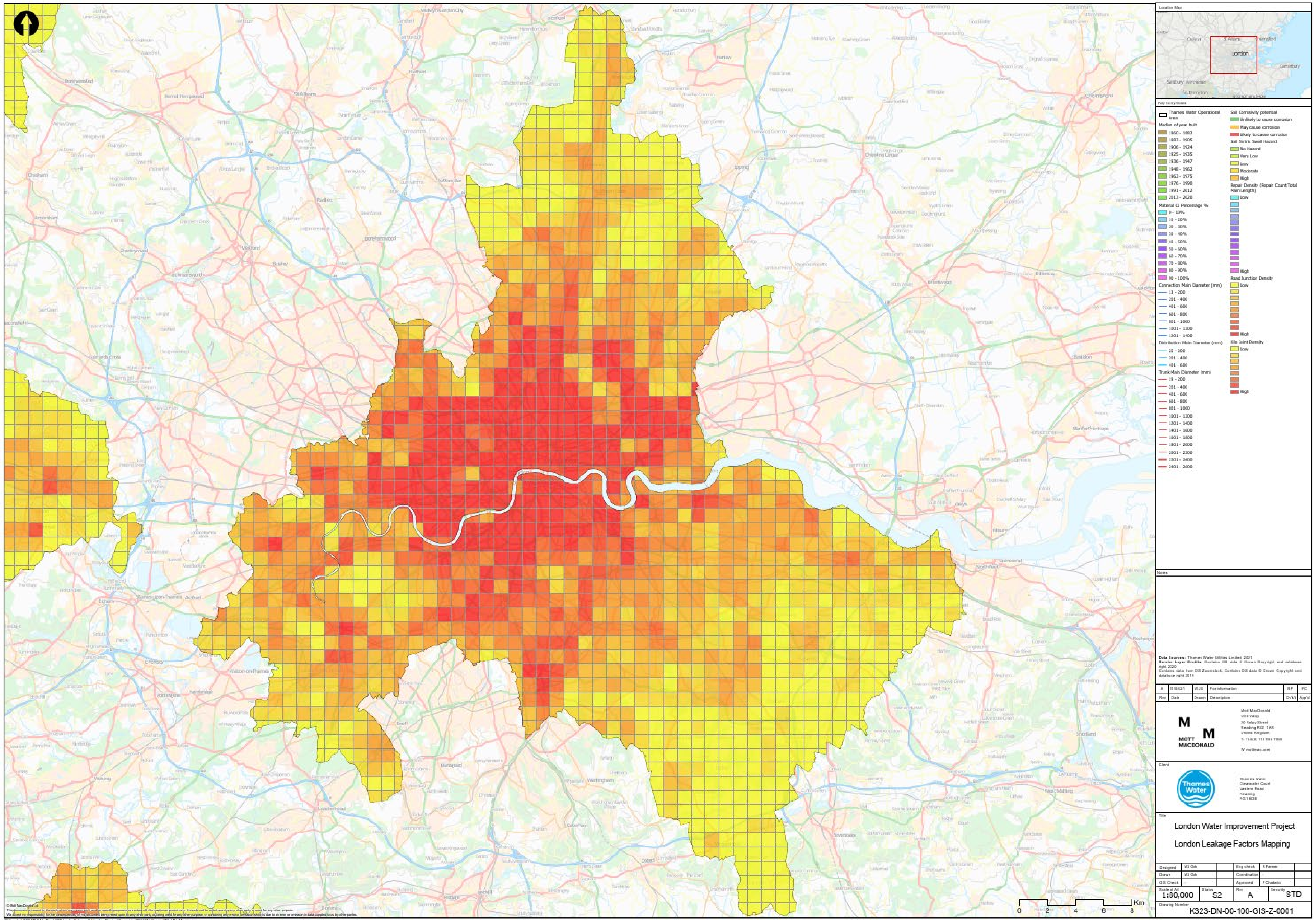
Source: Mott MacDonald

Figure B.7: Road junction density



Source: Mott MacDonald

Figure B.8: Joint density



Source: Mott MacDonald

C. Global practice – available technologies

C.1 Inspection technologies

Table 10.2: Available inspection technologies for pressure pipes

Method	Soil corrosivity surveys	Acoustic	Remote field electromagnetic	Ultrasonic	Magnetic flux leakage	Broadband electromagnetic	Other	Typical recommended approach
Description	Various electromagnetic, electrical, and laboratory methods characterise the corrosivity of soils, detect/measure corrosion activity, and assess effectiveness of corrosion protection / cathodic protection	Acoustic velocity: pipe wall stiffness is calculated from the speed of sound transmission Acoustic monitoring: alerts and pinpoints the location of wire breaks	Changes is electromagnetic signals indicate broken wires, corrosion pies, and changes in wall thickness and stress anomalies	Reflection of sound waves is used to measure the thickness of various types of materials. Tool must have direct contact or liquid coupling with material being measured	Changes in magnetic fields are used to detect corrosion pits and other defects. Tool must be at constant, close distance from pipe wall.	Changes in electromagnetic signals indicate corrosion pits and changes in thickness. Scanner held near pipe, but works through coatings, linings and scale.	Sampling of pipes for various physical tests. Manned entry for visual sounding (delamination testing) Petrographic (microscopic examinations of concrete and mortars.	General approach (all pipe types): 1. Statistical analysis of available data 2. Risk prioritisation (likelihood and consequence of failure) 3. Records review (leak/break repairs, drawings, specs, reports, soil info) 4. Site reconnaissance (accessibility, traffic conditions, other utilities) 5. Inspection planning (shutdowns, bypass, permits, alternative) 6. Leak detection and/or field condition assessment inspection.
Asbestos cement	Assess potential for AC (concrete) deterioration (pH and sulfates)	Acoustic velocity can detect gross deterioration	n/a	n/a	n/a	n/a	Testing of samples: ● Phenolphthalein stain ● SEM/EDS ● petrography	7. Tests of opportunity samples from repairs and service taps 8. GIS mapping of soil data, breaks, and condition assessment data 9. Targeted condition assessment of high-consequence pipes
Prestressed concrete cylinder	Assess potential for metal and concrete deterioration Detect active corrosion	Acoustic monitoring for detection of wire breaks. Acoustic velocity can be used for prioritisation of other assessments.	Used to detect broken wires.	n/a	n/a	External and internal spot assessments	Internal sounding to detect delamination. Internal visual (manned entry or CCTV). External direct assessment Petrographic analysis of mortar / concrete	10. Risk analysis based on pipe type, manufacturer, wire type, year of manufacturing, corrosivity 11. Manned entry / sounding (if feasible) 12. Electromagnetic scanning 13. Acoustic monitoring
Non-prestressed concrete	Assess potential for metal and concrete deterioration Detect active corrosion	n/a	Emerging method to detect broken cylinder corrosion	n/a	n/a	External spot assessments. Emerging method for internal scanning	Internal sounding to detect delamination Internal visual (manned entry or CCTV) External direct assessment Petrographic analysis of mortar / concrete	14. Corrosivity survey 15. External direct assessment where corrosion risk is highest 16. Manned entry examination 17. Electromagnetic scanning
Ductile iron and cast iron	Assess corrosivity to iron Monitor corrosion activity	Acoustic velocity can detect gross deterioration	Detailed internal scan of pipes and external spot assessment. Works with cement mortar and tuberculation	Used for external spot assessments	Internal scanning of non-CML lined pipes. External spot assessments.	External spot assessments. Emerging method for internal scanning	Petrographic analysis of mortar	18. Corrosivity survey 19. Remote field electromagnetic
Steel	Assess potential for metal and concrete deterioration Monitor corrosion activity	Acoustic velocity can detect gross deterioration	Used for detailed internal scan of pipes. Works with cement mortar and tuberculation	Used for external spot assessments	Internal and external scanning of both CML and non-CML pipes	External spot assessments. Emerging for internal scanning	Petrographic analysis of mortar	20. Corrosivity survey 21. Pipe-to-soil potential; cathodic protection assessment 22. Remote field electromagnetic or magnetic flux leakage
Copper	Assess potential for metal deterioration	n/a	Used for detailed internal scan of pipes	n/a	n/a	Potential for detailed scan of pipes	Forensic examinations of failed pipes Electrochemical noise monitoring	23. Evaluate construction methods and standards 24. Evaluate soil corrosivity 25. Forensic exams of failures
Plastic pipes (HDPE, PVC)	n/a	n/a	n/a	n/a	n/a	n/a	Forensic examinations of failed pipes, failed pipes, using laboratory and mechanical tests	26. Review of drawings, specs, and inspection records 27. Forensic examination if early or frequent failures have occurred

Source: Condition Assessment of Water Mains, M77 AWWA Manual

C.2 Locating leaks by sound

Locating leaks by sound is the basis of the majority of leak detection techniques and electronic equipment currently available:

- The traditional 'listening stick' equipped with an earpiece is used with one end of the stick placed on an exposed part of the main, and the other placed against the ear. An experienced waste inspector can recognise the sound emitted by a leak, even at 10-15m distance. By listening at another point of contact on the main, the inspector can judge by the difference in sound volume the probable location of the leak. this method is very labour intensive and is relatively ineffective on non-metallic pipes. In the UK where many service connections do not leak an inspector can sound up to 200 connections per shift. Overseas where pressures are lower and background conditions are less favourable, an experienced inspector should be able to sound 80-120 connections per day on average.
- Ground microphones, first introduced in the 1960s, amplify the sound of a leak and are effective for leaks from non-ferrous pipes. However, that not all leaks emit an audible sound, and the volume of sound is mostly not related to the size of the leak.
- Leak noise correlators, which have been available for about 40 years, are electronic devices used to analyse the sound of a leak picked up by sensors in contact with the pipe. The technology continues to be developed and are effective for all pipe materials and easy to use by less experienced operators.
- Acoustic loggers are used both to detect and locate leaks. When permanently installed, they monitor continuously for changes in noise characteristics, an indication of changes in network flows and possible leakage. The loggers are downloaded periodically either remotely or manually. Sets of loggers temporarily deployed – for 1-2 days to longer periods – can be used to target an area with the aim of reducing the baseline leakage level in the zone. According to equipment suppliers, the location accuracy is sufficient for instructing the repair work without the potential risk of digging a 'dry hole'. However, it is good practice to confirm the location on site using a leak noise correlator where the work is constrained by third parties.

C.3 Locating leaks by tethered in-pipe inspection tools

Tethered in-pipe inspection tools, such as Sahara and JD7t technologies comprise a sensor attached to a cable which is inserted into a pipe through a tapping point. The technology provides accurate location of specific features is repeatable so that a database of pipe condition can be developed over time.

- Sahara is deployed through a 50mm tapping, such as an in-line through bore hydrant or existing air valve. It is inserted under pressure while the pipeline is in service and has a range of 2km from the insertion point. The sensor is suitable for all material types and pipes of 150 mm diameter and larger. Readings from the sensor can be tracked on the surface and located to within 500 mm. The pipe wall assessment sensor, requiring a 100 mm diameter tapping, is used to assess the internal condition of metallic pipes of 400 mm diameter and larger.
- The JD7t tethered technology involves installing the sensor through an in-line fire hydrant. Different sensor heads can be deployed including camera, hydrophone for detecting leaks and ultrasonic scanner to produce a full diameter survey of the pipe wall thickness.

C.4 Locating leaks – other technologies

Free swimming sensor technology involves an acoustic sensor contained within a foam ball, which is inserted and retrieved through pipe tappings or other in-line network assets. The progress of the foam ball is tracked by detectors attached to fittings. Leaks can be located to within 3 m in pipes of 150 mm diameter and above including in larger diameter trunk mains. Sensors are also available to record flow rates along the pipe, the locations of valves, pipe joints and other fittings and the condition of the pipes.

Other techniques:

- robotic pipeline inspection vehicles suitable for inspecting larger diameter pipes,
- tracers and gas injection; gas injection is suitable for low-pressure systems and non-metallic and small diameter pipes,
- ground penetrating radar and thermal imaging to identify changes in soil moisture.

The more sophisticated tools tend to be more expensive to deploy and usually require a specialist contractor.

C.5 Pipe cleaning methods

Flushing is a technique used for small diameter mains where the mains pressure is adequate. It is an effective technique for removing loose sediment and for flushing polluted water from a pipe. It is not appropriate where there is an underlying persistent problem with sediments and discoloration which can only be resolved by eliminating the source of the contaminants. In practice pipes up to about 100 mm diameter can be flushed through one or two hydrants supplied from both ends provided there is adequate pressure in the main. For larger diameter pipes, flushing generally needs to be through three or more adjacent hydrants, supplied from one direction only. Achieving this may be difficult due to the system hydraulic conditions, and flushing is unlikely to be effective on mains over 300 mm diameter. Flushing is also unlikely to be effective for a heavily tuberculated main.

Pressure jetting is a more aggressive technique for cleaning sediments and biofilm off the pipe wall. The technique can be used for short lengths of pipes where access to the pipe can be gained and safe disposal of the waste water is viable. This technique is more applicable to unblocking sewers.

Air scouring can be used to generate higher velocities during the flushing process without using as much water. The injection of filtered compressed air forces slugs of water along the pipe; these cause the disturbance of loose deposits on the pipe walls as the slugs form and collapse. The procedure is suitable for pipes up to 200 mm diameter and for lengths of up to 1000m; its effectiveness relies on the skill of the operator in forming suitable air/water mixtures.

Foam swabs can be used to remove soft or loose material, such as organic debris, iron and manganese deposits, sand and stones. The process usually involves using a series of increasingly hard plastic swabs. The softer swabs can pass through butterfly valves and can be inserted into the main via a hydrant branch. For harder or larger swabs, the main must be opened. Swabbing can greatly improve the flow characteristics of a slimed main and is frequently used to clean out a newly laid main before being put into service.

Ice pigging, a patented technology developed in the UK between Bristol Water and Aqualogy, is a low risk method of removing sediment and biofilm from the inside of pipes using an ice-water slurry pumped into the pipe through a fire hydrant or similar suitable fitting. The slurry is moved along the pipe by the water pressure in the main to a downstream hydrant adjacent to a line valve. Water ahead of the slurry is discharged to waste in the normal way, but the slurry containing the pigging waste is collected in a tanker for safe disposal. The technique can be used to flush pipes up to 600 mm diameter and 3 km in length.

Scraping and relining is applicable to old tuberculated cast iron mains, which are structurally sound. Pipe scraping methods include drag scraping, power boring and pressure scraping. Pigs or aggressive swabs incorporating grades of wire brush or studs may be used. For harder encrusted materials, several passes may be required. An electrical transmitter incorporated in the swab or pig assists in tracking its progress along the pipe. Scraping with pigs is effective in removing hard deposits but can also damage and remove linings. Aggressive cleaning is usually followed by applying a secondary lining to the pipe. The scraping and relining processes are likely to dislodge, damage or block ferrule connections, requiring them to be excavated and repaired or replaced, thereby increasing costs.

C.6 Pipe lining methods

Cement mortar and epoxy resin linings are usually applied to cast iron mains to improve hydraulic capacity, protect the pipe and reduce discoloration from corrosion. The reduction in pipe bore needs to be considered as the relined pipe may not provide sufficient hydraulic capacity. Epoxy resins can be applied to most pipe materials, and technically it is feasible to reline mains with up to 2000mm diameter.

Structural lining methods are used where the structural integrity of the pipe has deteriorated. These techniques involve inserting a flexible lining into the main by methods such as ‘sliplining’, ‘Rolldown’, or ‘Swagelining’. Sliplining and Swagelining can be used for pipes of up to 1200mm or more and of length up to 1500m. Similarly to the non-structural lining methods, all these linings reduce the pipe bore, but can significantly improve its hydraulic performance because of the smoothness of the lining. They are quicker to install and less disruptive than relaying the pipe in open-cut but require each service pipe to be reconnected.

The ‘cured-in-place’ lining method involves and running a felt lining into a pipe. Resin within the liner is then exposed to a curing element to make it attach to the inner walls of the pipe. Lengths up to 500 m can be lined in one go. The method is suitable for pipes with difficult access and complex shapes, however it is more applicable to sewer pipes, and the finished hydraulic surface is not as smooth as that of other methods.

C.7 Pipe replacement

The main reasons for replacing a pipe are the risk of structural failure and inadequate hydraulic capacity. Good practice dictates that if a main has failed frequently during the last 5 years, typically more than two or three times per year per kilometre, it should probably be scheduled for replacement.

Traditional replacement methods involve laying a new main adjacent to the existing one and transferring service connections to the new main as a separate operation. As well as the traditional methods of trenching, newer techniques include narrow bucket open excavation, rockwheels, chain trenching machines and mole ploughing. Narrow trenching techniques (including chain excavators) for laying pipes up to 500 mm diameter are typically unsupported and avoid the need for an operative to enter the excavated trench and results in less handling of excavated material and reinstatement; but it can only be used for pipe materials that are sufficiently flexible for pipe lengths to be jointed before lowering into the trench. It is quicker and cheaper than traditional open cut excavation. However, it does increase the risk of disrupting other services and is therefore only suitable for uncongested locations, or where site possession is restricted or when rapid laying and reinstatement is required. Mole ploughing is only used for pulling small diameter pipes through soft ground.

The high cost of installing, replacing or renovating small diameter underground pipes and services by traditional methods, has resulted in the increased use of trenchless construction methods. There is a range of ‘no dig’ or ‘low dig’ pipe replacement and tunnelling techniques, which include pipe bursting, directional drilling, auger boring and microtunnelling. These techniques are typically used in urban areas, where the presence of many other underground services or traffic congestion makes trenching difficult and expensive.

Pipe bursting can be used to install new PE liner pipe of up to 300mm diameter. Extensive site preparation may be necessary to excavate or remove steel repair collars, pipe bends and fittings and concrete surrounds, and to disconnect mains and service connections to prevent their damage. Ground disturbance can occur and may be a problem.

Microtunnelling machines can be used for tunnels up to 2m diameter. The tunnelling shield can be steered accurately along the required alignment, which may be gently curved if required. A permanent pipeliner is jacked into position behind the shield (this is the primary lining). When the tunnel is complete, the water main is installed in the lined tunnel and the annular space filled by grout.

Pipe jacking is usually used for pipes over 900mm diameter. A tunnelling shield and string of tunnel lining is jacked into the ground from the drive shaft to a reception shaft (this is the primary lining). Lengths of several hundred metres up to about 2500mm diameter can be achieved. The water main is installed inside the jacked tunnel lining.

Auger boring installs a sleeve, up to 1200 mm diameter, usually steel, between two pits. The water main is then installed with the same technique as for microtunnelling.

Horizontal directional drilling can be used to install pipes under an obstruction, such as a road, railway or river. The technique involves drilling a bore between two points either side of the obstruction, using a steerable drill string. When complete the hole is reamed out to the required size and the pipe is pulled through. Depending on the pulling equipment, length of pull, size of pipe and ground conditions, pulls of up to 1500-2000m and up to 1200mm diameter of continuously welded steel pipes have been achieved.

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