Thames Water
Trunk Mains Forensic Review

Final Findings Report

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0 Executive Summary

0.1 Introduction

In mid-December 2016 Thames Water commissioned the Trunk Mains Forensic Review (the Forensic Review), an independent review of the Thames Water Trunk Mains assets and network in light of the 8 high profile bursts experienced in the period October to December 2016. The review also considers other significant Trunk Mains burst events from the remainder of 2016. The Forensic Review Terms of Reference were approved on 24 January 2017.

This is the 'Final Findings Report', which supersedes the 'Interim Findings Report', and is submitted to Steve Robertson CEO of Thames Water for internal use by the Thames Water Board. The report is led and authored by Paul Cuttill OBE. Thames Water has sole accountability for the accuracy of the data and information used to compile this Final Findings Report.

0.2 Background and context

The Thames Water Trunk Main network is composed of 3,214km of Trunk Mains and other assets. A Trunk Main is a classification of larger diameter mains (typically 18" or greater) in a water distribution system. In simplistic terms, they are large pipes carrying significant volumes of potable water under high pressure from treatment works and reservoirs into the distribution network for onward delivery to customers. Trunk Mains failure probability is low but the consequences can be very high, presenting particular challenges for investment, governance and management decisions for these assets. As a result trunk mains are treated as a separate asset class.

The majority of Thames Water's assets and customers are in London, which due to history and population means that 38% of the network was laid before 1930, that access to the assets is necessarily restricted by third parties, that traffic can play a dominant role in event response, and that when a Trunk Main bursts it can quickly impact many customers. The 8 bursts in October to December 2016 were rightly high profile due to their scale, location and customer impact and are part of what appears to be a gradually increasing rate of bursts on larger Trunk Mains. Thames Water understand this trend and, further, has worked extensively with the University of Surrey to improve their understanding of the condition of Trunk Mains by developing a statistical model that provides an indicative deterioration rate.

Thames Water has a clear, three-point strategy for Trunk Mains and has demonstrated progress against it. The investment to deliver AMP6 objectives for Trunk Mains totalled £147m post efficiency at 2012/13 prices. This included expenditure on:

- Expanding the monitoring of high consequence Trunk Mains from 5% to 8% of the Trunk Mains network.
- Replacing 45km of highest consequence Trunk Mains (equating to 0.19% per year).
- Gathering information, developing new technology, and building data models on Trunk Mains condition and deterioration in order to make a case for further investment in the next periodic review.

The 8 high profile bursts in particular had a significant impact on customers, including repeated flooding of homes, damage to businesses, risk to life and road closures. Throughout the Forensic Review it has been clear that Thames Water staff want to do everything necessary to address the customer impact of these bursts, they are open and honest about their performance and that they take pride in being customer centric. There is a commitment from Thames Water to learn from these events and to embed lessons learned.

The purpose of the Forensic Review has been to independently assess the major bursts of Thames Water Trunk Mains that occurred in 2016 in order to understand the root causes, patterns and Thames Water response in the context of the 'management framework' that Thames Water has in place to monitor, maintain and replace Trunk Mains. Interviews, workshops and data reviews were conducted on the 31 events that constituted 'major' bursts, with a particular emphasis on the 8 high profile events from late 2016. Reports from specialist water infrastructure engineers on the failure modes of the pipes were also considered. There are a number of findings and they are set out in terms of the Trunk Main asset lifecycle stage they are relevant to, alongside a series of outcome-based recommendations. These will need to be further developed, prioritised and planned by Thames Water; the Trunk Mains Strategic Review (in-flight) is tasked with driving and leading the implementation.

0.3 Summary of burst event reviews

Within the limitations of the available information, which are described elsewhere, the evidence found during the Forensic Review supports the conclusion that there is no common cause of the 31 bursts assessed, and in particular the 8 high profile bursts. In addition the evidence supports the conclusion that there were no systematic failings that could be said to have consistently caused or enabled the bursts. Examination of the available information on the 8 events has revealed that whilst age and condition of the pipes is an underlying factor in these failures, there is no single common cause of the bursts, for instance there were singular reasons for failure mode at 3 of the 8 bursts; a known leak at Northwold Road, accidental contractor damage at Lee Road, and damage caused to a pipe at Crayford Road.

The Forensic Review has analysed the 31 bursts by age of Trunk Main, burst date, burst time, day of the week, and risk ranking. No clear causal patterns have emerged that substantiate hypotheses about operating practice, age-related condition, material type or asset risk management and planning being the main drivers of Trunk Mains failure. Whilst 31 events are perhaps not a substantial sample upon which to base this type of analysis, it is also the case that they represent a substantial proportion of the total 2016 burst population (on larger Trunk Mains). These findings are included in more detail in Sections 2 and 7.

0.4 Summary of findings

The Forensic Review findings and recommendations are best understood across four asset lifecycle stages, asset planning, asset operations and maintenance, asset monitoring, and event response and aftercare. The key findings and recommendations related to each of these are summarised below in bullet points and are preceded by an overview of the current approach. More information on each of these is set out further in Section 2 and then explained in detail in Sections 3 to 6.

0.4.1 Lifecycle stage 1: Asset Planning

Asset planning refers to the activities that take place to plan the use, maintenance and replacement of the Trunk Mains network. There is a formalised corporate risk process and business planning framework with associated governance and assurance. Thames Water has a clear AMP6 investment strategy and plan for Trunk Mains that is supported by advanced risk modelling and statistical modelling. The models have been independently and externally validated, and in the Financial Determination 2009 (FD09) Ofwat went as far as to commend the work on service consequence modelling for Trunk Mains. The following are focus areas for improvement.

- Whilst there is a clear risk methodology and effective Asset Investment Manager Risk Model (AIM) efforts should be made to develop a dynamic risk management tool that can be updated based on the latest asset data and knowledge. In particular there is a need for better processes to integrate information and feedback from operations teams into risk modelling and planning.
- Currently there are inconsistencies and gaps in Trunk Main asset data, for example notable errors in valve location and operability information. This is symptomatic of the wider water industry for this type of underground asset, and means that Thames Water should further 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 the Geographical Information System (GIS), Thames Water's below-ground asset register.
- In line with the recommendations of the on-going Asset Owner Operating Model project, Thames Water 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.

0.4.2 Lifecycle stage 2: Asset operations and maintenance

Asset operations and maintenance refers to the activities that take place as business-as-usual on the Trunk Mains. For Trunk Mains these activities are delivered through the Infrastructure and eight$_2$O alliances, and Water Supply which is responsible for system control, and importantly the Control Room. Operational activities are defined by asset standards and informed by the outputs of the AIM Risk Model, which connects strategy and planning to on-the-ground outcomes. There are policies in place that set out the maintenance practices for Trunk Main assets, there are clear Permit to Work (PTW) expectations and processes, and operational staff have access to reliable asset information (including valve information) through GIS. Based on the above summary and the detail later in this report it is apparent that Thames Water has the building blocks necessary to deliver its plans and commitments. The following are focus areas for improvement.

- A PTW is required for all planned work on Thames Water network assets, as stated by the Asset Management Operational Standard. The controls in place to ensure the conditions or terms of the documents are fully adhered to should be improved. Sufficient oversight from supervisors and Network Service Technicians (NST) teams must be place in order to mitigate risks and prevent avoidable mistakes. Improved pre and post-work controls to be established to increase adherence to the terms of PTWs.
- Local knowledge is critical to the delivery of Trunk Main works and the quick resolution of issues during burst events. The Forensic Review has identified a 'critical individual' culture that is not uncommon in the industry, but that needs to be addressed by codifying local knowledge wherever possible. It would be beneficial to combine this with a refresh on shared Thames Water values across the alliances, including how to interact with customers when delivering operational or maintenance works on site.

0.4.3 Lifecycle stage 3: Asset monitoring

Asset monitoring refers to the activities that are performed to plan, install and use equipment on Trunk Mains to proactively identify potential bursts, and to reactively understand when bursts have happened. Asset monitoring is the first of the three core elements of the Thames Water Trunk Main strategy, with the ambition of expanding the monitoring of highest consequence Trunk Main spans from 5% to 8% of the network by the end of AMP6. Monitoring is mainly conducted using Hydroguard and Syrinix units, as well as Sahara leakage detection tools. The Syrinix solution arguably represents the forefront of currently available monitoring tools for this type of asset. Hydroguard can be considered reactive, Syrinix has the potential to be proactive if correctly used as well as reactive, and the Sahara surveys can be used in a proactive way to mitigate potential bursts. The information provided by these tools is monitored by Control Room

teams, primarily through the SCADA system which can be understood to be the ‘main screen’ for monitoring assets. The following are focus areas for improvement.

- The roll-out or implementation of monitoring units is constrained by a number of factors and this has caused delays in the roll-out of monitoring across the Trunk Main network. Monitoring supports the strategic goal of improving the Thames Water response to events. To optimise this the approach to prioritising, locating and installing monitors should be re-examined with the intended outcome of accelerating the roll-out of monitoring units within AMP6. There is a programme in place to do this and it would be beneficial to increase the scope and pace of this programme as part of this recommendation.
- Alarm email and text notifications from Syrinix and Hydroguard are sent to specified on-shift personnel but in general the Syrinix and Hydroguard systems and data are not fully integrated into the SCADA system, which means that they are not monitored in ‘real time’. It is recommended that these monitoring systems are fully integrated into SCADA at the earliest opportunity, that there is a refresh of the processes and policies for prioritising alarms to ensure consistent results each time, and that Thames Water increases its capability to statistically analyse the available monitoring data in order to potentially improve burst predictability.
- As is the case with the rest of the water industry and other industries with below-ground infrastructure, Thames Water does not have a large or particularly reliable understanding of the health of its Trunk Main network. This particularly impacts Thames Water’s ability to plan proactive works and accurately predict outcomes such as bursts. The risk modelling provided by the Strategy, Planning & Assurance (SP&A) team addresses this in some way, and the innovation team is actively working with the industry to identify and trial new ways of assessing Trunk Mains health; in fact the plans to establish an innovation testing area at Kempton Park were recently approved. These efforts should be increased wherever possible, with a focus on involving supply chain partners more in the identification and testing of innovative solutions for asset condition assessment.

0.4.4 Lifecycle stage 4: Event response and aftercare

Event aftercare and response refers to the activities that take place from burst notification through to closing out all customer aftercare. This includes the operational response to containing the burst and repairing the Trunk Mains, customer communications and care, stakeholder engagement, and operational rotas and working patterns. Thames Water has a set of Event Management Arrangements that explain to staff what steps to undergo in the case of 15 types of major events. One such major event identified is an interruption to water supply due to a burst main. The Event Management Arrangements form part of the training that all staff permitted to respond to an event are put through. There is also a specific training course for Event Controllers. When an event happens the shift patterns and standby arrangements in place for operations staff inform the selection of individuals who respond to the event. In addition to operations staff, the Control Room have an important role to play in informing and guiding the actions of operations staff on the network to isolate the burst main. Communications teams support the immediate response and ongoing aftercare providing the relevant communications to third party stakeholders and customers. The ongoing aftercare often involves insurance claims, attendance at community meetings, and may include hand-over of the event site to eight$_2$O if more comprehensive works are required. The following are focus areas for improvement.

- There was some inconsistency in the responses to the 8 recent 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 are required to complete event controller training at least once every three years, and have the relevant experience to manage events. However, there is no enforcement of ‘refresher’ training. There is a limited amount of detailed training and guidelines on Trunk Mains bursts. Thames Water should look to learn from the recent high profile events and develop a specific set of guidelines for Trunk Main-specific burst event response to ensure consistency where possible, with the acknowledgement that each site will have its own nuances.
- The communication with customers during the 8 recent high profile events 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, through improving the availability of communication channels and ensure staff have the relevant knowledge and training in responding to customer requests.
- The capacity for the out-of-hours staff to effectively and efficiently 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 of the out-of-hours staff to respond to a specific event is dependent on the knowledge of the event site and the availability of contingency plans and / or Control Room knowledge to support to identification of 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, who operate on a similar basis to fire services crews, balancing demand for the team and the cost of changes.
- There is a process or capturing and disseminating learning from events across the business, but this has been applied inconsistently. Therefore the underlying causes of the burst, execution of the event response and identification of trends are not consistently understood and used to inform future improvements in event response. 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 and implement the appropriate controls to enforce the use of the process. 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. Event learning and practice exercises should also be used to inform continuous improvement in event response, and the method and outputs of this Forensic Review should be used as a template for future similar reviews.

0.5 Next steps

The scope and remit of the Forensic Review is complete and the findings and recommendations are handed over to Thames Water for its active consideration. The suggested next steps are for the Forensic Review to hand over all documentation and data that forms the evidence for this report, for Thames Water to decide how it wishes to communicate the report and engage with the recommendations, and for Paul Cuttill OBE to agree with Thames Water the support required during review by the Audit, Risk & Regulatory Committee (ARRC) and the Board.

0.6 Acknowledgements

Sincere thanks to all at Thames Water for their willingness and commitment to providing all of the information that has been requested in writing, during interviews and workshops. Thanks are also extended to the Forensic Report team who have supported the Forensic Review. The review and this report would not have been completed in the time without this level of support.

1 Introduction

1.1 Background to Trunk Mains

A Trunk Main is a classification of larger diameter mains (typically 18" or greater) in a water distribution system. These mains are typically classified by their hydraulic function and usually refer to principal and transfer mains whose purpose is the transportation of large volumes of water from treatment works to Distribution Management Areas (DMAs). The Thames Water Trunk Main network is 3,214km long and has the important role of distributing large volumes of potable water from treatment works across the network to a number of service reservoirs.

Figure 2 - Modern Trunk Main

Figure 1 - Burst Trunk Main from the Upper Street event

Approximately 2,000km of these Trunk Mains and their control mechanisms are located in London, buried under busy streets, Red Routes and key third party assets. Much of the Trunk Main network was constructed in the early 19th century using simple techniques, and fabricated in challenging environments with little or variable quality control. Thames Water currently expects an average of 310 bursts and leaks per year[1] of which they expect approximately 60 to be the result of failures on larger diameter mains that are 18" and above.

Overall, the number of bursts in the entire network is lower than it used to be and running at about the same level as 2015. On Trunk Mains and other larger diameter mains below 18", from 2004 to 2013 the number of bursts ranged from as low as 28 per year to as high as 79 per year, with an average of 54 per year [1]. In the last three years the average is 71 per year, which is higher than the trend in previous years. One of the major concerns is that Trunk Main bursts of the type and scale recently seen represent a significant health and safety risk to staff, customers and the general public who are present when the main bursts or when responding to the event. The AMP6 objectives in the Thames Water Investment Strategy for Trunk Mains totalled £147m at 2012/13 prices. This included expenditure on:

- Expanding the monitoring of high consequence Trunk Mains from 5% to 8% of the Trunk Mains network by the end of AMP6.
- Re-laying 45km of the highest consequence Trunk Mains. This is a small scale replacement programme (1.2% of the overall network).
- Gathering information and building data models on Trunk Main condition and deterioration in order to support the case for further investment in the next periodic review.

Between October and December 2016 there were 8 high profile Trunk Main bursts, which had a significant impact on customers, including repeated flooding of homes, damage to businesses, risk to life, and road closures. A number of these bursts were covered in local and national media and attracted attention from MPs, the Mayor of London, the Greater London Authority, Transport for London (TfL), and the Department for Environment, Food & Rural Affairs (DEFRA). This has resulted in questions being asked about Thames Water's current approach to Trunk Main risk classification, asset condition and monitoring, network operation, and event response. In response to the recent bursts Thames Water has commissioned a staged review, referred to as the Trunk Mains Review Programme, shown in Figure 3. The Trunk Mains Review Programme incorporates 5 workstreams as shown below:

- **Customer response and re-lining critical Trunk Mains**: Event teams were despatched to isolate the bursts as quickly as possible, support immediate customer needs to provide alternative water supplies and accommodation, work closely with the emergency services, and to provide information on the ground and at residents' meetings. Thames Water also provided welfare units, flood remediation services, sent loss adjustors to site as part of the immediate response, and gave goodwill payments to domestic tenants with internal flooding. Work has been initiated to re-line sections of the burst trunk mains in order to fulfil commitments made to the customers, and due to the level of risk they pose. At the time of publication, 900m of the total 1,350m of 21" main at Leigham Vale had been replaced. Plans for relining 700m of the 36" main at Upper Street were in the late stages of finalisation. The total budget commitment of £95m, over the period up to 2020, to deliver the full programme of relining, monitoring, and reviews had been approved.

- **The Forensic Review** (this review): An independent analysis of the major burst/leak events that occurred in 2016, the potential causes of the failures and the response in the context of the management framework that Thames Water has in place to monitor, maintain and replace Trunk Mains. This is explained in detail in section 1.2.

[1] **average visible leaks from the last 13 years June Report (JR) JR04 – JR16**

- **Social media and communications**: A complete review of Thames Water's customer engagement methods, with the intention of helping Thames Water customer engagement teams manage their interaction with customers more effectively and position Thames Water as a role model for incident management. This includes analysis and improvement of Contact Centre practices, media engagement, social media response, and event broadcasting/narrowcasting.

- **The Trunk Mains Strategic Review**: A review of the approach to managing this asset class. The review examines the emerging themes in greater depth and across a larger baseline of events. It also analyses historical bursts for causes and patterns. This review will provide a plan and evidence based recommendations for changes to how Thames Water plans, manages and responds to the Trunk Main network and customers. The review benefits from an Ofwat resource to assist its work by bringing the experience and perspectives of the regulator.

- **Long term investment strategy/plan:** The outputs from the above workstreams will feed into the work that Thames Water is already doing to develop a long term investment strategy. This will form part of the proposed business plan for the period from 2020 onwards, on which Thames Water will consult widely with all customers and stakeholders.

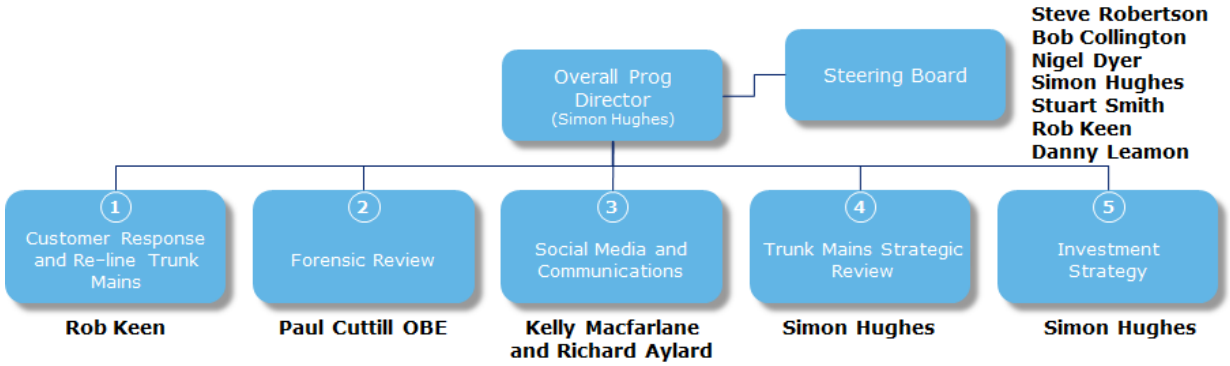


Figure 3 - Trunk Mains Review Programme

1.2 Purpose of the Forensic Review

The Forensic Review is an independent analysis of the major burst/leak events that occurred in 2016, the potential causes of the failures and the response in the context of the management framework that Thames Water has in place to monitor, maintain and replace Trunk Mains. The main scope requirements are listed below. The scope can be found in Appendix 1 and was agreed by the Trunk Mains Review Programme Steering Group on 24th January 2017. The scope is summarised below:

- To review the causes, impact and Thames Water response to all the significant Trunk Mains bursts in the last 12 months.
- To assess if there are any patterns that can be derived from available information on Trunk Mains bursts in the last 12 months.
- To review the approach to risk management of the asset.
- To assess if there are any gaps in the management framework.
- To recommend potential actions that should be taken.
- To highlight any learnings that should be taken forward into the Trunk Mains Strategic Review workstream.

The Forensic Review is led by Paul Cuttill OBE, a leading voice in the utility sector. Paul has over 30 years' experience in energy, including as EDF Energy Networks' (now UK Power Networks) Chief Operating Officer. The Forensic Review is an independent piece of work carried out for Thames Water.

1.3 Approach to the Forensic Review

The structure for the Forensic Review incorporated 3 workstreams supported by a desktop analysis of data from the 31 Trunk Main bursts in 2016. This is shown below in Figure 4.

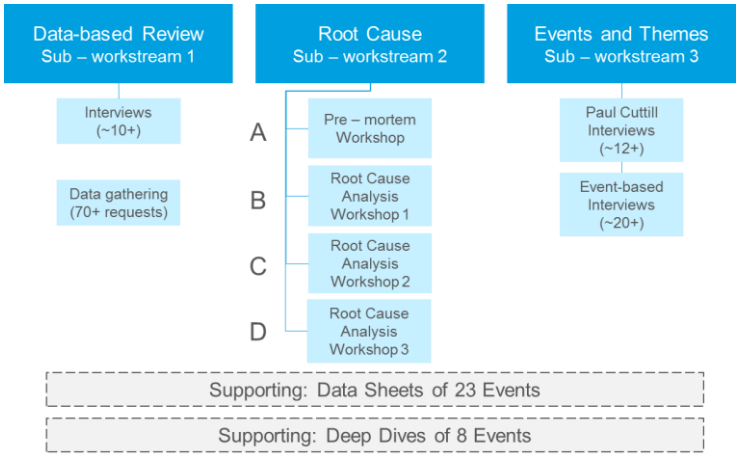


Figure 4 - The Forensic Review Structure

Sub-workstream 1 – Data-based Review gathered information and data from the following:

- Interviews: Interviews with individuals from Thames Water and its alliance partners (Infrastructure Alliance and eight$_2$O).
- Desktop reviews: Review of information and data provided to the Forensic Review by Thames Water.

Sub-workstream 2 – Root Cause gathered information and data from the following:

- Workshops: A pre-mortem workshop and 3 root cause analysis workshops were conducted with groups of individuals from Thames Water and its alliance partners.

Sub-workstream 3 – Events and Themes gathered information and data from the following:

- Desktop reviews: Review of information and data provided to the Forensic Review by Thames Water.
- Interviews: Interviews with individuals from Thames Water and its alliance partners.

A review of events was undertaken using the following information and data:

- 'Deep dives': Detailed documents developed by Thames Water for each of the 8 high profile Trunk Main bursts that occurred between October and December 2016.
- Datasheets: A document developed by Thames Water containing pertinent details for 23 other significant Trunk Main bursts from 2016.
- Engineering reports: Forensic engineering analysis reports on the Trunk Main failure modes. These reports were commissioned by Thames Water and conducted by Hydrosave (a specialist contractor within the water industry) as well as reports commissioned by Thames Water and conducted by independent water industry engineering experts.

Thames Water has sole responsibility for the accuracy of the data and information used to compile the report.

The Forensic Review uses a management framework (the components of which are shown as the horizontal bars on Figure 5) to assess the Thames Water approach to managing the Trunk Main asset network across 4 lifecycle stages (the lifecycle stages are shown as the chevrons at the top of Figure 5). The management framework used has been adapted from a Governance Framework and ISO 55001. A conscious decision was made not to include some elements of frameworks in the forensic review to help manage scope. More information on the Frameworks is provided in Appendix 2.

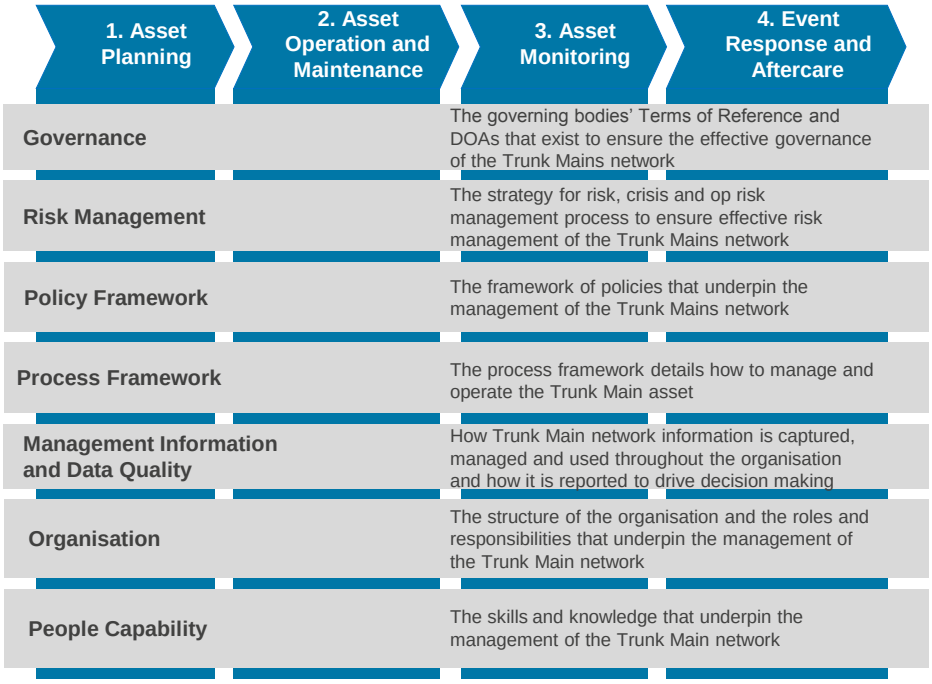


Figure 5 - Lifecycle Stages and Management Framework

1.4 Ways of working

The Forensic Review has benefitted from the full cooperation of Thames Water staff and alliance partners, in particular through:

- Providing frank and example-based insights and opinions on relevant topics during interviews and workshops.
- Providing data and other forms of documented information to fulfil the data request requirements.
- Development of the deep dive documents and datasheets.
- Validation of current state and context descriptions to assist with factual accuracy.
- Providing access to Thames Water offices, depots, intranet and systems.

1.5 Acknowledgements

We would like to thank the leadership and staff within Thames Water for providing information on a timely basis and being open, frank and honest. This has allowed Paul Cuttill and the team to carry out an in depth review within short time frames, which would not have been possible without the full cooperation of those involved.

1.6 Structure of this report

The Forensic Review Final Findings Report is structured as follows:

- Section 2 provides an overview of the key findings, and associated recommendations, across the asset lifecycle stages. It also provides insight into the 8 recent high profile bursts and 23 additional bursts in 2016 through data analysis and associated findings.
- Sections 3 to 6 detail the findings and recommendations for the following asset lifecycle stages:
  - Asset Planning
  - Asset Operations and Maintenance
  - Asset Monitoring
  - Event Response and Aftercare
- Section 7 outlines the probable failure modes and contributing factors to the end outcome for each of the 8 recent high profile bursts.
- Section 8 sets out the next steps for the Trunk Mains Strategy Review to ensure the findings and recommendations from the Forensic Review are actioned.
- Section 9 contains the supporting appendices for the main report.
- Section 10 contains the glossary of terms used in the report
- Section 11 lists all documents and data reviewed by the Forensic Review and includes the references used throughout the report.

2 Summary Findings and Recommendations

This Section provides an overview of the summary event reviews by showing a series of graphs highlighting the trends identified in the risk ranking, installation date, asset age, burst date, burst time, and burst day for the 8 recent high profile bursts, the 23 additional bursts in 2016 and a summary table of the key findings and recommendations.

2.1 Summary Event Reviews

The Forensic Review has sought to understand the contributing factors behind the 8 high profile burst events that occurred between October and December 2016. Information has been gathered through interviews with stakeholders and Event Controllers, workshops with staff who worked on the events, the draft Deep Dive Reports and Datasheets produced by Thames Water, Hydrosave Forensic Investigations and Cause of Failure Reports. By aggregating data from these sources into a single data set, the events have been analysed through several lenses, with the goal of identifying potential trends and root causes. This data set examines the information associated with a population of 31 'significant' bursts, including the 8 high profile Deep Dive bursts, as selected by Thames Water based on their location and impact. The list of 31 incidents was provided to the Forensic Review by the SP&A team. The list was derived from a comparison of Trunk Main Database, Control Room Logs and the Innovation tracker. Where a possible Trunk Main burst event appeared in all three sources it was considered to be accurate. This combined with the 8 high profile burst events comprised 18 of the 31 events. The list was circulated to Thames Water stakeholders who then added to the list based on personal experience and prior knowledge, and increased the total to 31. It is worth noting that three trackers from three different departments were needed to develop a reliable list of significant trunk main bursts from 2016.

The table below shows the event location and tag reference that applies to all figures in this Section. Events shown in the figures vary depending on the availability of data

Table 1 - Event Locations and Tag References

Tag	Event Location	Tag	Event Location	Tag	Event Location	Tag	Event Location	Tag	Event Location
1	Kingston Road	6a	Pinkham Way	10	Lower Elmstone Drive	14b	Farmoor GRP 2	17	Wood Lane 16"
2	Barhatch Lane	6b	Pinkham Way	11	Hayes Lane	14c	Farmoor GRP 3	18	Wood Lane 12"
3	Crayford Road (rail bridge)	7	Grosvenor Square	12	North Bar Street	14d	Farmoor GRP 4	19	Muswell Hill Road
4	Avenue Road	8	Well Hall Road	13	Buckingham Palace Road	15	New River Avenue		
5	Hook Road	9	Strand	14a	Farmoor GRP 1	16	Alric Avenue		

Burst Main Risk Ranking

Figure 6 below displays the risk ranking (as calculated by the Asset Investment Manager (AIM) Risk Model for PR14) of the recent 8 high profile bursts (diamond markers), as well as those of the other bursts for 2016. While there are bursts distributed across the breadth of the risk rankings, there is a notable concentration of bursts on mains above the rank of 20,000, with 13 of the 23 significant bursts in 2016 falling in this category. This is reinforced by fact that the 2 lowest ranked Deep Dive Events, Lee Road [2] and Crayford Road [3], were caused by human error, involving likely contractor strike and permit to work procedures not being followed respectively. Additionally, the Upper Street main was noted as being incorrectly ranked due to miss-documentation of a previous burst. Had this been correctly documented, the main would have been ranked significantly higher, likely within the 20,000 and above group.

This finding suggests there is validity to the current risk model and in particular the probability module's approach to long term planning. Without the probability module of the model it would be expected to see a more even distribution of events across the risk rankings, as high consequence events would be overall as likely to occur as low consequence events. The concentration of non-human error related failures within the high risk group above 20,000 suggests Thames Water has a useful tool with which to understand its Trunk Main risk exposure and prioritise mitigating works, though it should be noted that the risk model is not intended to provide a real time view.

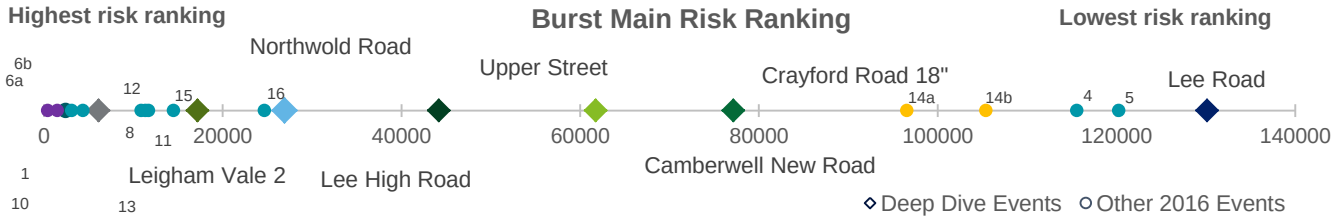


Figure 6 - Burst Main Risk Ranking

Asset Age

Mains associated with bursts were also analysed by their age, as it is generally perceived that age and condition have contributed significantly to the rate of bursts. While 18 of the 30 bursts where age data was available were on mains over 100 years old (pre-1916), the remainder of the sample was distributed evenly across the 1900's with the newest burst mains having been laid in 2000. This finding suggests that whilst the date of installation influences the likelihood of failure, it may not be the predominant factor. Furthermore it was not proven that any specific vintage of pipe was prone to failure.

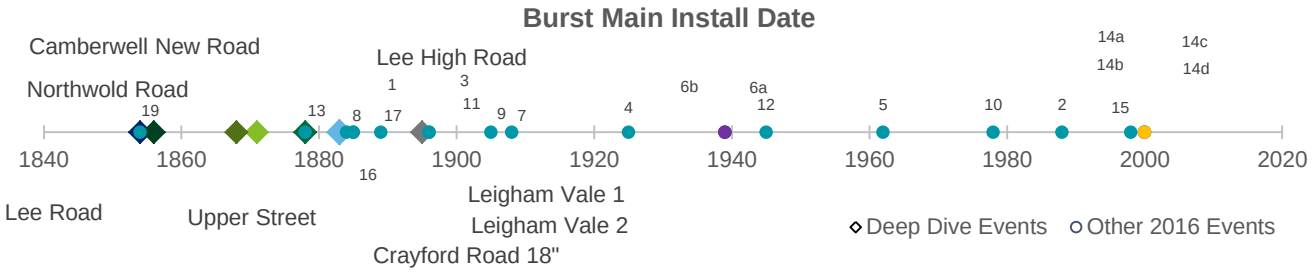


Figure 7 - Burst Main Installation Date

Burst Date

The data was analysed by date of the burst in order to establish if there was a marked step change in the rates of bursts associated with the latest group of high profile bursts. As shown in Figure 8, while the majority of events happened in the latter half of 2016, it is not uncommon to have grouping of events. This is clearly visible in the dataset, with groups of bursts occurring in early July, mid-August, and mid-September, with the early July grouping consisting of 6 significant bursts in 7 days. Based on the data available there is not a statistically significant trend that would suggest there has been a marked change in the rate of Trunk Mains bursts.

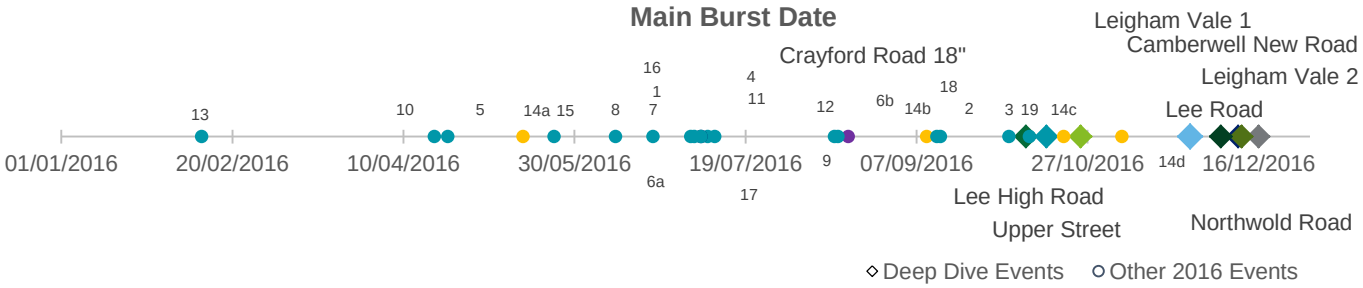


Figure 8 - Main Burst Date

Burst Time and Day

The data was analysed by the time and day of the week of the burst in order to identify any trends associated with daily or weekly changes in pressure or operational configuration. It is perceived that the immediate failure of many of the mains is a result of a rise in operating pressure to meet the morning demand after the overnight lull. However, there does not appear to be a concentration of events around the 05:00-07:00 time bracket where this would be expected. In fact, while there is an apparent trend in the Deep Dive events to occur before noon, the overall population of bursts events is generally evenly distributed throughout the day.

The trends found in the rates of bursts on various days of the week present a similar finding. While the recent high profile events appear more likely to occur on the weekend, this may be an anomaly of the small sample size, as the overall population of bursts in 2016 do not show a significant trend to be more likely to occur on any given day of the week.

9 of the 31 significant events where date and time values were available occurred within the primary operating hours of 08:00 to 18:00, Monday to Friday. These results highlight the high likelihood of burst events occurring out of primary operating hours, and the need to be able to respond to events at any hour or day of the week.

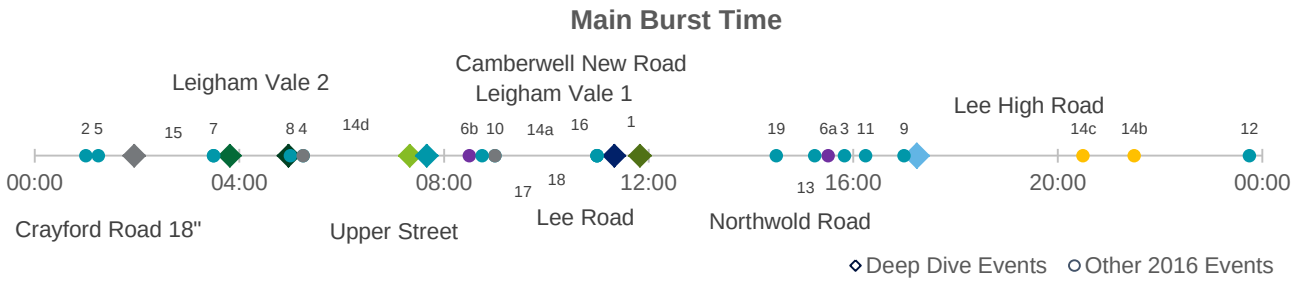


Figure 9 - Main Burst Time

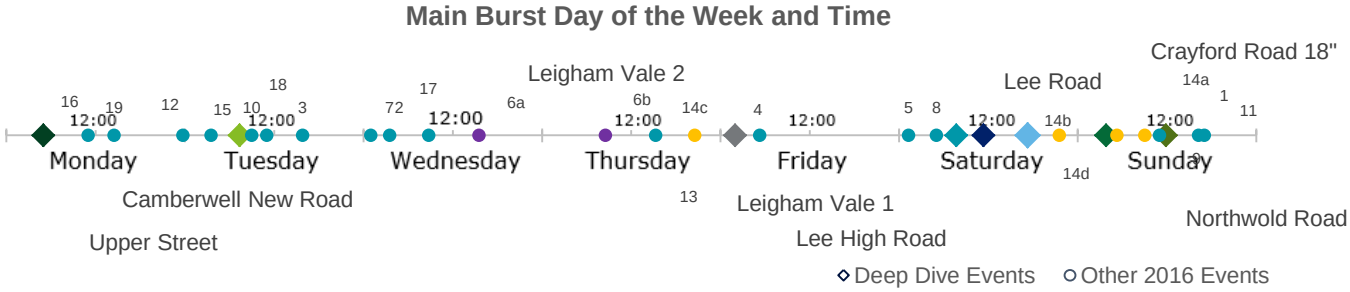


Figure 10 - Main Burst by Day of the Week and Time

2.2 Summary Findings and Recommendations

The Section contains our key findings along with recommendations for lifecycle stages of asset planning, operations and maintenance, monitoring and event response. The findings are provided in line with the management framework outlined in Section 1.3. The Forensic Review has given a high level estimate of the ease of implementation and cost to allow prioritisation. Ease of implementation is based on a non-analytical opinion of the cost estimate which will require further analysis to confirm. Cost is categorised as three brackets low, medium and high (Low < £0.25m, £0.25m < Medium < £1.0m, High > £1.0m).

The numbering found in the summary key findings and recommendations below aligns to the full findings and recommendations which can be found in sections 3 through to 6.

2.2.1 Key Findings for Asset Planning

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Governance	**3.1.3 - Corporate risk governance** Thames Water has a formalised corporate risk governance process that can be used to inform risk awareness, planning and embed a risk culture. A programme of improvement to enhance the maturity of the approach to Enterprise Risk Management (ERM) is in progress. The level of maturity is assessed at the end of each of the three phases. However, there is limited direct line of sight between risk governance in Wholesale Water and corporate risk governance.	**R3.1.3 – Specific Trunk Mains risk management** A focus on risk management at the Trunk Main asset class should be applied, making sure there is a clear process and escalation route to provide line of sight between Wholesale Water and corporate risk that drives remedial action.	**R3.1.3** Ease of Implementation – High Cost – Low

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Risk Management	**3.2.1 - Asset Investment Manager (AIM) risk model** Thames Water has developed an advanced tool to understand the risks posed to the public and the business from the burst of a Trunk Main. The risk model was designed for business planning purposes, not for day-to-day operational risk management, although outputs can be used by operations. The model was designed to present a static snapshot of the network from the last time the model was run (current outputs from Price Review 2014 covering the regulatory period from 1 April 2015 to 31 March 2020 PR14), and is not intended to provide a real time view on risk exposure or the probability of a main burst.	**R3.2.1 - Dynamic risk management** Efforts should be made to assess the requirements for a dynamic risk management tool, based on the current AIM Risk Model, which would be regularly updated based on the latest asset data. An assessment of the ease of implementation can be better made once the requirements are understood.	**R3.2.1** Ease of Implementation – High Cost – Low
	3.2.3 - Deterioration and replacement Thames Water uses two numerical models to understand and predict Trunk Main deterioration for asset planning purposes. In line with these models, the current rate of replacement for Trunk Mains is estimated at 0.19% per annum. It is recognised in the Trunk Mains Investment Area Document (IAD) that the replacement programme is not keeping pace with deterioration, and the trend in annual bursts of Trunk Mains is rising.	**R3.2.3 - Replacement Programme** Given the criticality of the Trunk Main network to Thames Water's overall operation, and the likely timescales required to replace these assets, it is recommended work be started to gather evidence and build a case for a long term Trunk Main replacement strategy. Analysis may also be required to shape the programme so as to prioritise high risk mains while minimising disruption to the network and the public.	**R3.2.3** Ease of Implementation – High Cost – Medium
Management Information	**3.5.2 – Infill analysis** The Trunk Main Risk Methodology describes how infill analysis is conducted to fill the gaps in data inputs to the risk model. These gaps are diameter, year laid, and internal pressure. When using the risk model it must be clearly understood what limitations are placed on the model and its outputs by the use of infill analysis to address data gaps.	**R3.5.2a – Improved predictive analysis** To enable continuous improvement of the model, further development of predictive analytics and infill analysis is recommended to ensure the model remains robust and the outputs can be used with high confidence.	**R3.5.2a** Ease of Implementation – Medium Cost – Medium
		R3.5.2b - New methods for data collection Investigation into the scope for new methods to measure asset condition should be undertaken. This could generate data that is used in the risk model.	**R3.5.2b** Ease of Implementation – Medium Cost – Medium

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Process Frameworks	**3.4.3 – Asset information update process** There is a process to gather information from operations and input it into Geographic Information System (GIS). However there is inconsistent awareness and understanding of the process throughout the business. Therefore while asset information is updated, there is no certainty that the information is being captured in accordance with the asset information update process.	**R3.4.3 – Systems Operations involved in data gathering** Systems Operations has insights into asset information and the updates that are required. The formal process to ensure these updates are captured and entered into GIS should be widely communicated across the business and its application monitored.	**R3.4.4** Ease of Implementation – High Cost – Low
Policy Framework	**3.3.1 - Overarching asset management policy** Thames Water has a business planning framework that embeds competencies from the internationally recognised Global Framework for Maintenance and Asset Management. It is clear that an asset planning policy is in place and actively reviewed and updated. There could be a better understanding of the framework, and underlying processes, across Asset Planning to ensure consistency in asset planning activities.	**R3.3.1 - Asset management policy communicated** The overarching asset management policy should be communicated more widely across the business and made accessible to ensure there is a common understanding and alignment across the business.	**R3.3.1** Ease of Implementation – High Cost – Low
Organisation	**3.6.1 - SP&A team structure** The Strategy, Planning & Assurance (SP&A) team reporting into the Head of SP&A, is structured according to capability (e.g. Strategy and Planning, Supply and Demand Strategy and Planning, and Investment Programme and Assurance). Currently across infrastructure and non-infrastructure there is no single Asset Owner for all assets, or a functional lead for Trunk Mains.	**R3.6.1 - Single asset owner** Thames Water should follow the recommendations of the Asset Owner Operating Model project that is ongoing and recommends that Thames Water should appoint a single asset owner for Trunks Mains, reporting to the MD for Wholesale Water. In addition the Trunk Mains as an asset group should be set aside, for at least 18 months before being reviewed, as a separate activity for a period of intensive care to establish a deep and consistent focus across the end-to-end asset management lifecycle.	**R3.6.1** Ease of Implementation – Medium Cost – Medium

2.2.2 Key Findings for Asset Operations & Maintenance

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Risk Management	**4.2.1 - Risk model operational inputs** Operational activities are informed by the outputs of the AIM Risk Model. The risk model was designed for business planning purposes, not for day-to-day operational risk management, although outputs can be used by operations. Within the business the risk model is used for purposes it was not intended for, without a proper understanding of its limitations.	**R4.2.1 - Operational information input into risk management** The risk model should be expanded to provide a dynamic operation decision support tool with a direct link to operational teams. The risk model should also enable the inclusion of data provided by operations.	**R4.2.1** Ease of Implementation – Low Cost – High

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Process Frameworks	**4.4.1 - Permit to Work process** A Permit to Work (PTW) is required for all planned work on Thames Water network assets, as stated by the Asset Management Operational Standard. There are limited controls in place to ensure the conditions of the documents are fully adhered to and that sufficient oversight from supervisors and Network Service Technicians (NST) teams is in place in order to mitigate risks. This is evidenced by the Crayford Road and Lee Road events, which both saw failures to properly follow the PTW conditions leading to the bursts.	**R4.4.1 - Permit to Work process controls** Controls should be put in place to ensure that work cannot proceed without a completed and approved Permit to Work, and that the conditions of the document are followed throughout the project.	**R4.4.1** Ease of Implementation – High Cost – Low
Management Information	**4.5.2 - Valve location information** Valve information is held on GIS, providing details on location, valve position, and automation. Having reviewed the documentation and the deep dives it is clear that valve information, including location and position, is available for use to operations staff. There are documented instances where the information is not reflective of the reality on the ground. This misalignment of information can prevent maintenance teams completing their roles effectively.	**R4.5.2 - Data as an asset** It is recommended efforts be made to drive a cultural change to highlight the importance of data to the business, and ensure that it is treated as a key asset that should be made readily available. This may include a programme of works to capture and confirm the location and position of all valves in GIS**.**	**R4.5.2** Ease of Implementation – Medium Cost – High
Organisation	**4.6.1 – Thames Water values** The alliances should display the values of Thames Water when out in the field. There have been instances of when contractors have not displayed the values having a negative impact on Thames Water. An example of this was the Lee Road event where the developer services team, conducting a routine procedure, did not display the values of the Infrastructure Alliance and were not familiar with dealing with customers resulting in poor customer feedback for Thames Water.	**R4.6.1 - Reaffirmation of Thames Water values** Training should be undertaken to confirm the importance of displaying Thames Water values when working on site, including how to interact with customers.	**R4.6.1** Ease of implementation – Low Cost - Low

2.2.3 Key Findings for Asset Monitoring

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Governance	**5.1.1 - Lack of end to end governance of monitoring** The Trunk Mains Monitoring Positioning Paper and the Trunk Mains Investment Area Document both set out the monitoring strategy and document the processes in place for monitoring. No clear governance structure to oversee the monitoring of the Trunk Mains assets was identified.	**R5.1.1 – Establish end to end governance for monitoring** Thames Water need to establish a clear governance structure around the monitoring of the Trunk Mains and its associated assets. This should include clear roles and responsibilities and decision making accountabilities.	**R5.1.1** Ease of Implementation – High Cost – Low

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Risk Management	**5.2.2 - Monitoring and meter risk management data** Raw data from the Syrinix monitors is aggregated and analysed by the Syrinix company in order to identify potential bursts and leaks. However, there is no in-house analysis of trends and precursors in the data that may help the business better interpret monitoring information. This is potentially a missed opportunity to improve Thames Water's ability to identify Trunk Main risks, predict bursts, and improve the overall understanding of the network. **5.2.4 - Real-time monitoring information** Syrinix and Hydroguard data are not fully integrated into the Supervisory Control and Data Acquisition (SCADA) system. Hydroguard is partially integrated. Syrinix data exists independently of the SCADA system, and notifies the Control Room of potential bursts through an email and text.	**R5.2.2 – Utilisation if monitoring and metering data for risk management** As assessment of potential further analysis that could be done based on available Syrinix data (whether in-house or through increased collaboration with Syrinix) in areas such as risk identification, burst prediction, and event response. **R5.2.4 – Integration of monitoring assets and information** It is recommended that all monitoring information and systems are integrated in to the Control Room and made available to all operational staff.	**R5.2.2** Ease of Implementation – Low Cost – High **R5.2.4** Ease of Implementation – Medium (in progress for Hydroguard) Cost – Medium
Policy Framework	**5.3.1 - Lack of policies for monitoring** Guidance exists in the Investment Area Document on how to invest in, use and manage Trunk Main monitoring solutions. However, this document does not provide guidance on which assets should receive monitoring, nor maintenance of monitoring equipment.	**R5.3.1 – Establish a Trunk Mains monitoring policy** A Trunk Main monitoring policy should be established providing clear guidance to the business on what and how monitoring will be undertaken on Trunk Mains.	**R5.3.1** Ease of Implementation – High Cost – Low
Process Frameworks	**5.4.1 - Non-standard alert validation processes** The processes used to validate alerts, such as what to respond to, how to respond, who to notify and when, are not standardised. Different individuals or teams may do this differently based on their own experience meaning some alerts could be missed.	**R5.4.1 - Establish controls to improve the consistency of alert validation** Efforts should be made to fully document the alert validation processes and controls to increase the chances of alerts being dealt with correctly and consistently. This will also require training in the processes.	**R5.4.1** Ease of Implementation – Medium Cost – Medium
Management Information	**5.5.2 - Asset condition assessment** Gaining the right level of understanding of the condition of large diameter Trunk Mains remains a challenge for Thames Water and the wider water industry as currently there are no 'off-the-shelf' tools/systems that meet the needs of the business. This directly impacts the business's ability to understand the health of its network and plan proactive works. The innovation team is actively working with the industry to address this and are currently looking to trial a tool by Breivoll. There are also efforts underway to look into building a testing area at the Kempton	**R5.5.2 – Innovation culture** It is recommended Thames Water move forward with the Kempton Park testing area to help foster industry involvement in developing new tools and methods for analysing pipe condition. Additionally wider investigation of new technologies in other industries and innovation trends should be prioritised.	**R5.5.2** Ease of Implementation – Medium Cost – Medium

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
	Park facility to encourage industry involvement in developing new tools to analyse pipe conditions.		
Organisation	**5.6.1 - Monitoring installation programme** Thames Water has set its strategy around and made a significant investment in monitoring technologies such as Syrinix and Hydroguard to help understand and manage its risk exposure. The installation and in particular the commissioning of these technologies has taken longer than initially planned.	**R5.6.1a - Monitoring unit structure** Thames Water should review the capabilities required for the life-cycle of the monitoring assets to make better use of the information available and ensure that the assets are maintained correctly. **R5.6.1b – Faster installation process for monitoring equipment** Reduce the number of hand-offs in the installation process.	**R5.6.1** Ease of Implementation – Medium Cost – Medium **R5.6.1b** Ease of Implementation – Medium Cost – Low

2.2.4 Key Findings for Event Response & Aftercare

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Governance	**6.1.1 - Event governance, including third parties** Thames Water has not provided a clear governance overview of the roles and responsibilities, decision making escalation routes and accountabilities across all parties (internal & external) involved in responding to an event. The Event Management Arrangements state the accountable party, within Thames Water, is the event controller with escalation routes leading to them. However there is no clear governance below the event controller and linked to external third parties.	**R6.1.1 - Formal governance group for event response** A formal governance process for third party stakeholders for event response, at least for the large bursts, should be implemented to ensure all parties are aware of their role and interactions.	**R6.1.1** Ease of Implementation – Medium Cost – Low
Policy	**6.3.1 - Customer care policy** Thames Water contract with Cunningham & Lindsey (C&L) to provide customer care and welfare support for major incidents, however a Thames Water individual is still the accountable owner. The Thames Water and C&L Major Incident Response Plan is clear and there is a detailed policy and process in place for customer care during and after a major event affecting 10 or more customers or for damage estimated at >£100k. All the recent high profile bursts were above the major event threshold. Any events below this threshold are managed through the Thames Water Event Management Arrangements, which do not clearly define customer care or what specific activities the event controller should undertake.	**R6.3.1 – Customer care policy for small incidents** A formal customer care policy for small incidents should be developed to ensure there is a consistent understanding across the business of the customer care role and responsibilities for such incidents.	**R6.3.1** Ease of Implementation – High Cost – Low

Area	Findings	Recommendations	Approximate Ease of Implementation & Cost
Process Frameworks	**6.4.6 - Contingency plans availability** The Asset Management Operational Standard states that detailed contingency plans are required for each site classified as being a high consequence location. These include valve packs for quick identification and operation to isolate any burst quickly. Contingency plans, including isolation valve packs, are important to assist the Control Room in making quicker decisions for the engineers and technicians in the field during an incident. The deep dives for the recent 8 high profile events highlight that contingency plans are not always readily available or contain all information. **6.4.9 - Event learning process** Thames Water has provided an Event Learning Process Flow for a Level 3 event, stating the actions that must be completed, by whom and the timeframe for completion. This process is controlled by the Business Resilience and Security team. Through a number of meetings and the workshops it was identified that the formal process was not always followed. Therefore, learnings and appropriate data points related to events are inconsistently captured and integrated back into the business.	**R6.4.6 – Develop contingency plans** Contingency packs should be developed, kept up-to-date and made easily accessible to all event response teams on the ground. **R6.4.9a – Formalise and communicate event learning process** The event learning process should be reviewed to ensure it remains fit for purpose. **R6.4.9b – Conduct regular practice exercises** Conduct regular event practice exercises, including third parties where relevant.	**R6.4.6** Ease of Implementation – Medium Cost – High **R6.4.9a** Ease of Implementation – Low Cost – Low **R6.4.9b** Ease of Implementation – Medium Cost – Low
Management Information	**6.5.1 - Notification of bursts** When a burst occurs there are several methods in which notification of the burst can be received. A review of the deep dives highlights that third party stakeholders, contractors working on site, pressure monitors and / or flow monitors are all used to identify leaks that could lead to bursts. It is understood that stakeholders and customers are often relied upon to provide notification or confirmation of a burst, rather than Thames Water's monitoring equipment. This is consistent across the water industry due to the monitoring technology available.	**R6.5.1a - Geographical area ownership** Ensuring clear ownership and accountability of specific geographical areas will embed accountability for awareness of assets in the area and may enable faster identification when the asset is not behaving as expected. **R6.5.1b – Contact Centre location moved** Move the Contact Centre location to sit alongside the Control Room.	**R6.5.1a** Ease of Implementation – Medium Cost – Low **R6.5.1b** Ease of Implementation – Medium Cost – Medium

3 Asset Planning

This Section details the findings and recommendations for the asset planning lifecycle stage. Asset planning refers to the activities that take place to plan the use, maintenance and replacement of the Trunk Mains network. The content derived in this Section includes the risk modelling, information used to inform planning and investment decisions, and insights into the structure and capability of the asset planning team. While it touches on the investment strategy a full review of this was not part of the scope of the Forensic Review and will be undertaken by the investment strategy workstream in the Trunk Mains Review Programme.

Area	Findings	Recommendations
3.1 Governance	**3.1.1 Investment ownership** Thames Water has set out Trunk Mains expenditure for AMP6. The plan, set in 2013, is expenditure of £147m post efficiency for AMP6. Of this, a total of £75m is allocated to relining and replacing pipes (including the Angelinos Main project) with the remaining investment split across activities such as monitoring, innovation, and leakage targets. This is detailed in The Trunk Mains Investment Area Document [4]. This indicates the investment ownership for the Trunk Mains asset type is spread across multiple areas. This can result in issues around misalignment of priorities, and a lack of overall accountability for asset health and performance.	**R3.1.1 Clarity regarding investment ownership** Clear ownership of Trunk Mains investment should be established and communicated. A dedicated Asset Owner should be appointed with accountability for Trunk Mains investment alongside accountability across the end-to-end Asset Management whole life value chain.

Area	Findings	Recommendations
	3.1.2 Investment governance Thames Water has a governance structure regarding the investment planning. The Company Business Plan Part B: Wholesale Water [5] states existing structures for individual performance and review meetings covering risk, performance, Capex, Opex, Capital Delivery, and Directly Managed Capital which will remain in place for AMP6, though it should be noted these are stated to be under review. The Investment Management Terms of Reference [6] details the official route of approval for projects requesting capital spend. The Thames Water Investment committee, the CEO and CFO must be in attendance. The committee has the authority to approve projects, studies and estimates up to £75m, while those with estimates over £75m must be approved by the Thames Water Board. The committee is also advised of the performance of the investment programme against budget. There are separate business unit investment committees, the Wholesale Water committee is chaired by the Wholesale Water MD, which has the ability to approve investment up to £10m. The Capital Approval Team co-ordinate and manage the monthly committees. The Strategy, Planning & Assurance Team is responsible for asset planning within Wholesale Water. The Organisation Design Templates Strategy, Planning and Assurance – Water [7] document the roles and responsibilities of the team across investment programme & assurance, strategy & planning, customer & stakeholder engagement, and innovation. The Investment Committee meetings are captured detailing the attendees, actions and decisions made during the meeting [8]. The Capital Approval team distribute the meeting minutes to invitees. Review of the documentation indicated that there is governance around investment planning that should provide the structure needed to guide decision making and approvals. The minutes from meetings ensures the relevant controls are in place to ensure the governance is followed.	

Area	Findings	Recommendations
	3.1.3 Corporate risk governance There is a clear hierarchy of corporate risk governance within Thames Water. The Risk & Controls Management Policy [9] states that the following are responsible for risk: • The Board • Audit, Risk & Regulatory Committee • The Risk Opportunities & Controls Committee • Executive Team • Senior Leadership Group • Corporate Risk & Controls Team • Audit and Assurance • Individuals (all employees and third party contractors) The Annual Performance Report [2] states in March 2015 the Audit and Risk Review Committee joined with the Regulatory Committee to form the Audit, Risk and Regulatory Committee. This committee is responsible for monitoring compliance with the risk management framework applied by the Board. The Risk, Opportunities & Controls Committee (ROCC) Terms of Reference [10] from October 2016 outline the purpose of the ROCC. For example this includes risks, opportunities & related controls framework, risk appetite setting, embedding of a risk culture, and monitoring of controls. Thames Water provided risk registers, the Audit, Risk and Regulatory Committee (ARRC) paper – Top Risks January 24 [11] and Detailed Risk Register [12], as examples of the way corporate risks are logged and viewed. For example in September 2016 submission to ARRC main risks in Wholesale Water that were raised were: • Leakage • Asset health & resilience • Extreme weather • Customer satisfaction The risk registers also hold the information around the controls pertinent to mitigating each risk. The Asset Planning System (APS) is an aggregation of all of Thames Water' risks across the business and is intended to show a strategic level of risk exposure and mitigation for the business. ARRC publish a list of the top wholesale water risks, notably Trunk Main risks are not	**R3.1.3a Specific Trunk Mains risk management** To ensure there is a focus on risk management at the Trunk Main asset class, a Trunk Main risk management approach should be established. While the Forensic Review is focused on Trunk Mains, an assessment of overall approach to asset risks would be beneficial to ensure there is a consistent approach across all asset classes. **R3.1.3b Line of sight between Wholesale Water and corporate risk** A clear process and escalation route to ensure a line of sight between Wholesale Water and corporate risk should be established. This will ensure the appropriate risk cultures are embedded down through the business and the relevant wholesale water risks are discussed and controlled at the corporate level.

Area	Findings	Recommendations
	addressed by name, but it does reference asset health and resilience of supply as a top level risk [13]. Wholesale Water has a risk committee. The Terms of Reference for Senior Risk Review and Gateway 0 & 1 Forum [14] defines the role of the committee in approving funding of risks, appropriate mitigation actions, financial reporting on programme budgets, and review of business needs. Having reviewed the documents it is clear that Thames Water has a documented corporate risk governance process [9] that can be used to inform risk awareness, planning and embed a risk culture. A programme of improvement to enhance the maturity of the approach to enterprise risk management (ERM) is in progress [15]. The level of maturity is assessed at the end of each of three phases. However, there is limited direct line of sight between risk governance in Wholesale Water and corporate risk governance. The Forensic Review has not conducted a detailed review of corporate governance and policies to provide further insight into corporate risk management.	

Area	Findings	Recommendations
	3.1.4 Strategic intent for Trunk Mains The Thames Water Investment Area Document [4] sets out the investment strategy for Trunk Mains over the AMP 5 to 7 periods. It highlights 4 key areas of investment, which are: • An ongoing programme of work (currently with the University of Surrey) to understand corrosion, confirm deterioration rates, and the causal factors that lead to large ferrous mains failing. • Initiating steps to develop an internal material analysis tool (PIG) to find the causal factors in the metal of the main ensuring Thames Water is replacing main lengths at the end of their design life. • Developing a hydraulic model that allows the optimal network to be developed and to confirm the level of rationalisation of the transmission network to meet the needs of London for the next 100 years. This ensures Thames Water rehabilitate where needed, and carry out repairs or abandonment elsewhere. • Trial and utilise alternative rehabilitation methods to provide cost effective solutions that will work in the congested London sub-surface, such as pipe jacking. Having reviewed the Thames Water 2015-2020 business plan [16] it provides a strategy across Wholesale Water rather than a clearly defined strategy for specific assets, such as Trunk Mains. The IAD [4] lays out Thames Water's strategy for Trunk Mains over AMP6. Whilst the document does set out the how Thames Water is going to invest within the Trunk Main network there is no clear line of sight down to how the asset will be operated and maintained.	**R3.1.4 Overarching Trunk Mains strategy** Develop a Trunk Mains strategy that provides a clear line of sight from the Investment Area Document to how the asset will be operated and maintained. This should become the strategy which informs all activities on the Trunk Mains asset class.

Area	Findings	Recommendations
3.2 Risk Management	**3.2.1 Use of the Asset Investment Manager (AIM) Risk Model** Thames Water has developed an advanced tool to understand the risks posed to the public and the business from the burst of a Trunk Main in order to make informed asset planning decisions for the Pricing Review process. The Asset Investment Manager (AIM) Risk Model was designed for business planning purposes, not for day-to-day operational risk management, although outputs can be used by operations. The AIM Risk Model was developed in conjunction with the University of Surrey, and uses two primary calculations to create a risk ranking of Trunk Mains. • Consequence model: Using a 1-directional rolling-ball model to estimate the area affected by the bursts of a Trunk Main at 100m intervals, this calculation quantifies the consequence of the burst, with particular attention being paid to high-risk locations, including hospitals, underground stations and inhabited basements [17]. • Probability model: The probability of failure is determined using a weighted average of actual failure history and an engineering-based probability model, which provides an estimated number of failures per metre per year given certain asset properties [18]. These two modules produce consequence and probability (burst frequency) scores, which then are then combined together to create the Trunk Main Risk Ranks spreadsheet [18], consisting of over 100,000 individually ranked mains for PR14. The outputs of the AIM Risk Model are used primarily to influence investment decisions, however the rankings influence a large number of decisions and plans in the business. As an example, the High Consequence Mains and Valves lists influence operational strategies and steers priorities for maintenance through AMP6. The model presents a static snapshot of the network from the last time it was run (current outputs from PR14), and does not provide an up-to-date view on risk exposure or the probability of a main burst. The tool is advanced for its intended purpose of informing business planning. There is a desire for the tool to be made available for more regular analysis in order to inform operations planning throughout the AMP.	**R3.2.1 Dynamic risk management** Efforts should be made to assess the requirements for a dynamic risk management tool, based on the current AIM Risk Model, which would be regularly updated based on the latest asset data. This would allow better decision making and planning by both Asset Planning and Operations, in the short and medium term, by assuring risk information was up to date, thus allowing the most pressing risks to the business and the public to be prioritised. The outcome of the requirements assessment may be that a dynamic risk management tool is not suitable. An assessment of the ease of implementation can be better made once the requirements are understood.

Area	Findings	Recommendations
	3.2.2 Asset condition knowledge Trunk Main bursts are generally failures resulting from six major mechanisms [19]: • Corrosion of the main, causing either general loss of Section and graphitisation or localised pitting, thus increasing the net stress in the material. • Damage, either incurred during construction or from third party interaction. • Loss of support, often caused by leaks washing away material below the pipe, thus increasing stress in the pipe wall. • Transient pressure waves from pump and valve operations, which can significantly raise the pressure in the pipe. • Fatigue of the material through repeated loading cycles, such as daily changes in the operating pressure. • Impact loading from traffic and construction equipment. Understanding the probability and consequence of these causes of failures is challenging as it often requires access to the Trunk Main network, however when known it helps inform the accuracy of data fed into the risk model. Data is received through monitoring (Syrinix, Sahara and Hydroguard, and non-destructive testing – see Section 5 for more detail) however this is limited. This highlights a known issue, as other water companies face similar challenges, with the ability of Thames Water to fully understand the condition of its assets, which in turn impacts the accuracy of its investment planning.	**R3.2.2 Innovation in asset condition tools** Developing a thorough understanding of asset condition is useful to being able to plan effectively. As such, it is recommended that efforts be made to collaborate with the supply chain to develop innovative new tools to assess the condition of large diameter Trunk Mains.
	3.2.3 Deterioration and replacement Thames Water use two numerical models developed in conjunction with the University of Surrey to understand and predict Trunk Main deterioration for asset planning purposes. Based on an engineering model of material performance, and a statistical model, these give an estimated rate of deterioration ranging from 0.95% to ~5% respectively per year [4]. The upper bound presented by the engineering model is based on research that was still in its infancy at the time, and as such the lower bound of 0.95% was used for the investment forecasts. In line with these models, the current rate of replacement for Trunk Mains is estimated at 0.19% per annum, based on the remediation of 'No Regrets' mains, and planned rehabilitation works [4]. It is recognised in the Trunk Main Investment Area Document, Executive Summary [4], created as part of the AMP6 planning process, that the replacement programme is not keeping pace with deterioration, and that the trend in annual bursts of Trunk Mains is on the rise. This presents an asset planning challenge to effectively plan investment to address this trend alongside other areas	**R3.2.3 Replacement Programme** Given the criticality of the Trunk Main network to Thames Water's overall operation, and the likely timescales required to replace these assets, it is recommended work be started to gather evidence and build a case for a long term Trunk Main replacement strategy. Analysis may also be required to shape the programme so as to prioritise high risk mains while minimising disruption to the network and the public.

Area	Findings	Recommendations
	that may require investment i.e. monitoring coverage.	

Area	Findings	Recommendations
	3.2.4 Risk model improvements In May 2015 a Trunk Main Risk Model Proposed Improvements [20] plan was developed by a Thames Water risk modelling specialist. This included suggestions for improvements in input data, methods, areas requiring specific review, and data requiring a refresh. The Trunk Main Model Development Plan [21] put the recommendations into a plan and owners were assigned to each action, effort estimated, priority assigned and start date allocated. In reviewing the documentation it appears that the intention to improve the model was clear and a knowledgeable modelling specialist provided the recommendations. However this appears to have been a one off exercise that has not been completed, with the individual driving the development and tracking of the plan having left Thames Water. It is understood there is a new modelling specialist starting in April 2017 who will fulfil this role.	**R3.2.4 Continue risk model improvements** Ensure there is explicitly stated and assigned responsibility with the SP&A team for risk model continuous improvement.
3.3 Policy Framework	**3.3.1 Overarching asset management policy** Thames Water has a business planning framework [22] that embeds competencies from the internationally recognised Global Framework for Maintenance and Asset Management. This is supported by a set of end-to-end core business planning processes that cover all steps to build and execute a business plan. This was signed off in October 2013, following assurance from Mott MacDonald as part of the PR14 submission. At the beginning of AMP6 the AMA framework was updated with support from Mott MacDonald to produce a capability assessment tool called the Framework for Expenditure Decision Making [22]. This tool focuses specifically on business planning processes to build a plan. It is clear that an asset planning policy is in place and actively reviewed and updated. There could be a better understanding of the framework and underlying processes, across asset planning to ensure consistency in asset planning activities. **3.3.2 Risk management policy** There is a corporate Risk & Controls Management Policy [23] that was approved in 2016 and currently under review due to a new risk manager. The policy explains the scope, application, risk appetite of the company, roles and responsibilities, implementation and monitoring of the policy. This policy is as expected from a standard policy document and shows that Thames Water has a risk and controls management policy in place which is applicable to all personnel within Thames Water. The senior leadership group have a responsibility to ensure adherence to this policy for their areas of responsibilities, such as wholesale water. The ARRC and ROCC are responsible for implementing and monitoring the framework. The ROCC committee held in Oct 2016 had 2 agenda	**R3.3.1 Asset management policy communicated** The overarching asset management policy should be communicated more widely across the business and made accessible to ensure there is a common understanding and alignment across the business.

Area	Findings	Recommendations
	items relating to reviewing the roles and responsibilities and self-certification. [24]	

Area	Findings	Recommendations
	3.3.3 High consequence spans Ultra high or high consequence spans of Trunk Mains are used to plan three things – the valves that should be exercised, the location of monitoring asset installation, and contingency planning. The Forensic Review was not able to identify any documentation that specifically identifies which spans are classed as ultra-high consequence, high consequence, and those spans that the risk is deemed acceptable. For example the ultra-high consequence valves that require exercising every 5 years total 25,000. To identify which valves should be included in the ultra-high consequence exercising Thames Water conducted a capacity assessment to identify how many valves could be exercised on an annual basis, approximately 5,000. This figure was extrapolated out over 5 years to total 25,000 valves; Thames were then able to identify, specifically for ultra high consequence valve checking, that those 25,000 valves were located on 20,000 spans of Trunk Main; this is the definition of ultra-high consequence spans for valve exercising. However the threshold of top 20,000 spans constituting 'high consequence' is not something that is carried out consistently throughout Thames Water. Contingency planning uses previous burst history in order to drive contingency planning and for the planning of monitoring asset installation locations the HSE ALARP process is being used. Having reviewed the documentation, and anecdotally, there is nothing documented that defines how Thames Water identifies exactly which spans of Trunk Main are identified as ultra high or high consequence.	**R3.3.3 Clarification of definitions** A clear definition of the Trunk Main risk level classifications (e.g. highest criticality main) used in the asset standards should be documented and communicated throughout the business to ensure there is a common understanding that prevents incorrect assumptions being made.
3.4 Process Framework	**3.4.1 Risk model and consequence model methodology** Thames Water has provided the Trunk Mains Risk Methodology [17] which details the process for calculating risk in the Asset Investment Manager (AIM) tool: • Asset data is loaded into AIM. This includes all information that will be needed by AIM to calculate the probability and consequences of failure. • A risk map is created to define how consequences and probability are scored. • Interventions are created that include Thames Water's Capex and Opex costs, together with the benefits of using these solutions. • Scenarios are created that define the objectives and constraints. • AIM optimises the scenario to determine the best mix of solutions to meet the objectives and constraints. A review of this document shows that it provides the process, assumptions, data inputs, and linear model restrictions. However it does not show the detailed calculations or validation method of the model. The detailed calculations and validation of the model is undertaken by an external	**R3.4.1 Awareness of detailed calculations and validation** Continue to ensure there is at least one Thames Water individual who has a working knowledge of the AIM detailed calculations and validations undertaken.

Area	Findings	Recommendations
	company, ICS, who are expected to hold this documentation.	

Area	Findings	Recommendations
	3.4.2 Rolling ball model methodology Thames Water has provided the Handover Document for the In-House Burst Consequence Model [25]. The rolling ball model is used to understand the approximation of a flood route from a burst and was developed by MWH for the PR09 business plan. MWH Limited is a local water and natural resources firm, providing technical engineering, construction services and consulting services who are part of the eight$_2$O alliance. MWH developed the model as they had the modelling expertise required to develop the base model. In December 2012 the model was transferred to Thames Water. The document states the key process steps as: • Mains selection • Burst point creation • Surface processing • Flood route generation (rolling ball) • Flood extents • Consequence analysis • Common flood routes • Water course analysis • Adjacent mains analysis A review of this document shows that it provides the process, data inputs, and applications / databases used. However it does not show the model assumptions or how it has been validated.	**R3.4.2 Easily available rolling ball model assumptions and validation methods** Ensure the rolling ball model assumptions and validation methods are documented and made readily available to those using the model.
	3.4.3 Asset information update process Thames Water has provided a documented process for redlining (redlining is a process used by operatives in the field to add / amend data within GIS). This can be found in the WM07 Mobile GIS Redlining [26] document. The document provides an overview of why redlining is important and the five types of redlining updates that can be made alongside the process for how to do them including step-by-step instructions with screen shots. While there is a documented process for asset information updates, there is an inconsistent awareness and understanding of the process throughout the business. Therefore while asset information is still updated, there is no certainty that the information is being captured is a complete representation of the as-built environment to inform asset planning.	**R3.4.3 Systems Operations involved in data gathering** Systems Operations has insights into asset information and the updates that are required. The formal process to ensure these updates are captured and entered into GIS should be widely communicated across the business and its application monitored.

Area	Findings	Recommendations
3.5 Management Information and Data Quality	**3.5.1 Trunk Mains definition** The Trunk Main Investment Area Document [4] classifies a Trunk Main as a larger sized mains which are classed as 18" (450mm) and above. The risk model uses different definitions of Trunk Mains over time as a better understanding of risk profile has emerged. The Trunk Mains Risk Methodology [17] states: • Up to and including version 3 of the risk model, mains with a diameter of greater than 24" (or 600mm) were included. • In version 4 of the risk model within London, all mains greater than or equal to 12" (300mm) in diameter and within Thames Valley (including Guildford), all mains greater than or equal to 10" (250mm) in diameter were included. • In version 5 (January 2014) a diameter split was used and all Trunk Mains less than 12" (300mm) in London and less than 10" (250mm) in Thames Valley were moved into the distribution mains model. For planning purposes the SP&A team need to ensure they can classify Trunk Mains within their data sets. Thames Water provided the Price Review Clean Water Mains Data Split [27] which outlines how clean water mains data has been classified as either distribution or Trunk Main for the purposes of the Price Review risk models. The methodology was developed for the PR14 modelling process and has been used subsequently on all risk modelling efforts. There were issues with the raw Integrated Asset Repository (IAR) data that saw mains incorrectly identified as trunk or distribution, or not identified at all, hence the need for SP&A to conduct their own classification. It is understood since this document was written in December 2015 a GIS model has been developed to help consistently classify Trunk Mains. However through conducting the interview and workshop process it was identified that this is not a commonly understood definition across the business. SP&A use hydraulic class, rather than size to classify Trunk Mains. Within SP&A this definition is widely understood. Outside of SP&A anecdotal insight suggested some individuals and business areas believed anything to be 12" and above to be a Trunk Main. Reviewing the documentation and through interviews, individual's understanding of what constitutes a Trunk Main highlights there is a consistent understanding within teams i.e. SP&A, however across the business there is no consistent understanding of what constitutes a Trunk Main and this may impact data provided for Trunk Mains planning purposes. It also impacts the	**R3.5.1 Consistent Trunk Mains definition** There needs to be an awareness and consistent understanding of what a Trunk Main is throughout the business to ensure decisions across the Trunk Mains asset lifecycle is consistent. While there is a clear awareness of the definition within SP&A, there is not the same understanding across the business.

Area	Findings	Recommendations
	integration of planning and operations where plans are set for assets not considered Trunk Mains by operations.	

Area	Findings	Recommendations
	3.5.2 Infill analysis The Trunk Mains Risk Methodology [17] describes how the infill analysis is conducted to fill the gaps in data inputs to the risk model. These gaps are: • Diameter • Year laid • Internal pressure It is stated that, particularly for internal pressure, there are large number of spans for which Thames Water has low or very low confidence in the pressure value assigned. This is partly because the age and location of pipes mean that not all information used for asset planning is available and / or accurate therefore infill analysis is required to complete the picture. When using the risk models it must be clearly understood what limitations are placed on the model and its outputs by the use of infill analysis to address data gaps. **3.5.3 Trunk Main database** Information on Trunk Main bursts are inputs into asset planning decisions around risk and consequence as they provide real examples of data. There are currently a minimum of four trackers, used by different business areas, where bursts are recorded as shown in the Data Sheet – All Bursts 2016 [28]: • South & North London tracker • Event tracker • Innovation tracker • Trunk Main database Having reviewed the various trackers for Trunk Main bursts in 2016, it is clear that not all have been updated consistently to reflect a clear record of bursts. This also highlights there is no one version of the truth for tracking Trunk Main bursts and therefore various trackers must be pulled together to provide a comprehensive view of all bursts.	**R3.5.2a Improved predictive analysis** To enable continuous improvement of the model, further development of predictive analytics and infill analysis is recommended to ensure the model remains robust and the outputs can be used with high confidence. **R3.5.2b New methods for data collection** Investigation into the scope for new methods to measure asset condition should be undertaken. This could generate data that is used in the risk model. **R3.5.3 Single Trunk Mains database** A single database for Trunk Main bursts should be selected and all historical bursts complied into the database. An assigned owner of the database should ensure all future bursts are recorded consistently and in a timely manner.

Area	Findings	Recommendations
	3.5.4 Data and Model Validation Thames Water has provided documentation on model and data validation. The PR14 Bottom Up Audit of Data [29] conducted by Halcrow to ensure the data and associated methodology are appropriate, reliable and complete. The Peer Review of Integrated Demand Management Modal [30] documents the peer review carried out by Thames Water to review the model inputs, set-up, accuracy and robustness of outputs. The Business Plan Strategy Review [31] conducted by Strategic Management Consultants provided a review of specific investment areas during the development of the investment plan, outlining their strengths and weaknesses. This documentation outlines that Thames Water has internal and external validation of data sets, models and investment plans to ensure the robustness and completeness of the. The recommendations from these reviews should be actioned where appropriate. **3.5.5 Trunk Mains replacement tracking** The Trunk Mains Investment Area Document [4] prepared as part of the PR14 process identified 'No Regrets' and 'Emerging Risks' Trunk Mains for relining or replacement over the course of AMP6. eight$_2$O provide updates on relining and replacement progress. The latest updates were provided in November 2016 and again in February 2017 as evidenced in the Trunk Main Performance – Feb 2017 [32] spreadsheet. It shows the following progress has been made against plan: • 9.39km replaced to date against 25.79km planned • 4.39km relined against 4.39km planned In addition, Thames Water provided the Trunk Mains Risk Reduction Analysis [33] which is used to ensure any changes to rehabilitation projects deliver the stated risk reduction, to offset deterioration. This is re-run throughout the AMP to track risk reduction. Reviewing the documentation provided, it is clear that progress is being made and tracked. There is management information available to review progress against plan and ensure any changes to the plan are tracked and their impact understood.	**R3.5.4a Understanding of data collection process** Efficacy of data governance and the data collection process should be better understood, in order to limit the risk of misreporting burst histories and other key variables used in modelling. **R3.5.4b Collaboration with TTA to develop analytics** To further develop predictive analytics and infill analysis to ensure it is robust and the outputs can be used with high confidence. Further work to collaborate with TTA is recommended to explore new developments.

Area	Findings	Recommendations
3.6 Organisation	**3.6.1 Strategy, Planning & Assurance (SP&A) team structure** The Strategy, Planning & Assurance (SP&A) team reporting into the Head of SP&A, is structured according to capability (e.g. Strategy and Planning, Supply and Demand Strategy and Planning, and Investment Programme & Assurance,). Strategy and Planning is split between non-infrastructure and infrastructure, with infrastructure teams focused on below ground assets and non-infrastructure teams focussed on above ground assets. Currently across infrastructure and non-infrastructure there is no single Asset Owner across all assets. **3.6.2 Operations input into planning** In infrastructure, there is currently no role that bridges the strategic asset management planning (directional strategy, which SP&A is accountable for) to the tactical delivery within the alliances (eight$_2$O and IA). As a result, there is no senior manager or team responsible for translating the strategic asset management objectives into an operational delivery strategy. The roles and responsibilities across the end-to-end asset management whole life value chain are not clear.	**R3.6.1 & R3.6.2 Single asset owner** Thames Water should follow the recommendations of the Asset Owner Operating Model project that is ongoing and recommends that Thames Water should appoint a single asset owner for Trunks Mains, reporting to the MD for Wholesale Water. In addition the Trunk Mains as an asset group should be set aside, for at least 18 months before being reviewed, as a separate activity for a period of intensive care to establish a deep and consistent focus across the end-to-end asset management lifecycle. While the Forensic Review is focussed on Trunk Mains, other asset groups with similar risk profiles may also benefit from this approach.
3.7 People Capability	**3.7.1 Succession Planning** Succession planning for L4 roles through to the Senior Leadership Group is undertaken every 6 months. The succession plan [34] assesses the readiness of individuals to take over more senior roles and develops, or refreshes, a development plan for the individuals. Succession planning also identifies if the succession route is go-to-market recruitment, rather than developing capability in-house. The existence of succession planning, and the accompanying development plans, provides Thames Water with the ability to ensure knowledge and skills transfer is planned. The transfer of knowledge is further supported through the processes, manuals and guidelines discussed throughout this report.	**R3.7.1 Review of succession planning** Measures should out in place to ensure Thames Water have access to the appropriate knowledge and skills to manage events.

4 Asset Operations and Maintenance

This Section details the findings and recommendations for the asset operations and maintenance lifecycle stage. Asset Operations and Maintenance refers to the activities that take place as business-as-usual on the Trunk Main network, as an asset class. This Section looks specifically at the physical operation of the Trunk Main assets on a day-to-day basis, the regular routine maintenance that is required to keep the network functioning and also the ad-hoc maintenance that is required when incidents, such as leaks or bursts, are identified; focusing on the various hand offs, the ownership of the different roles and how this aligns to Thames Waters' strategies and policies.

Area	Findings	Recommendations
4.1 Governance	**4.1.1 Prioritising the needs of the network** The operation of the network must balance a number of needs, particularly water quality, water supply and leakage. As these needs can impact each other, a strategy has been developed to prioritise the supply interruption Outcome Delivery Incentives (ODI) as detailed in Appendix 6 [35]. There is a strategy in place to achieve this, and is managed at the network level using the iHub system, which takes into account variables such as outages, weather, performance targets and projected demand to produce daily, 10 day, seasonal, and annual production plans that meet the needs of the network. This strategy aligns with evidence found in a small number of documents, such as the Burst Alarm Process for Hydroguard [36] and the efforts seen in the 8 high profile events to keep customers in supply. However this is not broadly visible in formal processes, policies, and governance structures reviewed by the Forensic Review, thus raising a risk that decisions are made at the lower levels may not align with the strategy. **4.1.2 ODI effect on job prioritisation** During the interviews and workshops it was raised that the primary drivers in the business are associated with reducing leakage and improving Service Incentive Mechanism (SIM) scores (ODI metrics WC2 and RA6 respectively) [37]. Therefore the jobs to reduce leakage and those related to customer satisfaction (e.g. water supply) are prioritised. This impacts the prioritisation of other jobs (e.g. valve maintenance) that are not directly linked to a specific ODI. This is evidenced through the operational programme of inspecting and maintaining the high consequence mains services 4,500 of the approximately 25,000 'high consequence' valves annually. The typical return period for servicing high consequence values would be roughly 5 years on average which is a longer return period than detailed in the Asset Management Operational Standards [38].	**R4.1.1a Strategic objectives** The strategic objectives of Water Supply should be backed up with a clear set of outcomes and outputs from clearly defined programme of works and projects. **R4.1.1b Network operating priorities** A governance approach addressing the decisions and approvals required to appropriately balance the needs of the network (water quality, water supply, customer service interruptions, leakage, and cost of energy) should be clearly documented and communicated to ensure that operations staff can make informed decisions on how to operate the network and the associated trade-offs that are acceptable.
4.2 Risk		

Area	Findings	Recommendations
Management	**4.2.1 Risk model operational inputs** Operational activities are informed by the outputs of the AIM Risk Model. This includes the prioritisation of high consequence mains and associated assets for inspection and maintenance, such as the 4500 high consequence valves that are assessed annually by the Strategic Field Technicians (SFTs). Currently eight$_2$O utilises the strategic hydraulic model in order to assess the second order effects of closing valves on the Trunk Main network. However the strategic hydraulic model is not widely used by the operations team for this purpose, thus requiring more involvement from the Control Room. The risk model was designed for business planning purposes, not for day-to-day operational risk management, although outputs can be used by operations. Therefore, the outputs of the model do not incorporate the latest updates to the asset information within GIS, raising the risk that operational decisions are being made on outdated and possibly misleading information. Furthermore, there is no formal process in place to allow operations teams who work on these assets to feed their updates back into the model, thus limiting the ability of the business to gather and distribute important local and asset-specific knowledge. **4.2.2 Risk and mitigation tracking** The APS system is used by Thames Water to document and track asset-related risks and mitigations in order to understand overall risk exposure at operational and strategic risk levels. A copy of the full risk register held within APS was downloaded and reviewed. There risks register did not contain any related to the 8 high profile Trunk Main bursts. However it was noted that there are a number of risks within APS that cover Trunk Mains as an asset class and other specific Trunk Main spans. There are defined policies and procedures for the use of APS. Participants in Forensic Review interviews and workshops have said that there is a perception that the system unintuitive and lacks reliable, up to date information. As a result, people are less likely to use and update the system, thus limiting the business' ability to understand its overall risk position for Trunk Mains assets.	**R4.2.1 Operational information input into risk management** The risk model should be expanded to provide a dynamic operation decision support tool with a direct link to operational teams. The risk model should also enable the inclusion of data provided by operations. **R4.2.2 Risk-based culture** Efforts should be made to improve engagement with the APS risk management system, as well as to build an understanding of risk within the business, and a culture of risk-based decision making. Potentially this could be helped by improving APS functionality and user experience, improving or enforcing processes for keeping the risk registers up to date and keeping the information relevant.

Area	Findings	Recommendations
	4.2.3 Remote valve operation Thames Water currently has a small percentage of remotely operable valves installed on the Trunk Main network. Remotely operated valves are valves that can be operated to isolate a Trunk Main by an individual from the Control Room or other location without having to go to the valve. This is different to automated valves which operate within a set of given parameters without human intervention. Remotely operated valves have been installed on Trunk Main spans that have been defined by Thames Water as "ultra-high" consequence, such as areas where multiple bursts have occurred in the past, and also on a number of pipes leading to and from reservoirs. Remotely operated valves reduce the labour required to operate the valves, and have the potential to reduce the time that it takes to isolate a valve in the event of a burst main. There is no policy on remote operation of Trunk Main valves, nor a documented plan for the roll-out of remotely operated valves to identified "ultra-high" consequence Trunk Mains. Rather it could be said that remotely operated valves are installed on a case by case basis. Given the benefits that remote valve operation brings, there is a desire to install more. However the location restrictions due to the size of the chamber for the valve actuator, as well as the cost, limits the number of additional valves that can feasibly be installed. As a result, there is currently no programme to install additional remotely operated valves.	**R4.2.3 Remote valve cost/benefit analysis** Work should be undertaken to better understand the feasibility and risks of increasing the number of remotely operated valves on the Trunk Main network. This will provide a cost/benefit analysis for investment. A policy should be created to give the business clear direction on the use and maintenance of currently installed remote operated valves, as well as guidelines for planning for new remote operated valves.
4.3 Policy Framework	**4.3.1 Asset maintenance policies** There are policies in place that set out the maintenance practices for assets associated with Trunk Mains as seen in the Trunk Main Asset Management Operational Standards [38]. For example the standard states highest ("high high") risk mains, as defined by their consequence calculated at 100m intervals, should be surveyed and maintained annually, with their associated valves being checked every 6 months and "normal" high risk mains being checked bi-annually with their valves checked annually. The review of the documentation identifies there is a set of asset maintenance polices in place which enable operations staff to understand what should happen with each asset and how often.	

Area	Findings	Recommendations
4.4 Process Framework	**4.4.1 Permit to Work process** A PTW is required for all planned work on Thames Water network assets, as stated by the Asset Management Operational Standard – Risk Management for Water Supply and Network Distribution [39]. However, while there are processes in place to monitor compliance with the PTW system (e.g. random site reviews, health and safety checks, and PTW system audits), there are no controls in place to physically stop crews from working without or outside of the conditions of the PTW. As such there is a possibility work can be done without assessing and mitigating project risks, or ensuring sufficient oversight from supervisors, NSTs, and Network Managers. The review of the Crayford Road and Lee Road events highlighted this, as both saw failures to properly follow the terms of their respective PTWs, which in turn lead to the bursts [3] [40].	**R4.4.1 Permit to Work process controls** In order to ensure that works on Trunk Main and other assets is being done to correct standard while minimising risk to the business, it is critical that crews follow the PTW process. Controls should be put in place to ensure that work cannot proceed without a completed and approved PTW and that the conditions of the document are followed throughout the work.
	4.4.2 Valve operations process The Water Network Operational Standards – Valve Operations [38] sets out the drivers and purpose of valve operations, accreditation requirements, valve capping procedures, and a field checklist. Additionally, Thames Water has provided a Good Practice for Valve Operations [38] overview document that outlines step-by-step instructions for valve operations. There are documented processes for valve operation. However, the processes are not consistently followed in practice. For example, when an operative opens or closes a Trunk Main valve they are required to notify the Control Room. Whilst this control is documented there is nothing in place to ensure that the operative actually notifies the Control Room. In Forensic Review interviews and workshops area managers and individuals from System Operations stated that there have been instances where the number of notifications from operatives working on valves was less than the number of valve operations scheduled for that day. The impact of this is potentially exacerbated by the apparent inconsistency of redlining (this is covered in more detail in finding 3.4.3) so that when operatives do not contact the Control Room they may be relying upon inaccurate information on GIS or the valve about valve operation.	**R4.4.2a Embedding valve operation processes** Given the criticality of high consequence valves and the potential risk to the network from incorrect operation of valves, it is important that all operatives use consistent and approved methods for valve operation, in line with documented processes and standards. It is recommended that there is a programme to raise the profile of the processes and the need to adhere to them, highlight the effects of non-compliance, and identify additional types of control that could be used to enforce adherence pre or post works. **R4.4.2b Programme of works for valve operation** It is important that valve information is clearly stated on all network diagrams and is easily accessible. There is an opportunity for Thames Water to focus current resource (NSTs currently carry out valve checks, however this information is not consistently updated on diagrams) on setting up a programme of works for valve operations, which would include identifying left hand or right hand valves on all schematic diagrams as well as tagging actual valves.

Area	Findings	Recommendations
	4.4.3 Asset information update process Thames Water has provided a documented process for redlining (updating GIS while in the field) has been written. This can be found in the WM07 Mobile GIS Redlining [41] document. The document provides an overview of why redlining is important and the five types of redlining updates that can be made alongside the process, including step-by-step instructions with screen shots. It is clear upon speaking to operations teams they are not aware of a clear and consistent process for updating GIS information. While there is evidence of documentation being produced it is not being communicated effectively or widely used. Therefore, asset information is still updated, but there is no certainty that all information is accurate and will inform future planning.	**R4.4.3a Summary version of redlining process** A summary version of the existing redlining process should be developed and provided to operations staff for reference when redlining in the field. **R4.4.3b User-friendly GIS interfaces** Thames Water should explore developing a more user friendly interface for operations staff. This should incorporate feedback and viewpoints from operations.
	4.4.4 The impact of third party actions on Trunk Mains damage When a PTW is submitted assurance checks are carried out to ensure that the request is fit for purpose [42], this includes a check of power / gas / communication assets in the ground in the area of the potential work. There are currently no controls in place to preclude third parties, such as power, communication and utilities, from digging and working around Trunk Main assets. Damage from these kinds of events are a known issue, especially in central London, where pipes are often very close to electrical, gas, and telecoms assets. While this risk may be difficult to eliminate completely, it highlights the need for open communication and information sharing with other utilities, as well as a firm understanding of Thames Water asset locations in order to limit risk to assets from possible third party strikes.	**R4.4.4 Third party engagement** Undertake an exercise to share information and Trunk Main network diagrams with councils and other third parties, to inform them where critical asset information is to reduce the risk of third party damage. Consider more formal controls or collaborating when working around Trunk Mains.

Area	Findings	Recommendations
4.5 Management Information and Data Quality	**4.5.1 Data validation checks** Updates to GIS information, submitted by operations teams, must pass through a data validation check. Basic validation checks, such as identifying if a user has tried to add a Trunk Main valve to a distribution main, are carried out and errors flagged. Once the checks have been completed, an off-shore team in India manually input all the updates and confirmation of completion is sent back to the in-house GIS team. There is a 24 hours Service Level Agreement (SLA) for updates received by digital redlining and a 10 day SLA for documents received by paper [43]. If an error is flagged the individual who submitted the update request is contacted for further investigation. Having the data validation checks helps ensure the data uploaded into GIS is accurate, which is critical in assuring the quality of management information and locating assets at site level. However, there is a high level of dependency on operations' cooperation in the data gathering and submission process.	**R4.5.1 Review of data validation SLAs** Review the SLAs and process for GIS data validations to understand if the paper validation SLA of 10 days can be brought closer to the 24 hours SLA for digital redlining. In addition review the incentives for operations staff to use digital redlining rather than paper redlining to reduce the time it takes to validate the data.
	4.5.2 Valve location information Valve location information is held on GIS. Thames Water provided an example of View Tool (GIS) Oxleas Wood Trunk Mains [44]. The information provides details on location, position and automation. This information is important as it helps locate the valves, and their open or shut status, during operational work and event response. Having reviewed the documentation and the deep dives it is clear that valve location information is available for use to operations staff. The valve number and location on the network is accessible through the View Tool (GIS). However, there are instances where the information contained on GIS is not reflective of the reality on the ground. An example of this is the Crayford Road event where there were anomalies in how GIS showed valve setup leading to a delay in isolating the main. This highlights the importance of ensuring the end-to-end process for updating GIS information is followed, starting with operations input through to the meeting of update SLAs by the Technical Information Team.	**R4.5.2 Data as an asset** It is recommended efforts be made to drive a cultural change to highlight the importance of data to the business, ensuring that it is also treated as a key asset to be made readily available. This may include a programme of works to capture and confirm the location and position of all valves in GIS.

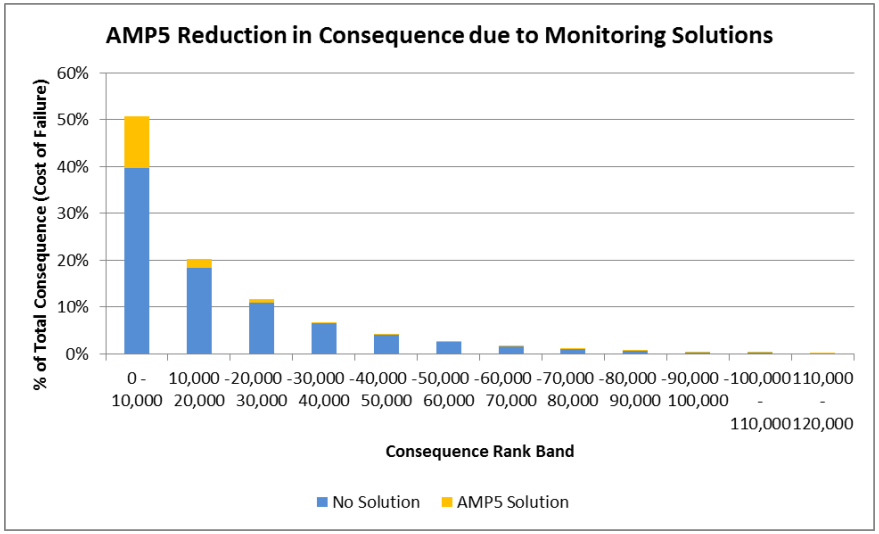
Area	Findings	Recommendations
4.6 Organisation	**4.6.1 Alliance structures – values** Thames Water has developed an alliance structure to work with contractors to deliver both Opex and Capex work in AMP6. The Infrastructure Alliance (IA) is composed of Thames Water, Morrison & Murphy and Kier & Clancy Docwra. eight$_2$O is composed of Thames Water, Atkins, Balfour Beatty, Costain, IBM, MWH and Skanska. The Infrastructure Alliance organisation structures are documents in the Operations Transition Support Packs [45] [46] [47] [48]. The alliances should display the values of Thames Water when out in the field. There have been instances when contractors have not displayed the values having a negative impact on Thames Water. An example of this was the Lee Road [40] event where the developer services team, conducting a routine procedure, did not display the values of the Infrastructure Alliance and were not familiar with dealing with customers resulting in poor customer feedback for Thames Water. **4.6.2 Alliance structures – hand-offs** The accountability and hand-offs between the Infrastructure Alliance and eight$_2$O are not clearly documented and understood. Having clear accountability and hand-offs between the IA and eight$_2$O would potentially reduce delays in completing jobs as the additional time to handover jobs would be minimised as well as reducing potential rework due to not understanding actions previously taken.	**R4.6.1 Reaffirmation of Thames Water values** An exercise should be undertaken to confirm the importance of displaying Thames Water values when working on site, including how to interact with customers. **R4.6.2 Roles and responsibilities during handovers** Thames Water should look to review roles and responsibilities associated with hand-off processes to ensure awareness from all parties on when, how and by whom the process works.
4.7 People Capability	**4.7.1 Large mains skills** To undertake operational and maintenance work on Trunk Mains additional skills are required to undertake risk assessments, understand the implication on the wider network of actions taken, and make decisions with potentially less accurate information i.e. on precise location of a suspected leak. Therefore, operational and maintenance work on Trunk Mains is passed to the Large Asset Group who have these skills. If this team does not have the capacity to undertake the work there may be a delay due to the limited Trunk Mains skill set elsewhere in the operations teams. The impact of this is not directly traceable to any of the recent burst events.	**R4.7.1 Increase Trunk Mains skills** An assessment of work and capacity for the Large Asset Group on Trunk Mains should be carried out to assess the risk of Thames Water not being able to respond to reactive Trunk Mains work.

5 Asset Monitoring

This Section details the findings and recommendations for the asset monitoring lifecycle stage. Asset monitoring is one of the three core elements of the Thames Water Trunk Main strategy, with the ambition of expanding the monitoring of highest consequence Trunk Main spans from 5% to 8% of the Trunk Mains network by the end of AMP6 through a £31.3m investment [4]. Highest consequence Trunk Main spans are understood to be the spans in the top 10,000 of consequence rankings, and described in the Investment Area Document [4], see Figure 11. Monitoring systems and activity on Trunk Mains are described in Figure 12 below, and can be understood in terms of three stages:

1. Pre-event: Use of noise loggers, satellite imaging and the Sahara leakage detection tool (Sahara surveys).
2. Time of event burst/leak: Hydroguard and TrunkMinder (Syrinix) units which monitor flow, pressure and noise and provide burst and leak alarms. These systems are monitored by the Control Room; alarms which are raised by the units are highlighted on the systems and also prompt emails and text messages to be sent to personnel, triggering a response process.
3. Post-event: Use of and meters to capture flow data and pressure data to understand whether a leak or a burst has occurred.

This Section contains findings and recommendations on the monitoring assets being used on the Trunk main system and how they are integrated with each other and with Thames Water systems. In addition, this Section includes findings and recommendations on the end-to-end process of procuring and commissioning monitoring assets through to final hand over to Thames Water. This aligns very closely to methods used for operations and maintenance however with a more distinct focus on current telemetry monitoring, and the Trunk Mains network as a whole.



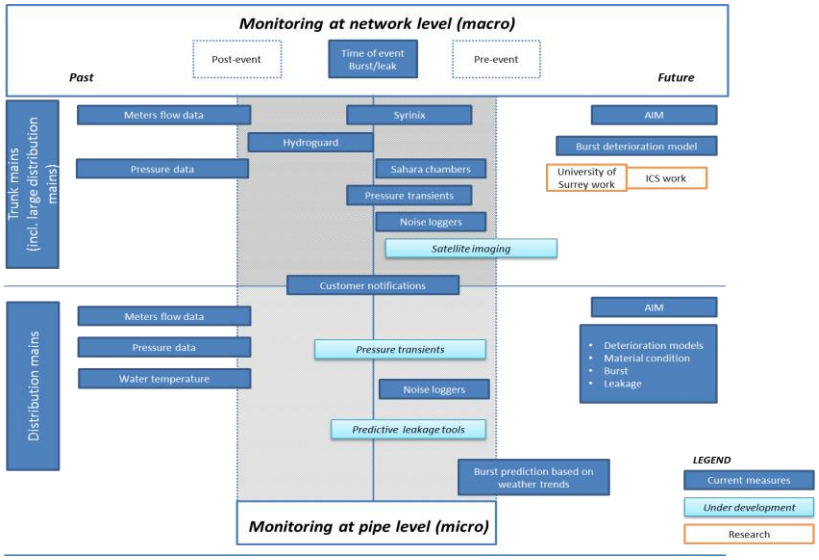


*Figure 11 - Graph Representing the Consequence Risk Ba*Figure 12 - Overview of Monitoring Systems

Area	Findings	Recommendations
5.1 Governance	**5.1.1 Lack of end to end governance of monitoring** The Trunk Main Monitoring Positioning Paper [49] and the Trunk Mains Investment Area Document [4] both set out elements of the monitoring strategy, and there are processes in place for how monitoring should be undertaken. However, there is no governance structure for reviewing and ensuring the monitoring strategy and investment is followed. The lack of governance is potentially a contributor to what is perceived to be a dis-jointed procurement and installation process [50] (see finding 5.4.2), as well as the limited use of monitoring data to inform wider business decisions.	**R5.1.1 Establish end to end governance for monitoring** Thames Water needs to establish a clear governance structure to provide oversight and drive improvements in monitoring of the Trunk Main network and its associated assets. This should include clear roles and responsibilities and decision making accountabilities.
5.2 Risk Management	**5.2.1 Limited opportunity to use monitoring to predict bursts** The Trunk Mains Investment Area Document [4] states that Thames Water is using Hydroguard and Syrinix to reduce the likelihood or improve rapid identification and notification of an event allowing the event response process to start. For Syrinix to be effective in providing notifications of potential leaks, the alarm thresholds [51] need to be appropriately set. An example where this has not been the case was highlighted through the deep dive of the Leigham Vale 1 [52] event. When the burst occurred the Syrinx units, which were on an adjoining span of Trunk Main, were set to alert when a gradient of 0.5 bar within 3 seconds; at the point of the burst the Syrinix units registered a max gradient of 0.48 bar within 3 seconds; as such no burst alert was triggered. Since the event all the Syrinix units within Thames Water now have a threshold set to notify of a burst if a 0.35 bar gradient within 3 seconds is recorded. This was highlighted by the following December burst in Leigham Vale being clearly identified to the Control Room [53]. To enable leaks and bursts to be detected, and the Control Room notified via an alarm, the correct alarm thresholds need to be set. There is a clear set of guidelines and process for setting alarm thresholds. There is a need to re-calibrate the thresholds following bursts to ensure the continuous improvement of understanding the appropriate alarm thresholds. The two recent Leigham Vale events have shown when the re-setting of alarm thresholds has been successful in notifying of a second burst.	**R5.2.1 Review logic underpinning monitoring alarms** In order to make the most of the potential for Syrinix to improve the response to burst events, it is recommended that Thames Water reviews the logic underpinning alarms and how they are responded to, e.g. how quickly a pressure change occurs, or optimal alarm thresholds.

Area	Findings	Recommendations
	5.2.2 Monitoring and meter data not being fed into risk management Data from zonal meters (flow and pressure information) can be made available to Control Room teams via the SCADA system; this is enabled by the installation of Netconn into Netbase. This improves the ability of Control Room teams to understand how the network is being affected in the event of a burst Trunk Main and the rectification actions necessary. Whilst it is not documented in the Investment Area Document (IAD) [4] it is informally documented [54] that the original plan for the Syrinix data was for it to be transmitted from the Syrinix units to The Cloud server, managed by Syrinix where the data analytics would be carried out; once the analytics had been completed the data would be transferred into the Thames Technology Alliance (TTA) for analysis of trends and patterns related to bursts and inclusion in the risk (AIM) model. However due to a number of IT issues, such as capacity, it was identified that the data should sit on, in its entirety, Syrinix servers and that Thames Water would receive email notifications once a threshold has been crossed. Raw data from the Syrinix monitors is aggregated and analysed by Syrinix in The Cloud in order to identify potential bursts and leaks. However, there is no in-house analysis of trends and precursors in the data that may help the business better interpret monitoring information. This is potentially a missed opportunity to improve Thames Water's ability to identify Trunk Main risks, predict bursts, and improve the overall understanding of the network.	**R5.2.2 Utilisation of monitoring and metering data for risk management** It is recommended that Thames Water establishes further analysis based on available Syrinix data (whether in-house or through increased collaboration with Syrinix) in areas such as risk identification, burst prediction, and event response.
	5.2.3 Perceived false positives in leak alert information Syrinix monitoring units can identify the potential location of a leak as well as trigger alarms when a burst is detected. Currently, every Monday leak alerts are emailed to specified members of the Control Room and the System Optimisation team to support a proactive approach to identifying and fixing potentially high-risk leaks. Through workshops and interviews it has been highlighted that there is a perception amongst some Control Room and System Optimisation team members that the leak alerts contain false positives and reoccurring notifications for the same potential leak. This perception leads to the leak alert information being questioned or disregarded rather than acted upon. Whilst this issue was not highlighted with any of the 8 high profile bursts last year, it could potentially slow down the response to addressing a leak that has the potential to cause a burst.	**R5.2.3 Increased Control Room training** It is recommended that Thames Water carries out a review of current processes and competencies around analysing the data being received from third party systems, such as Hydroguard and Syrinix, and carry out training where gaps are identified.

Area	Findings	Recommendations
	5.2.4 Issues with the accessibility of real-time monitoring information The SCADA system is designed to consolidate and aggregate all telemetry information from monitors for use in the Control Room. There is a 24 hour team dedicated to reviewing and acting upon this information and triggers / alarms in line with documented processes [55]. Hydroguard is partially integrated with alarms identified on the main SCADA screen. The location of the event must be identified on a separate computer or through the use of the GIS systems and NSTs on the ground. Alarms raised by Syrinix units are sent via emails and text messages to on-shift personnel, and consolidated into a daily report. Syrinix and Hydroguard data sets are not fully integrated into the SCADA system. Hydroguard is partially integrated. Syrinix data exists independently of the SCADA system. If the Control Room team members need access to real-time monitoring data they are required to login to a separate portal to view a dashboard [56]. There is evidence to suggest that occasionally this process is followed inconsistently. The net effect is that Control Room teams have no access to real-time and aggregated monitoring data across all platforms simultaneously, due to the number of systems and the way in which information is fed to different teams. This potentially reduces the ability to spot and prioritise issues on the network, and potentially increases the time taken to identify a burst.	**R5.2.4 Integration of monitoring assets and information** It is recommended that all monitoring information and systems are integrated and made available in real time to Control Room and other operational staff managing or working on the Trunk Main network. This could improve the Control Room teams' situational awareness of during an event and speed up the response time for resolution. This may also provide Thames Water with an increased data resilience and the opportunity to improve the business' understanding of the network.
	5.2.5 Use of monitoring to predict bursts The Trunk Main Monitoring Positioning Paper [49] states that "monitoring of Trunk Mains for flow, pressure and leak-noise at strategic positions can be used to predict areas of weakness and/or locate them quickly and would help to mitigate the effects of these immensely damaging events". However Hydroguard, Syrinix and other 'monitoring' methods do not provide asset condition ('health') information. Hydroguard units trigger alarms when a burst or leak is detected. Syrinix identifies the potential location of a leak as well as triggering alarms when a burst is detected. The use of Hydroguard and Syrinix does not necessarily support the proactive prediction of a burst. There is also little available evidence that there is a correlation between the size of a leak, if Syrinix identifies one, and the probability, size, location and timing of a potential burst. This is symptomatic of the water industry as a whole due to the lack of maturity within technological advancement in monitoring assets and being able to pro-actively predict bursts.	**R5.2.5 Statistical analysis capability** Establish the capability to use available monitoring data for statistical analysis to improve the ability to predict bursts more accurately.

Area	Findings	Recommendations
5.3 Policy Framework	**5.3.1 Lack of policies for monitoring** The strategy and processes for Trunk Main monitoring are set out in documents such as the Asset Management Operational Standard [39], the Trunk Main Investment Area Document [4] and the Trunk Main Monitoring Positioning Paper [49]. The Asset Management Operational Standard and the Trunk Main Investment Area Document (IAD) both refer to, or document, monitoring policies. Through the documents referenced above there collectively exists guidance on how to invest in, use and manage Trunk Main monitoring solutions. However, there is no evidence of the existence of clear Trunk Mains monitoring policy documentation. The AIM model has given each span of Trunk Main, approximately 100 meters in length, a risk ranking based on probability and consequence resulting in over 100,000 individually ranked spans. Thames Water has not documented the threshold that define what is considered high consequence, through the meetings and workshops carried out anecdotally it is understood to be any span in the top 10,000. The lack of clear policy is potentially symptomatic of the lack of end to end ownership of Trunk Main monitoring, and contributes to a lack of consistency in the use of monitoring. The lack of clear policy also limits the organisational ability to categorise which high consequence vales need exercising [57], which spans require contingency plans written up and where further monitoring assets should be installed.	**R5.3.1 Establish a Trunk Mains monitoring policy** It is recommended that a Trunk Main monitoring policy is established providing clear guidance to the business on what and how monitoring will be undertaken on Trunk Mains. This should be integrated with existing strategies and processes, and have an accountable owner. This should be done in conjunction with any changes to the end to end Trunk Main asset ownership.

Area	Findings	Recommendations
5.4 Process Framework	**5.4.1 Non-standard alert validation processes** The Control Room is staffed on a 24 hour basis by the Water Control and Transmission (WCT) and Network Maintenance Teams (NMT), who are responsible for reviewing and acting upon monitoring and other information, and coordinating work on the Trunk Mains network, including responses to events. The SCADA system consolidates and aggregates all telemetry information that is integrated into it. Processes are documented [55] and are available to the teams. Hydroguard is partially integrated with SCADA, and alarms raised by Syrinix units are sent via emails and text messages to on-shift personnel, and consolidated into a daily report. Through workshops and interviews it is understood that in practice the processes used to validate alerts, such as what to respond to, how to respond, who to notify and when, are not standard and that different individuals or teams may do this slightly differently based on their own experience. There is no evidence that there are processes in place to prevent individuals from working inconsistently. This has the potential to delay responses to issues, or to miss issues that might eventually contribute to Trunk Main bursts. An example of the lack of a single process for addressing a notification to a burst is during the Upper Street event [58]. The Fire Brigade called the Control Room at 05:07 to notify Thames Water of the burst, however anecdotally it was confirmed that the person receiving the call didn't not understand the severity of the situation; the job was logged as per the documented process for a NST to asses at the next available slot. As this call was not escalated immediately it lead to a delay in response from Thames.	**R5.4.1 Establish processes to improve the consistency of alert validation** Efforts should be made to fully document the alert validation processes and controls to increase the chances of alerts being dealt with correctly and consistently. This will also require training of people around the expected processes and controls to ensure effective implementation.

Area	Findings	Recommendations
5.5 Management Information and Data Quality	**5.5.1 Quality of the monitoring data** Thames Water' monitoring assets, Syrinix and Hydroguard, are currently installed on 5% of the high consequence Trunk Main network [4] and inform Thames Water when there has either been a leak, or burst. Currently both Hydroguard and Syrinix send all the data from monitoring units back to their respective third party servers [55]. The data sets are analysed by Hydroguard or Syrinix on their servers and notifications are sent to Thames Water when certain thresholds are crossed. Currently Thames Water staff receive an email and text message notification whenever Syrinix detects a potential burst, this is supplemented by weekly emails that list all the potential leaks that the Syrinix units have found. Hydroguard sends an email notification to the Control Room when it has detected a potential burst on the Trunk Main network. There is no data quality assurance undertaken by the third parties, Hydroguard or Syrinix, prior to sending the data to Thames Water; this limits Thames Water' ability to utilise the data without having carried out ad hoc data quality assurance processes. An example of this was seen in the Control Room when a burst notification was received it had to be corroborated with the Water Control and Transmission teams to see if there had been anything of note happening on that trunk main, such as pumping changes etc. If the data was held on Thames Water infrastructure it would allow for analysis to be carried out before being received by the Network Maintenance Teams. **5.5.2 Trunk Main health data** Currently there is no tool/system that can be procured 'off-the-shelf' to gain an understanding of the internal and external condition of the pipe. The innovation team is actively working with the industry to address this, and are currently looking to trial a tool by Breivoll that will allow Thames Water to gain an understanding of the health of the asset. Thames Water is currently looking into developing a testing area within the Kempton Park facility in order to carry out testing on different monitoring solutions without having to access the live Trunk Main network. Gaining an accurate and detailed understanding of the health of the Trunk Main asset remains a challenge, not just, for Thames Water but the water industry as a whole. This directly impacts the business's ability to understand the health of its network and plan proactive works	**R5.5.1 Internal data analytics** It is recommended that the data from monitoring assets are incorporated into Thames Water IT infrastructure to allow internal data analytics to be carried out. This would ensure that there is a minimal amount of false positives being reported to the Control Room. **R5.5.2 Innovation culture** It is recommended Thames Water move forward with the Kempton Park testing area to help foster industry involvement in developing new tools and methods for analysing pipe condition. Additionally, wider investigation of new technologies in other industries and innovation trends should be prioritised.

Area	Findings	Recommendations
5.6 Organisation	**5.6.1 Monitoring installation programme** Thames Water has set its strategy around, and made a significant investment into, monitoring technologies such as Syrinix and Hydroguard to help understand and manage its risk exposure. However, there is evidence to suggest the installation, and in particular commissioning (the installation of new Syrinix units requires minimum of six approvals. These approvals are from at least 6 different third party stakeholders [57]), and has taken longer than planned. A prime example of this is the Leigham Vale main [52], which had Hydroguard installed on it in 2009 that had not been commissioned at the time of the burst. The delays in commissioning have been primarily due to difficulties in coordinating the connection of power and data lines with the respective utility providers. This highlights the need for the business to prioritise and dedicate sufficient capacity to support the monitoring installation programme in order to ensure the required infrastructure is in place to fulfil the monitoring strategy. Due to the complex nature of the sign off process this has contributed to the monitoring units not being installed. Therefore they are not providing monitoring data to Thames Water for use in operations and planning.	**R5.6.1a Monitoring unit structure** Thames Water should review the capabilities required for the life-cycle of the monitoring assets to make better use of the information available and ensure that the assets are maintained correctly. **R5.6.1b Faster installation process for monitoring equipment** The number of hand-offs in the installation process should be reduced to decrease the time taken to receive full approval for installation and commissioning of new Syrinix units.
5.7 People Capability	**5.7.1 In-house monitoring analysis capability** Data from Syrinix monitors is held and analysed by the supplier before being passed to Thames Water. This is because Thames Water does not have the in-house capability to undertake the analysis required for the Control Room to be able to interpret the information. This dependency is a potential underlying cause of the delays in response, as without in-house analytical capability Thames Water is reliant on the Syrinix company to inform it of bursts either by email and text or updates to the portal.	**R5.7.1 Capability building within Control Room** It is recommended that a review of the Water Control and Transmission and Network Maintenance Teams structure is carried out to establish what the current level of capacity and capability is before looking to increase levels of skill/staff within the Control Room.

6 Event Response and Aftercare

This Section details the findings and recommendations for the event response and aftercare lifecycle stage. Event response and aftercare refers to the activities that take place from burst notification through to closing out all customer aftercare. This includes the operational response to containing the burst and repairing the Trunk Mains, customer communications and care, stakeholder engagement, and operational rotas and working patterns. It particularly focusses on the responses to the 8 recent high profile bursts as the response during and after these events has been documented in the deep dive reports provided by Thames Water.

Area	Findings	Recommendations
6.1 Governance	**6.1.1 Event governance, including third party stakeholders** Thames Water has not provided a clear governance overview of the roles and responsibilities, decision making escalation routes and accountabilities across all parties (internal and external) involved in responding to an event. There is documented evidence of the overall governance for certain elements Thames Water is responsible for; such as event levels are documented in the Thames Water Event Management Arrangements [59]. These classify events based on impact and uncertainty therefore determining the level assigned and management level informed. The Operational Transition Support Packs [47] [48] [45] [46] detail the event escalation arrangement for operations teams based on the level of event assigned. Not having formal governance in place for event response may cause confusion as to the escalation routes and accountabilities when an effective and efficient response is required to minimise the impact of the burst.	**R6.1.1 Formal governance group for event response** A formal governance process for Thames Water and third party stakeholders for event response, at least for the large bursts, should be created and implemented to ensure all parties are aware of their role and interactions during an event response.

Area	Findings	Recommendations
6.2 Risk Management	**6.2.1 Event risk assessments** The Thames Water Event Management Arrangements [59] outline the guidelines for undertaking an initial risk assessment upon notification of an event and a comprehensive risk assessment. Templates are provided to aid the completion of such an assessment. The guidelines provide an overarching starting point for risk assessments across any type of event, of which Trunk Main bursts is one, however there is no specific guidance on the prevalent risks during a Trunk Mains burst and the method of assessing risks. The guidelines for event management do not specifically provide contingency plans for the risk of multiple bursts occurring within a brief time period as seen in the Event Management Arrangements document [59]. Feedback from this recent spate of events suggests that the short period of time which these events happened stretched the disaster and support companies' ability to respond and Thames Water had to involve an additional supplier to meet demand [60].	**R6.2.1 Event management capacity planning for multiple events** It is recommended that a review of the current Event Management Arrangements document is carried out with specific focus around multiple event scenarios and capacity planning.

Area	Findings	Recommendations
6.3 Policy Framework	**6.3.1 Customer care policy** Thames Water contract Cunningham & Lindsey to provide customer care and welfare support for major incidents. The Thames Water Major Incident Response Plan [61] developed with Thames Water's insurance providers (RSA), their onsite teams, (Cunningham & Lindsey), and issued in December 2014, stresses 'customer care is of paramount importance'. It states a major incident response team should be deployed to site within 30 minutes, and should arrive within 2 hours. However, it covers major incidents defined as 10 or more customers suffering significant damage, damage estimated at £100k+ or when serious injuries have been sustained by customers. The Thames Water Major Incident Response Plan [61] is clear and there is a detailed policy and process in place for customer care during and after a major event, including specific performance criteria and timelines for the response. In the immediate aftermath of the event payments and accommodation, needs are met to ensure customers are prioritised. All the recent high profile bursts were above the major event threshold. It is understood that any events below this threshold are managed through the Thames Water Event Management Arrangements [59] which relies on the event controller to coordinate customer care and Thames Water to provide all aspects of customer care. Even in major incidents there still needs to be a Thames Water accountable owner, with Cunningham & Lindsey responsible for activities. The Thames Water Event Management Arrangements [30] which do not clearly state the definition of customer care or what specific customer care activities the event controller should undertake. In addition, the event controller often delegates customer care activities. **6.3.2 Insurance policy** In Thames Water's Press Office Key Lines [62] document an overview of the Thames Water insurance policy is provided. The policy provides in the event of claims like-for-like replacement, with claims evidenced through appropriate paperwork. This is a standard industry wide approach to the provision of this type of insurance. Customer claims should be settled in accordance with the terms of the insurance policy Thames Water holds however these terms are not always communicated clearly to customers. There appears to be instances where customers were supposedly promised 'full' compensation which can cause problems with the insurance companies based on standard claim procedures [63]. However this is an exception as event response staff are briefed to confirm any messaging with the relevant person. Customers are also advised they can claim on their own insurance policies as this is often new-for-old.	**R6.3.1 Customer care policy for small incidents** A formal customer care policy for small incidents should be developed to ensure there is a consistent understanding across the business of the customer care (communications and immediate welfare, i.e bottled water) for such incidents. **R6.3.2 Clear communications regarding insurance policy** Thames Water should provide the necessary training and guidelines to staff who respond to burst events to ensure they understand Thames Water's insurance policies, messaging to customers and are therefore equipped to respond to customers when required.

Area	Findings	Recommendations
	6.3.3 Goodwill payments Due to the impact of several of the recent bursts there was an informal policy of domestic tenants being given goodwill payments and a promise of no water bills for a year for ad-hoc events. Domestic tenants flooded for the first time received £1000 and domestic tenants flooded for the second time received £2000. This was provided in at least 2 of the 8 recent high profile events, the Upper Street event [58] and the Leigham Vale 2 [53] event. Since then landlords, tenants of businesses, landlords of businesses, and neighbours affected by noise due to the repairs have requested compensation as well. Having reviewed the documents and the financial compensation given to customers following the recent bursts it is noted that Thames Water has an industry standard insurance policy that can be used by customers should they not have their own insurance or who wish to make use of Thames Water's insurance. The quote from the Managing Director of Wholesale Water that 'no customer would be massively out of pocket' whether that is through insurance claim top ups or goodwill payments highlights the additional customer care Thames Water will provide, however it is not formalised and written into policy so there is a clear and consistent understanding across the business.	**R6.3.3 Formalised goodwill payment policy** A formal policy for compensation needs to be agreed to support the event response going forward to enable customer representatives to make informed decisions and provide consistent information to customers. The policy should focus on circumstances when goodwill payments may apply and the individuals who have the authority to authorise their distributions.

Area	Findings	Recommendations
6.4 Process Framework	**6.4.1 Process documentation** Thames Water provided a copy of Thames Water Event Management Arrangements [59] which is their approach to dealing with major events. This is the process document which they have in place to explain to staff what steps to undergo in the case of major events. All major events are included in this document, with a Trunk Main burst captured under the 'interruption to water supply – main burst' event. A copy of Event Comms: Keeping Customers Informed [64] was also provided, which outlines their communications process, internally and externally which Thames Water would use when a major event occurs. The document was published in December 2016 and has a review date of December 2018, where the document controller is the Business Resilience & Security Manager. Having reviewed the documentation, reviewed the evidence within deep dives and discussed the response to Trunk Main bursts there is no evidence of a detailed set of process documentation or working instructions that clearly documents the steps Thames Water must take to resolve a burst Trunk Main from the call from customer to leaving site (the full end-to-end process). The documentation provided does include key roles and responsibilities for operational individuals responding to a burst main which is a description of their responsibilities. Having a clear and detailed end-to-end process should result in managing bursts and managing customers effectively and efficiently. The documentation does not contain different elements for effective response and there is no clear link to: • Timings • Communications • Resources • Third party engagement • Contingency plans	**R6.4.1a Process objectives for event response sub-processes** There are multiple moving parts when responding to a Trunk Mains burst. Drafting process objectives to clearly outline the intent of each process within the response framework helps to clearly define the processes required to better manage supply of water, flood mitigation and customer management during a Trunk Mains emergency event. **R6.4.1b End-to-end process for a Trunk Main burst** A clear end-to-end process for a Trunk Mains burst would enable clearly defined roles and responsibilities throughout the response process mitigating inefficient handovers, improved communication internally in Thames Water as well as better communication with third parties and customers. Thames Water should thus review their response processes and create end-to-end processes for managing and Thames Waters response times to Trunk Main bursts. **R6.4.1c Major incidents customer care policy – roles and responsibilities** The major incidents customer care (communications and longer term welfare, i.e alternative accommodation and support for insurance claims) policy should be updated to reflect roles and responsibilities both for third parties i.e. Cunningham & Lindsey, and Thames Water. This will ensure that those responding to an event have clarity on what is expected across the end-to-end customer care process.

Area	Findings	Recommendations
	6.4.2 Third party stakeholder engagement process Thames Water has provided an overview of the process and approach to stakeholder engagement. Stakeholder relationships are maintained with organisations such as Transport for London, emergency services and Local Authorities. The Stakeholder Engagement for Operational Events [65] document states the approach seeks to adopt a rapid response to engage with stakeholders during an event, in particular the engagement with local and regional government. The Local and Regional Government Liaison (LRG) team are informed by text from the Operational Control team as soon as a major event (Level 3 event) is taking place. Once the LRG team are notified of a major event, the relevant LRG member will join the event calls and determine which stakeholders should be updated and how frequently. The stakeholders contacted can range from ward councillors, council portfolio holders, council leaders and MPs. The document details the degree of event impact and reputational risk which helps to determine which political stakeholders will be contacted. Good stakeholder engagement during an event entails responsive, informed, regular and co-ordinated engagement with targeted stakeholders. The Thames Water Event Management Arrangements [59] has a functional brief for a multi-agency event representative to represent Thames Water at a multi-agency strategic (Gold) or tactical (silver) command meeting. This covers both events where the primary cause was the failure of a Thames Water asset or when an external major incident has an impact on Thames Water. Having reviewed the documentation it is evident the approach to stakeholder engagement, especially with local and regional government, is focused on building relationships with stakeholders before and throughout the crisis and to minimise stakeholder complaints following operational events. It highlights there is a clear process, depending on the impact of the event and reputational risk, as to who and how needs to be engaged. If a multi-agency event is declared there is a dedicated Thames Water representative. However, information from the deep dives highlights that stakeholder communication and engagement is not always executed efficiently. An example of this is the Crayford event [3] where traffic management support was required from TfL to access the valves and this increased the time it took to get valves closed.	**R6.4.2a Collaborative third party relationships** Strengthen third party engagement with the emergency services, TfL, Local Authorities and others through collaborative contingency planning, response mechanisms and post-event reviews. This may support the development of working relationships and differentiated responses based on the seriousness of the scenario. This may also open opportunities for access to CCTV footage allowing 24hour monitoring of key assets, or even agreed circumstances where event response teams could receive ‘blue light’ escorts to get to events faster. **R6.4.2b Responsibility for third party relationships** Set up a group whose responsibility it is to develop the third party relationships and execute a comprehensive approach to ‘big picture’ contingency planning for major trunk main bursts.

Area	Findings	Recommendations
	It is understood that since the recent bursts a number of improvements have been made to stakeholder engagement to address areas where engagement was not performed as well as expected. These include: • Ofwat's communication team will be notified of an event by the Strategy and Regulation Director or the Director of External Affairs. This Ofwat notification process was introduced in December 2016. • An 'Out of Hours Event Communications Lead' to support the event team. Members of staff with stakeholder experience are on a 7 day out of hours rota to provide stakeholder communication event support. This was created in October 2016.	

Area	Findings	Recommendations
	6.4.3 Customer communications process Communications with customers during and post event is through a number of channels. Event Comms: Keeping Customers Informed [64] documents detailed the channels and an overview of the roles put in place to keep customers informed. When a Level 3 event is triggered a dedicated communication and stakeholder plan is put into action. An event controller appoints a communications lead who is responsible for co-ordinating and aligning all messaging across all channels, and keeps customers informed through channels such as a live twitter feed and website updates. During an out of hours event (outside of 9am-5pm) the communications lead is to play an active role in delivering communications, however there is no clear description of the transactional activities this role entails. During the interview process proactive engagement with customers via communication channels as discussed. When a burst occurs a message is placed on the Thames Water website and on the IVR system for customers to view or see before they contact Thames Water. Information from the deep dives highlights how the social media channel of communication in particular was not able to keep up with customer demand. An example of this was the Crayford event [3] where the digital team representative on out-of-hours duty was not willing to respond to individual tweets and the back-up 24 hour team was unable to deal with the volume. This also happened during the Leigham Vale 1 [52], Lee Road [40], and Lee High Road [66] events. Since these bursts a 24/7 social media team has been put in place with support from Yellow Jersey PR to provide social media training.	**R6.4.3a Formal social media approach** Thames Water has proactively used social media to provide information to customers relating to major Trunk Main bursts. There is an opportunity to formalise the approach to which Thames Water has adopted around communication as social media approach and align roles and responsibilities to this communication approach. **R6.4.3b Clearly identified site roles** Site roles during an event vary according to individual skills, there is an opportunity to use either coloured jackets or descriptions on reflective vests to clearly define an individual's role during an event. This will naturally guide customers to speaking to the appropriate individuals during an event. This ensures technicians can focus on flood mitigation and managers are able to handle customer queries on site effectively.

Area	Findings	Recommendations
	6.4.4 Insurance and loss adjustment process Thames Water has provided the Upper Street Resident Meeting Pack [67] which includes an overview of the insurance and loss adjustment process. This is the first time the process has been documented and discussed with customers. It includes a step-by-step flow chart from when a pipe bursts through to recovery action. It highlights the various parties involved during the process (up to five different stakeholders). Customer information should be provided by Cunningham & Lindsey as stated in the Major Incident Response Plan [61]. Having reviewed the documentation it is clear that Thames Water can articulate the insurance and loss adjustment process. However, due to the number of different stakeholder groups involved it can be confusing for customers. Feedback from the Meeting Minutes and Actions from the Upper Street Residential Meeting [68] and Upper Street Commercial Meeting [69] highlight customers did not always have awareness of compensation policies and who to call for what help.	**R6.4.4 Documented insurance process for customers** The insurance process should be clearly documented, and readily provided, to customers at the start of an event to ensure they have a detailed understanding of the options available to them and the process they will need to follow.
	6.4.5 Community meetings Thames Water has provided copies of the Meeting Minutes and Actions from the Upper Street Residential Meeting [68] and Upper Street Commercial Meeting [69]. These document the senior attendance at these meetings (the Head of Wholesale Water was in attendance at the residential meeting alongside representatives from the Infrastructure Alliance, eight$_2$O, Cunningham & Lindsey and RSA). They also highlight the customer feedback received. Several points of feedback included lack of emergency flood defence, slow set up of Control Rooms, mixed messages provided and slow response of claims providers. Having reviewed the documentation it is clear there is a willingness to engage with the community and a desire to ensure it is taken seriously by Thames Water, this is shown by sending senior representation to community engagements. Documented responses to customer questions highlighted where Thames Water response could be improved, with actions take away where necessary. However the customer feedback has highlighted gaps in the communications process with customers, especially around insurance, and slow response in aftercare provision.	**R6.4.5 End-to-end customer care owner** A review should be undertaken of roles and responsibilities for staff members being involved in customer care during major events, particularly in regards to on-going care through community meetings, and how they are managed around the day-to-day operational running of the business. A single owner responsible for end-to-end customer care should be appointed and this communicated to affected customers.

Area	Findings	Recommendations
	6.4.6 Contingency planning approach The Asset Management Operational Standard (Section 2 of 3) [70] states that detailed contingency plans are required for each site classified as being a high consequence location. These include valve packs for quick identification and operation to isolate any burst quickly. Contingency plans, including isolation valve packs, are important to assist the Control Room in making quicker decisions for the engineers and technicians in the field during an incident. Thames Water provided a Clean Water Operations Network Contingency Plan [71] for two 30" pipes in the Surbiton area. The plan was issued in June 2015. The purpose of the contingency plan is to ensure the main can be shut within 2 hours following the identification of burst. Having reviewed the documentation it is clear that for the locations where a contingency plan has been developed they clearly state the following: • Map of network assets, including location of valves • DMAs affected • Process for isolating the main with 2 hours • Resource plan • Checklists • Expected customer impacts, and infusion process The deep dives highlight that contingency packs are not always available or robust enough to enable fast and efficient management of the network. Examples of this were the Lee Road [40], Camberwell New Road [72], Crayford Road [3] and Leigham Vale 1 [52] events. It should be noted that the Leigham Vale event had a risk ranking higher than 10,000 and should therefore have been expected to have a contingency plan. It is understood that since the bursts contingency plans have been developed, especially for the Leigham Vale location.	**R6.4.6 Develop contingency plans** Contingency packs should be developed, kept up-to-date and made easily accessible to all event response teams on the ground.

Area	Findings	Recommendations
	6.4.7 Working on site – handover process On review of the deep dives, the Forensic Review has found that there is no evidence of documented processes for the handover of a burst site from the NSTs and repair gangs to eight$_2$O which can cause time-consuming delays to the repairs and site clean-up; furthermore the handover can result in key information on the burst being lost. An example of this is the Camberwell New Road event [72] where the hand over between eight$_2$O and IA repair teams caused issues with permits and delays with site clean-up. The efficiency and effectiveness of the handover process is based on individual's relationship with the other party, conference calls and experience in conducting the handover. If the relationships or experience are not as strong at a particular site this can result in a longer handover time and potential for re-work.	**R6.4.7 Clear handover roles and responsibilities** Clear roles and responsibilities during hand-offs during the event response process should be clearly documented and the accountability highlighted. This should include transactional roles and responsibilities to ensure consistency and clarity through the hand-offs between the lifecycle stages of asset planning, delivery, and operation.
	6.4.8 Availability of event response equipment Plant, equipment and supplies required to respond to a burst are available at Thames Water yards (e.g. the Murphy yard at Kentish Town), or ordered from Burdens, who are located near Gatwick. Space restrictions at Thames Water yards and the cost of stock sitting idle is higher for Trunk Mains, as this asset class generally requires large plant, equipment, and supplies. As a result, many yards are not readily able to supply works on Trunk Mains in the event of a burst. This may mean supplies and equipment need to be ordered from Burdens or eight$_2$O, creating a delay in getting it to site. An example of this was in the Crayford Road event [3] whereby customers were promised sandbags to help minimise flooding and none were made available. In addition, there is currently one event response vehicle for all of Thames Water. If this vehicle is allocated to another event then third party support must be relied upon. This impacts the customer care that can be given and the provision of communication equipment for response teams.	**R6.4.8 Review of event response equipment** As identified in the pre-mortem workshop, it is recommended to review the requirements for the number and capability of emergency response vehicles available to respond to burst events, and ensure they have sufficient equipment and supplies to efficiently manage the response efforts.

Area	Findings	Recommendations
	6.4.9 Event learning process Thames Water has provided an Event Learning Process Flow [73] for a level 3 event, stating the actions that must be completed, by whom, and the timeframe for completion. This process is controlled by the Business Resilience and Security team. Through a number of meetings and workshops, it was identified anecdotally that the formal process was not followed. As a result, learnings and appropriate data points related to events were not being consistently captured and integrated back into the asset information, asset planning data and maintenance schedules. Currently, the following post-event follow-up activities are not being consistently performed: • A deep dive seeking to confirm the situation around the incident and how it was executed. • The commissioning of a Hydrosave report in order to establish the technical reason for a pipe/valve burst. • Capture of lessons learnt where Thames Water could have carried out certain processes differently. • Post incident wash-up with key stakeholders to identify organisational root causes that led to the incident. This represents a missed opportunity for capturing information on key lessons learned and areas for improvement, as well as technical information on possible root causes of the burst. While there is a process documented, it is not consistently used throughout the business, thus preventing the use of information to inform business decisions.	**R6.4.9a Formalise and communicate event learning process** The event learning process should be reviewed to ensure it remains fit for purpose. The process should enable strategic themes and trends across events to be noted. This should then be formally communicated across the business and checks put in place to ensure the process is adopted. **R6.4.9b Conduct regular practice exercises** Practice event response exercises should be undertaken to ensure event learning is incorporated back into the event response process and additional learnings from practice exercises are captured. **R6.4.9c Engage with local resilience forums** The Local Resilience Forum consists of representatives from emergency services, local authorities and any other organisations who potentially would be involved in an emergency. Through the forum, these organisations work together to prepare for, respond to, and recover from emergencies [74]. Engagement with local resilience forums on a regular basis to prepare and practice for external events that impact Thames Water or Thames Water has a role to play in the event response. The learnings and insights from attendance at these groups should be incorporated into the event response process and documentation.

Area	Findings	Recommendations
	6.4.10 NST Service Level Agreements In the Clean Water Operations Network Contingency Plan [71] for isolating 2 mains in New Malden it clearly states 4 NSTs as a minimum must be sent to site as this is the number required to shut the valve. These NSTs are resourced from the teams on standby. Actual times for NSTs to arrive on site will vary to a certain degree depending on traffic and the location of the NST as NSTs cover a wide geographical area i.e. central south or central north. A review of the deep dives has shown that NSTs generally arrive on site within 2 hours, this may be due to a number of reasons ranging from traffic issues to delayed notification and identification of an available NST. There is also lack of clarity around the time the NSTs were notified to the time they arrived on site. Examples of events that took over 2 hours to get NSTs on site include Leigham Vale 1 [52] and Camberwell New Road [72]. However there are is no formal set of SLAs written into the policy and process. Having SLAs stated in a contingency plan does not evidence a business wide set of agreed SLAs. Therefore NSTs are not held to account for ensuring they meet SLAs regarding response time.	**R6.4.10 Re-establish NST response time SLAs** Re-establish NST response time SLAs and the supporting controls to enforce the SLAs. This will ensure an improved consistency in response across geographical areas. Continuous improvement should be embedded to work towards reducing the SLA times.

Area	Findings	Recommendations
6.5 Management Information and Data Quality	**6.5.1 Notification of bursts** When a burst occurs that are several methods by which notification of the burst can be received. A review of the deep dives highlights the following methods of notification: • Third party stakeholders i.e. fire brigade or Transport for London (Lee High Road [66], Northwold Road [75], Camberwell New Road [72], Crayford Road events [3]) • Customer calls (Leigham Vale 1 [52], Upper Street events [58]) • Contractors working on site (Lee Road event [40]) • Pressure monitors and / or flow monitors (Leigham Vale 1 [52], Upper Street events [58]) It is understood that stakeholders and customers are often relied upon to provide notification or confirmation of a burst, rather than Thames Water's monitoring equipment. Where pressure monitors or flow monitors have notified of bursts customers or stakeholder confirmation has been key. This highlights the reliance on customers and stakeholders to notify of a burst and start the event response process. This is consistent across the water industry due to the monitoring technology available.	**R6.5.1a Geographical area ownership** Ensuring clear ownership and accountability of specific geographical areas will embed accountability for awareness of assets in the area and may enable faster identification when the asset is not behaving as expected. **R6.5.1b Contact Centre Location** Move the Contact Centre location to sit alongside the Control Room to improve the dissemination of customer information and insight to the Control Room. **R6.5.1c Notification via pipe walking** Notification via pipe walking was a method previously used to identify a leak or a potential burst of Trunk Mains. These patrols would speed up the initial notification/identification of a burst but would allow the patrol to report back on exact location and severity in order to speed up actual incident response. Reinstating this process would help to identify high risk leaks, however this is limited to above ground pipes.

Area	Findings	Recommendations
6.6 Organisation	**6.6.1 Roles and responsibilities** Thames Water provided a copy of the Thames Water Event Management Arrangements [59] which is the approach to dealing with major events. Step 2 in the described event management procedures includes the appointment of an event team. An example event team is described showing the strategic, tactical and operational roles that may be required. A series of function briefs detail the scope, roles, responsibilities, resources, reporting and communications for key event response team roles. There is however no functional brief for the overall event controller role. Having reviewed the Thames Water Event Management Arrangements [59] there is no specific documentation detailing the assignment of roles for the event team. It is understood through interviews and workshops that an event response team is established from individuals who are part of the local operations teams (Thames Valley, North London or South London) and central operations management based on availability at the time of burst and knowledge of the burst location required. Depending on the scale of the event there may be a reliance on locally available individuals to support as is typical of water industry event responses. An example of this was the Upper Street event [58] where an out of hours duty manager driving close to the area had direct knowledge of the mains network in the area. Out of hours management of the Trunk Main network by Wholesale Water is primarily fulfilled by System Operations staff in the Reading-based Control Room and Operational (Infrastructure Alliance) staff in depots and in the field.	**R6.6.1a Response staff resilience** Analysis (including scenario testing) of the resilience of staffing levels for a range of out of hours eventualities should be undertaken to understand staffing needs both in the field and in the Control Room. **R6.6.1b Establish maximum response times** Analysis of flood impact over time in different scenarios should be undertaken in order to understand the impact of response times on the extent of flooding and establish a ‘maximum response time’ for Trunk Main bursts, with a clear and detailed policy accordingly.

Area	Findings	Recommendations
	6.6.3 Communications rotas and working patterns Thames Water provided a copy of Event Comms: Keeping Customers Informed [64], which outlines the out of hours communication coverage. It is delivered through a combination of 24 hours teams outside of core hours for the website incident bar, customer centre / IVR and text message channels, and rotas for the media-press office. The communications on call rota is managed by the press office and shared with the duty manager / 24 hours team every month. Confirmation was provided by the Head of System Operations that the Contact Centre is staffed 24 hours a day. There are 13 FTE in the Control Room at all times, with an additional 8 FTE between the hours of 08:00 and 16:00. Having reviewed the overall rotas (note the Forensic Review did not look at specific individual's rotas and contracts) it is documented that there are less staff available outside of standard working hours, with staff working in these hours generally offered out of hours payment or a percentage uplift to cover all unsociable and additional hours. Having an out of hours rota and standby arrangement is typical in infrastructure management for many types of asset and represents a trade-off between availability and cost. Use of standby working patterns means that there are no teams that are waiting awake at night for events.	**R6.6.3 Review of 24 hours communications** Thames Water should continue to assess the performance of the 24 hours communications teams arrangements as part of a more structured and formalised lessons learnt approach to events, and as part of continuous improvement.

Area	Findings	Recommendations
6.7 People Capability	**6.7.1 Network knowledge** During the interview and workshop process it was noted on several occasions that local knowledge was relied upon to efficiently and effectively execute the required event response. Local knowledge refers to an understating of the asset location, condition, age and impact of actions on the network. While asset standards exist they are not always acknowledged and used. There is also limited evidence of procedures and policies for network operations, which is common in other water industry organisations. An example of this is the Upper Street event [58] where an out of hours manager happened to be driving close to the area and had direct knowledge of the local network. It was noted in the deep dive that if that manager had not been available, the isolation would possibly have been delayed. The reliance on local knowledge can affect the outcome of the event, as the capability of response teams can vary depending on experience and the geographical area. While this has been improving gradually over the last few years, based on discussions in workshops and interviews, it is not yet consistently undertaken across operations. **6.7.2 Critical individuals** Several critical individuals being heavily relied upon for their knowledge and experience in event response. This is particularly true in the response to major events, where decision making flows through a particular group of senior operations managers. This is particularly relevant to the Control Room, important individuals in the response to a burst, as the out-of-hours managers may not have the same capability level as other managers requiring decisions to be escalated to on-call senior managers adding in an additional process step. In addition, the Head of Systems Operations is often seen as a 'single point of failure', in the response to a major event, as there is no one else in the business trained to this level. To help mitigate the risk of a critical individual not being available there is a succession planning framework [34] that is reviewed every 6 months. The framework applies to leadership and management down to level 5, identifying individuals for succession and an indication of their readiness. It is peer reviewed and associated development plans provided.	**R6.7.1 Local knowledge captured in systems** Data collection procedures for field staff should be improved and clearly communicated with required incentives in order ease the process of updating central systems, and alleviating the issue of critical local knowledge being held by a select few technicians. **R6.7.2 Capability depth assessment** Staffing needs of the organisation in key decision making positions should be assessed in order to develop the necessary depth of resources to properly address events whenever they occur. As this capability will be highly specialised in Thames Water assets and processes, it will presumably need to be developed in house, and so likely take at least 2-3 years.

Area	Findings	Recommendations
	6.7.3 Capacity and availability of flood response companies The Thames Water Insurance Manager provided an overview of the support Thames Water has for flood response. If a burst causes flooding to commercial or domestic properties Thames Water relies on flood response and disaster recovery companies to support customer care. The number of major bursts within a short period of time during October to December 2016, particularly in December in heavily populated areas of London, the resource availability of flood damage and disaster recovery companies was stretched. There are three companies retained by Thames Water while a fourth company had to be sourced during the recent bursts as all contracted resources were deployed. It should be noted that London is not a particularly flood prone city and does there not have a high concentration of flood damage companies. There is no evidence that this had a direct or adverse impact on customers.	**R6.7.3 Flood response companies contingency plan** A contingency plan to ensure availability of flood response and disaster recovery companies during incidences of multiple bursts in a short timeframe. The plan should be communicated to Event Controllers and event processes and guidance updated.
	6.7.4 Media / public engagement training Limited media and public engagement training has been provided to those setting up and running the community meetings following the recent bursts. This increases the risk of individuals sharing information that should not be shared or promises being made to customers that are not appropriate.	**R6.7.4 Provision of media / public awareness training** Media / public awareness training should be developed, or if already developed made available to, individuals attending community meetings to ensure they are fully prepared to be the face of Thames Water and distil the relevant, and correct, information to the public.
	6.7.5 Event response training Training is provided for event responders and event controllers, including refresher courses. This training has been developed and delivered by an event training specialist. The training material is stored centrally on CentreStage Space for frequent reference. In 2016-17 37 event controllers were trained, 20 attended refresher courses and 233 people undertook event response training [76]. These figures account for both Wholesale Water and Waste. However, the event response training is not a one-off course. It must be refreshed every 3 years. 57% of out-of-hours Senior Managers have been trained, or had refresher training, within the last three years [77]. This drops to 33% of control staff and 23% of senior escalation first point of call staff. This highlights that event response training has a high rate of non-compliance.	**R6.7.5a Event training – competency framework** A competency framework for event response should be developed to ensure an understanding of the competencies expected during event response. This should also be used during event response training to ensure event response staff have the required competencies and there are enough staff trained in each competency to provide adequate coverage. **R6.7.5b Management of event response training** Compliance with event response training should be reviewed and a targeted course of action put in place to ensure a high level of compliance.

7 Review of the 8 High Profile Trunk Main Burst Events

This Section outlines the probable failure modes and contributing factors to the end outcome for each of the 8 recent high profile bursts.

7.1 Event discussion

Examination of the available information on the 8 high profile events has revealed that whilst age and condition of the pipes is an underlying factor in these failures, there is no single common cause of the bursts. There are some themes that span several of the recent high profile events that contribute to either the immediate failure mode of the burst, or the overall outcome of the entire event:

- **Failure mode**: The physical mechanism of the failure and the factors that immediately resulted in the burst.
- **Contributing factors to end outcome**: Current understanding of factors that were either involved in the failure of the main, or that contributed to the overall adverse outcomes of the event.

Event	Failure mode	Contributing factors to end outcome
Camberwell New Road, SE5 **Size: 30”** **Material: Cast Iron** **Burst Time: 07:24** **Burst Date: 25 October 2016**	The Hydrosave report on the failure of the Trunk Main is confident the burst was due to the pipe bearing directly on a brick structure, which combined with heavy traffic loading elevated the stress on the pipe at this location. This may have been due to a previous leak washing away supporting material, thereby increasing the point loading. Further investigation of the main has found that the portion of the pipe that failed was stamped as being from 1941, whereas the GIS information for the rest of the pipe estimates it was laid in 1870. It is understood that this was a wartime repair from a bomb strike, and may have been done without proper planning, this resulted in the pipe bearing directly on the culvert below, which was likely also damaged at the time.	• **Asset condition assessment process**: This main had been extensively surveyed in AMP4 (5 historic NDT tests). The good condition suggested by these reports (and the Hydrosave report) contributed to the main being ranked 61,725 on the Risk Log. This highlights an inherent weaknesses of current condition appraisal tools, and raises concerns about how condition information is extrapolated from discrete locations, particularly as conditions may vary substantially along the length of the pipe. The discovery of the wartime repair highlights Thames Water’s gaps in understanding of the asset information across the Trunk Mains network. It is likely there are numerous repairs of this nature throughout the network that could potentially pose a risk, however their location and condiditon is unknown. Overall these factors contribute to potentially misleading risk ranking scores, which in turn result in miss-prioritised investment, maintenance and operational decisions. • **Contingency planning**: The setup of emergency traffic management measures and take-over from Transport for London (TfL) during the event response has been described as slow, leading to frustration from emergency services stakeholders and impacting the response time. This highlights the need for comprehensive contingency plans with clear roles and handoffs for the various stakeholders involved to expedite the response and minimise confusion.

Event	Failure mode	Contributing factors to end outcome
Crayford Road, DA1 **Size: 12" and 18"** **Material: Cast Iron** **Burst Time: 03:49** **Burst Date: 9 October 2016**	This event centres on work being done by a Thames Water Developer Services crew to install a line stop on the 12" main. The first burst occurred on the 12" main during the installation of the line stop. In order to respond to this burst, a second line stop was installed on the 12" main, however this work most likely lead to a burst on the adjacent 18" main. The two mains burst due to different primary failure modes: • The 12" main failed in a circumferential fracture due to an oversized line stop, which significantly reduced the main's cross-sectional area. • The 18" main failed in a longitudinal fracture due most likely to a combination of increased loading from heavy vibrating equipment and pressure waves from valve operations as a part of the installation of the line stop on the 12" main.	• **Works processes**: The burst of the 12" main is directly attributable to human error and highlights an issue with the controls that should ensure Thames Water processes are followed when working on Trunk Main assets (e.g. the main should have been concreted in place to minimise movement and additional stress, but was held down using sandbags). • **Valve operation process**: The 18" main burst is likely due to human error that may be attributable to a lack of sufficient understanding of valve operation, as it is thought that pressure waves from closing incorrect valves during the isolation of the 12" main may have contributed to the failure. While 'Calm Network' training is in place, it is unclear whether a prescribed process is in place that sets out how the valves should be closed. • **Valve accessibility**: To isolate the burst main, access was required to valves that were located under a recently designed roundabout, and requiring the road to be dug up. This burying of the valves was due to a breakdown in the process of sharing information with the local authorities about location of assets and planned work near Thames Water infrastructure. This is a common issue encountered by operations, and highlights the need for improved stakeholder relationship managememt. • **Permitting process**: In the investigation of this event, it was found that while the initial work done on the first 12" main line stop was completed under the correct permit process, work to install a second line stop was not. If proper Permit to Work and Permit to Dig procedures had been followed it is thought the risk to the 18" main would have been identified and mitigating measures put in place. This highlights the need for improved controls to ensure that risk evaluations are undertaken as part of routine and emergency works.

Event	Failure mode	Contributing factors to end outcome
Leigham Vale 1, SW2 **Size: 21”** **Material: Cast Iron** **Burst Time: 07:40** **Burst Date: 15 October 2016**	The Hydrosave forensic report suggests that the burst was due to significant corrosion of the 21” cast iron main, resulting in both a circumferential crack and longitudinal fracture along the invert of the pipe. While the base material appears to be of acceptable quality, the corrosion may have been accelerated by stray electrical currents from the nearby railway line. It is likely the main was leaking prior to the failure, as indicated by smoothed edges around the circumferential crack, possibly washing away support and increasing stress in the pipe walls.	• **Burst history**: The Leigham Vale main was a known high risk, ranked 6,100 (top 10%) within the Trunk Main risk log due to a history of bursts in 2002, 2005 and 2009. As a result Hydroguard and Syrinix units were installed on Leigham Vale and the adjacent Palace Road mains respectively. • **Monitoring**: Although the Hydroguard units had been installed on Leigham Vale, they had not yet been commissioned at the time of the event. In addition, the alarm thresholds for the Syrinix units on the adjacent main were set too high to trigger during the event. As a result, no monitoring alarms were raised in the Control Room to alert operations to the event, thus delaying response until called in by a customer. • **Contingency planning**: Despite the high risk ranking, no contingency plans were in place at the time of the burst. This manifested in a lack of traffic management plans for accessing valves in a nearby junction. Accessing these valves required a police road closure, and in turn contributed to the 5 hour gap between the first ‘no water’ call and isolation.
Leigham Vale 2, SW2 **Size: 21”** **Material: Cast Iron** **Burst Time: 01:57** **Burst Date:16 December 2016**	As seen in the first failure of this main, the pipe was in very poor condition, with considerable corrosion throughout. The pipe burst in a longitudinal failure most likely caused by a combination of transient pressure waves as a result of the recharging of the main, and leakage undermining the support for the pipe.	• **Recharging process**: Given the 1 hour gap between recharging of the main and the burst event, it is highly likely that the way that the main was recharged caused additional stress in the pipe walls which in turn caused the burst. This highlights the importance of building a thorough understanding of asset condition, as well as specialised processes for working on high risk assets such as this one. • **Repeatedly flooded properties**: Customers flooded as a result of this burst have also been flooded by other bursts in the area in recent years, resulting in significant customer relationship issues. While this main has been ranked high on the risk log, no additional works were undertaken to reduce the consequence of bursts that would have affected these properties. This may have been due to “promises made” not being followed up or not being prioritised sufficiently highly. Whilst the promises made are tracked at a local level there is no central ownership of them.

Event	Failure mode	Contributing factors to end outcome
Lee High Road, SE13 **Size: 24”** **Material: Cast Iron** **Burst Time: 17:05** **Burst Date: 26 November 2016**	The main failed at a bell and spigot joint caused by a combination of loss of support from rotten plinths and high repetitive loading from the bus stop above. This most likely caused the pipe to displace at the joint, causing leaking, thus washing away support and increasing stress until the joint failed. This main also appears to have been a wartime repair, as the failed segment is 1.5m long with a normal pipe socket at one end (the location of the failure) and a leaded double collar at the other. This may explain the failure to remove the plinths, as the work may have been done quickly before recovering the main.	• **Valve Identification**: The burst resulted in a large number of SI4 (a service interruption of up to 4) hours and SI12 (a service interruption up to 12 hours) interruptions 20,000 and 1,385 respectively. However, a large number of these were due to the wrong main being isolated for 7 hours during the response due to the misidentification of a valve. This is an example of the importance of accurate asset information, and in particular the location and function of critical valves in order to effectively respond, and limit disruption of bursts.
Upper Street, N1 **Size: 36”** **Material: Cast Iron** **Burst Time: 04:58** **Burst Date: 5 December 2016**	The inspection of the main following the burst found the pipe to be in very poor condition with large areas of external and through-wall corrosion. It is believed the failure propagated from an area of through-wall corrosion on the invert of the pipe, with the gradual weakening of the wall eventually causing it to fail under normal service pressures.	• **Management Information**: At the time of the burst the main was ranked as 44,198 within the Trunk Main risk rankings, 28th percentile out of 150,000 spans, however this was due to a previous burst being erroneously logged against an adjacent main, which would have significantly elevated its rank had it been properly recorded. As a result the main did not have Syrinix or Hydroguard monitoring. This demonstrates the importance of data quality in the asset planning AIM model, the investment decisions this data informs. • **Monitoring**: Reviews of the event have shown a 20% increase in flow of water through the main during the event, but these meters were not monitored and did not trigger an alarm. This may have delayed the overall response time, with 2 hours between emergency services notification and NST log-on to the permit, and 4 hours to pump deactivation and main isolation. • **Consequence and Modelling**: The current one directional rolling ball model used to estimate the consequences of bursts does not take into account the topography of the burst site, and as such did not accurately predict the breadth and severity of impact from this burst. This reinforces the need for advancement of the two directional rolling ball model which has been shown to depict the potential impact area more accurately.

Event	Failure mode	Contributing factors to end outcome
Lee Road, SE3 **Size: 12”** **Material: Cast Iron** **Burst Time: 11:20** **Burst Date: 10 December 2016**	The burst was a result of the vibration from a breaker on a Thames Water Developer Services excavator that was removing a concrete slab above the main to install a new valve.	• **Permit to Work Adherence**: Thames Water Developer Services has undertaken a review of the incident and found the burst was due to human error and incomplete adherence to the Permit to Work. This demonstrates the importance of controls to ensure processes are followed and risk mitigations are in place before commencing work. • **Completeness of Asset Information:** One of the contributing factors to excavator causing the burst was that the crew did not know from the Permit to Work (PTW) that the main was 2” below the concrete slab above, and therefore more vulnerable to damage. Had the PTW had this information, different working practices would have been used. • **Public and Stakeholder Interaction**: Reports of Thames Water Developer Services teams not displaying the values of the company while interacting with the public highlights the need for updated processes and training on how to engage with the public during an event (and in general) and who should be speaking on behalf of the company.
Northwold Road, N16 **Size: 30”** **Material: Cast Iron** **Burst Time: 12:11** **Burst Date: 11 December 2016**	The burst appears to be a result of multiple factors, including significant corrosion, stress concentrations from arrangement at time of installation, leakage, and traffic loading causing additional displacement and stress. It is thought a pressure wave caused the final fast fracture of the joint, resulting in a large portion of the bell breaking away.	• **Repair Planning**: Thames Water was notified of a leak on this main on 5th December. Due to the complexity of the repair, additional test procedures were required, delaying the planning process until 9th December (2 days before the burst). This delayed response likely gave the leak time to undermine the support of the pipe, elevating the stress in the pipe wall, and eventually resulting in the failure. • **Leak Location**: The planning required to fix the leak involved liaising with TfL to shut part of the road. The process was complicated due to the road being a Red Route which requires additional time to receive approval from TfL. This highlights the importance of stakeholder relations with TfL, and the need to actively involve them in leak and burst repair programmes. • **Monitoring**: Being ranked 16,000, out of 157,000, puts this span of Trunk Main as moderately high consequence however there was no monitoring systems installed. This might have enabled Thames Water to better understand the severity of the leak and expedite repair works accordingly.

8 Next Steps for Trunk Mains Strategy Review

The scope and remit of the Forensic Review is complete and the findings and recommendations are handed over to Thames Water for its active consideration. The suggested next steps are for:

- The Forensic Review to hand over all documentation and data that forms the evidence for this report.
- Thames Water to decide how it wishes to communicate the report and engage with the recommendations.
- Paul Cuttill OBE to agree with Thames Water the support required during review by ARRC and the Board.

9 Appendices

This Section contains the supporting appendices for the main report.

Appendix 1 – Scope of Works

An excerpt from the Trunk Mains Forensic Review terms of reference is provided below. It was agreed on the 24th January 2017 at the Trunk Mains Initiative Project Board Meeting. The Engagement letter for the Forensic Review was agreed and signed on the 25th January 2017 by Simon Hughes, the Head of Strategy, Planning and Networks at Thames Water Utilities.
Context
There have been 8 high profile Trunk Main bursts in the period between October and December 2016. These events have had a significant impact on customers, including repeated flooding of homes, damage to businesses, risk to life and road closures.
The bursts have resulted in a number of challenges internally and externally about Thames Water's current approach to Trunk Main risk classification, asset condition and monitoring, network operation and event response. As a result Thames Water has commissioned a forensic review of major Trunk Main failures in 2016 as part of a wider review programme.

Purpose of the forensic review
The purpose of the forensic review is to perform an independent analysis of the major burst/leak events that occurred in 2016, the potential causes of the failure, and the response in the context of the management framework Thames that has in place to monitor, maintain and replace Trunk Mains. Specific scope areas are as follows.

- To review the causes, impact and Thames Water response to all the significant Trunk Mains bursts in the last 12 months
- To assess if there are any patterns that can be derived from the data sets
- To review the approach to risk management of the asset
- To assess if there are any gaps in the management framework
- To recommend the short-term actions that should be taken
- To highlight any learnings that should be taken forward into the wider review programme, specifically the Trunk Mains strategy review workstream
- To produce a findings report that will be authored by Paul Cuttill for internal Thames Water use, and made available to Ofwat and other interested parties

Description of work
1. Gather and review evidence about each of the major Trunk Main burst/leaks that occurred in 2016 (full list of major bursts/leaks to be confirmed during mobilisation of the forensic review). This will be conducted through the development of 'deep dives' on 8 of the bursts/leaks, 'datasheets' on the remaining burst/leaks, desktop-based analysis and evidence gathering from interviews, and root cause analysis working sessions.:

    - Document the event timeline - what happened and when at the time of the event and the lead up to the failure of the Trunk Main
    - Document the impact of the burst during and after then event, including:
        - Customer; health & safety, flooding, supply, infrastructure such as road, rail
        - Water quality
        - Mitigating actions to isolate burst and maintain supply
        - Clean up and repair actions including costs
        - Insurance and compensation costs

    - Analyse the Thames Water response:
        - Timings
        - Event log
        - Process including internal 'hand-offs' etc.
        - Thames, Alliance and Third Party roles and accountability
        - What worked well and areas for improvement
        - Lessons identified and whether they have been embedded

    - Analyse the management framework in place to support the effective operation of the assets
        - The approach and application of risk management
        - The existing policy framework
        - The governance arrangements over the asset
        - The process and controls framework

    - The approach to data quality and MI

- The root causes of the burst, e.g.:
    - Asset condition
    - Environment
    - Network configuration
    - Pump operations
    - Any other causal factors

2. Develop an appropriately written findings report that:
- Summarises the evidence
- Describes root causes
- Highlights any patterns identified from the 25 major bursts/leaks in 2016
- Suggests immediate actions for Thames Water
- Informs the scope and scale of strategic change to feed into PR19 planning (and the Trunk Mains strategy review workstream)

3. Playback and consultation of the findings report with relevant Thames Water stakeholders

Appendix 2 – Assessment Frameworks

The Forensic Review uses a management framework (the components of which are shown as the horizontal bars on Figure 5) to assess the Thames Water approach to managing the Trunk Main asset network across 4 lifecycle stages (the lifecycle stages are shown as the chevrons at the top of Figure 5). The management framework used has been adapted from a Governance Framework and ISO 55001.

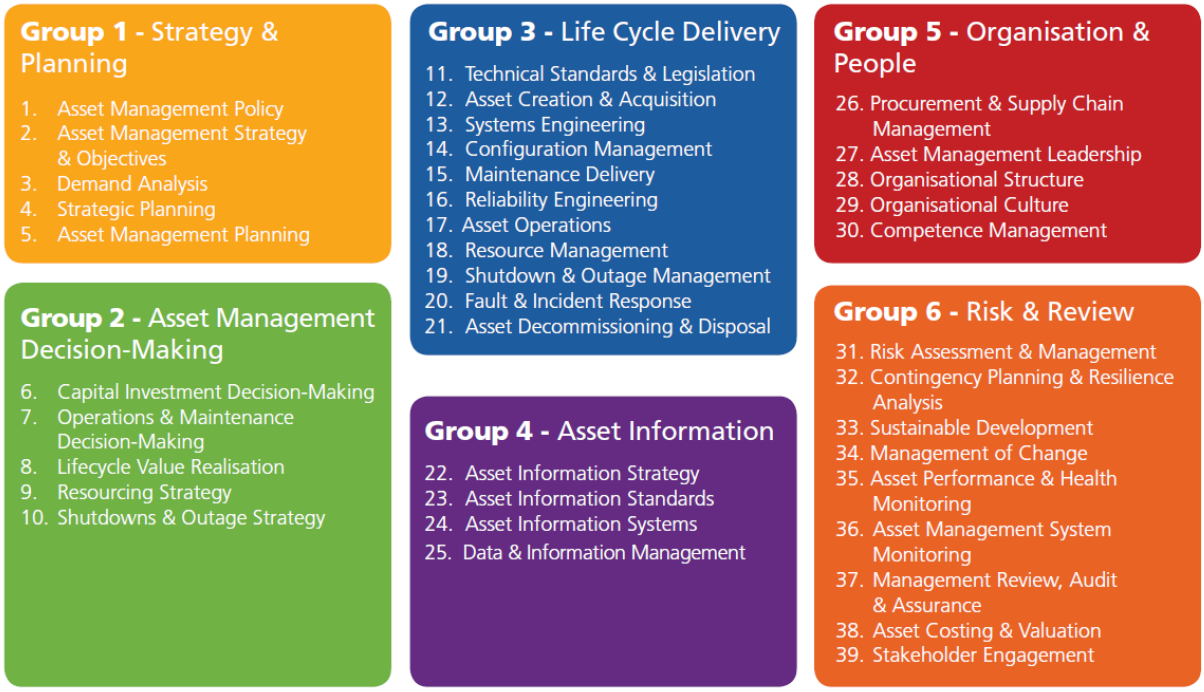


Figure 13 - ISO 55001 Asset Management Anatomy

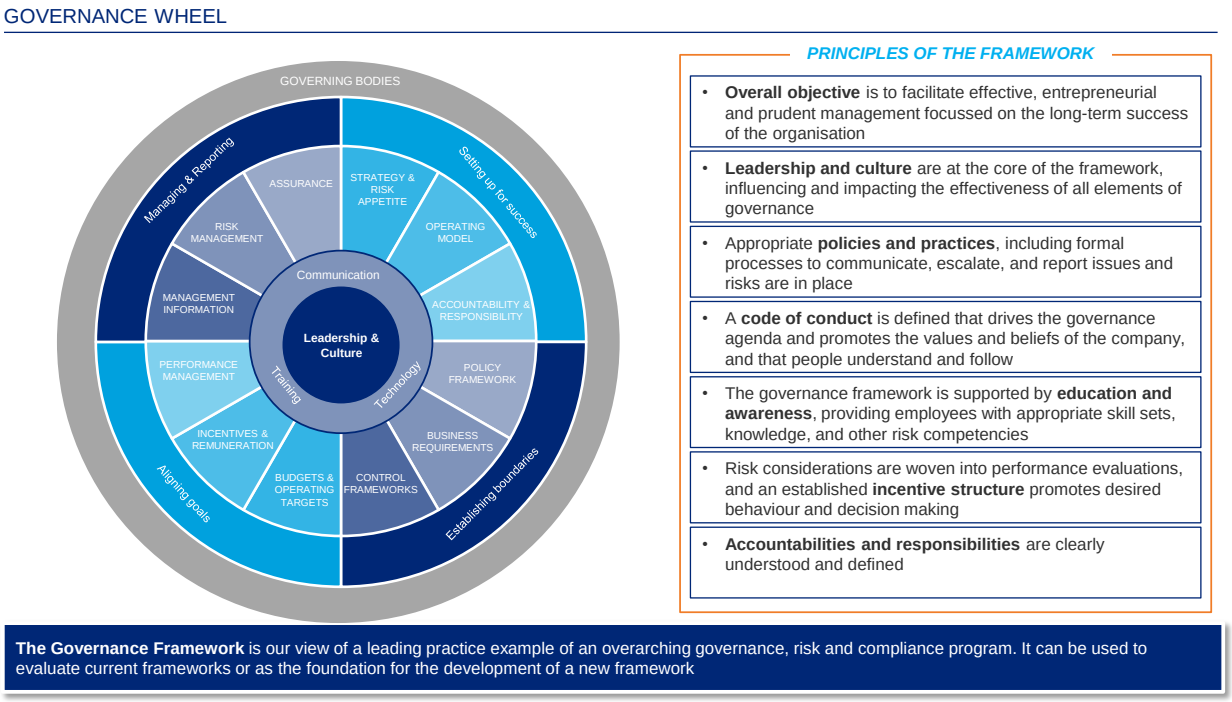


Figure 14 - Governance Assessment Framework

Appendix 3 – Meetings Held

The Forensic Review team held multiple meetings and 4 workshops across the business in February in order to gather sufficient evidence to develop a set of findings. In March various meetings were held to further evidence and validate the findings put forward in the Forensic Review report. Figure 4 above stipulates the Forensic Review structure used to carry out various meetings and workshops, alongside continued data analysis of the eight events.

Table 2 - Meetings and workshops summary of attendees

Reference	Meeting Name	Stakeholder	Sub - workstream	Date
M-001	Simon Moore meeting	Simon Moore	Events & Themes	26/01/2017
M-002	Danny Leamon / Paul Cuttill Meeting	Danny Leamon	Events & Themes	02/02/2017
M-003	Neil Doherty / Paul Cuttill Meeting	Neil Doherty	Events & Themes	02/02/2017
M-004	Tony Owen / Paul Cuttill Meeting	Tony Owen	Events & Themes	03/02/2017
M-005	Jeff Farrow Meeting	Jeff Farrow	Events & Themes	04/02/2017
M-006	Asset Planning Meeting	Richard Tull	Events & Themes	06/02/2017
		Sarah Frame	Events & Themes	06/02/2017
		Simon Moore	Events & Themes	06/02/2017
M-007	Natalie Lye Catch-up	Natalie Lye	Events & Themes	01/02/2017
M-007 / M-006	Asset Planning Meeting	Amanda Ford	Events & Themes	06/02/2017
M-008	Natalie Lye Formal Interview	Natalie Lye	Events & Themes	07/02/2017
M-009	Georgina Seely / Paul Cuttill Meeting	Georgina Seely	Events & Themes	08/02/2017
M-010	Richard Aylard / Paul Cuttill Meeting	Richard Aylard	Events & Themes	08/02/2017
M-011 / M-006	Asset Planning Meeting	Amanda Ford	Events & Themes	06/02/2017
M-013	Head of H&S	Carl Simmons	Events & Themes	09/02/2017
M-014	Head of Strategy and Regulations	Nick Fincham	Events & Themes	14/02/2017
M-018	Innovation	Paul Rutter, Tim Evans		07/02/2017
M-019	Control Room Visit	Mark Jenner	Events & Themes	13/03/2017
M-020	Operations	Mark Jenner	Events & Themes	14/02/2017
WS-001	Pre-Mortem Workshop	Tony Owen	Root Cause	13/02/2017
		Akshat Sharma	Root Cause	13/02/2017
		Chris Davis	Root Cause	13/02/2017
		Jeff Farrow	Root Cause	13/02/2017
		Jennifer Rhodes	Root Cause	13/02/2017
		Mark Jenner	Root Cause	13/02/2017
		Mike Shepherd	Root Cause	13/02/2017
		Neil Doherty	Root Cause	13/02/2017
		Rob Casey	Root Cause	13/02/2017
		Tim Evans	Root Cause	13/02/2017
		Paul Knight	Root Cause	13/02/2017
		Michael Nicholson	Root Cause	13/02/2017
M-036	Michael Nicholson Meeting	Michael Nicholson	Data – based Review	08/02/2017
M-037	Asset Planning, AIM and modelling	Richard Tull	Data – based Review	08/02/2017
M-038	Operations Meeting	Akshat Sharma	Data – based Review	10/02/2017
WS-002	Root Cause Analysis 2	Andrew Bailey	Root Cause	21/02/2017

Reference	Meeting Name	Stakeholder	Sub - workstream	Date
		Calum Chesterman	Root Cause	21/02/2017
		Dersh Patel	Root Cause	21/02/2017
		Kyle Crawford	Root Cause	21/02/2017
		Steve Wilson	Root Cause	21/02/2017
M-053	Asset Planning Meeting 2	Simon Moore, Sarah Frame, Ash Sharma	Events & Themes	06/02/2017
M-054	GIS data management	Lawrence Smith	Events & Themes	13/02/2017
M-055	PR19 Lead PMO	Sarah McMath	Events & Themes	13/02/2017
M-056	Lead Asset management PR19	James Baker	Events & Themes	13/02/2017
M-057	Water - Health and Safety Lead	Joe Hall	Events & Themes	13/02/2017
M-066	Operations Meeting	Akshat Sharma	Data – based Review	20/02/2017
M-066	Operations Meeting	Akshat Sharma	Data – based Review	22/02/2017
M-067	Control Room Meeting	Mark Jenner	Events & Themes	14/02/2017
WS-003	Root Cause Analysis 2 - Ops Working Session 1	Jamie McGrath	Root Cause	22/02/2017
		Stuart Doolan	Root Cause	22/02/2017
		Nico Swart	Root Cause	22/02/2017
		John Drake	Root Cause	22/02/2017
		Phil Alger	Root Cause	22/02/2017
		Hank Fowler	Root Cause	22/02/2017
		Alex Brown	Root Cause	22/02/2017
		Lucky Obuseh	Root Cause	22/02/2017
M-076	Upper St/Crayford/Camberwell - Event Discussion	Danny Leamon	Events & Themes	21/07/2017
M-081	Raw Data Meeting	Tony Tyler	Data – based Review	21/02/2017
M-082	AIM and Modelling Meeting	Amanda Ford, ICS	Data – based Review	01/03/2017
M-083	Neil Doherty Meeting	Neil Doherty	Data – based Review	17/02/2017
M-084	Events Interview	Thierry Droulez	Events & Themes	20/02/2017
M-085	Raw Data Meeting	Lawrence Smith	Data – based Review	21/02/2017
M-086	Customer Feedback	Nigel Dyer	Events & Themes	21/02/2017
M-087	Customer Feedback	Matthew Hackshaw	Events & Themes	20/02/2017
M-088	Leigham Vale 1 - Event Discussion	Steve Crabb	Events & Themes	16/02/2017
M-089	Leigham Vale 2 - Event Discussion	Mark Jenner	Events & Themes	23/02/2017
WS-004	Root Cause Analysis - Ops Working Session 2	Lewis Dargavel	Root Cause	22/02/2017
		Gary Barnett	Root Cause	22/02/2017
		Matt Banks	Root Cause	22/02/2017
		Field Team	Root Cause	22/02/2017
		James St Jean	Root Cause	22/02/2017
		Roland Tingey	Root Cause	22/02/2017
M-096	Syrinix CEO	James Dunning	Events & Themes	20/02/2017
M-097	Stoke Newington - Event discussion	Rob Hales	Events & Themes	17/02/2017
M-098	NST Area manager	Chris Davis	Events & Themes	24/02/2017
M-099	Risk Management	James Bairstow	Events & Themes	27/02/2017
M-100	Risk Management - Validation	Debbie Smith	Events & Themes	07/03/2017

Reference	Meeting Name	Stakeholder	Sub - workstream	Date
M-101	Data Quality - Validation	Lawrence Smith	Events & Themes	07/03/2017
M-102	Customer & Operations Validation	Matthew Hackshaw	Events & Themes	06/03/2017
M-103	Draft report findings validation	Steven Perry	Events & Themes	06/03/2017
M-104	Developer Services	Neil Titchener	Events & Themes	06/03/2017
M-105	Event Response Validation	Phil Alger	Root Cause	13/03/2017
		Hank Fowler	Root Cause	13/03/2017
		Hilton Bradish	Root Cause	13/03/2017
		Gary Page	Root Cause	13/03/2017
M-106	Operations Validation	Matt Banks	Events & Themes	09/03/2017
M-107	Operations Validation	Gary Barnett	Events & Themes	09/03/2017
M-108	Risk Model Validation	Richard Tull	Root Cause	10/03/2017
M-109	HR Validation	Marilyn Stevens	Root Cause	14/03/2017
M- 110	Asset Planning Validation	Sarah Frame	Events & Themes	08/03/2017
M- 111	Steering Group Meeting	Steve Robertson	All	14/02/2017
		Bob Collington	All	14/02/2017
		Simon Hughes	All	14/02/2017
M- 112	Steering Group Meeting	Steve Robertson	All	28/02/2017
		Bob Collington	All	28/02/2017
M- 113	Forensic Review Consultation A	Bob Collington	All	02/03/2017
		Simon Hughes	All	02/03/2017
M- 114	Forensic Review Consultation B	Bob Collington	All	09/03/2017
		Simon Hughes	All	09/03/2017
M- 115	Forensic Review Consultation C	Simon Hughes	All	21/03/2017
M- 116	Customer Care	Stephanie Beckley	Root Cause	23/03/2017

Appendix 4 – Workshop Outlines

The below details the various workshops carried out by the Forensic Review Root Cause sub – workstream, highlighting the objectives, approach and output of each.

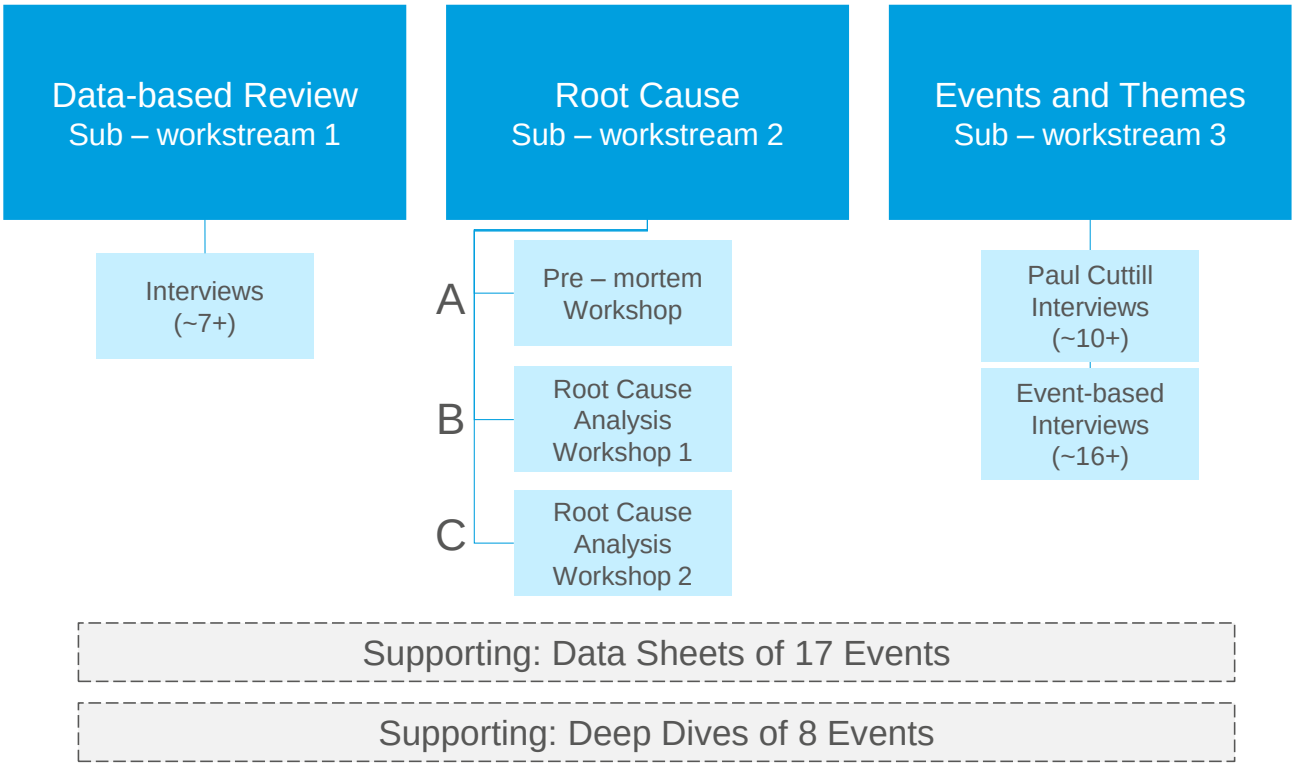


Figure 15 - Schematic of the Forensic Review Structure

Pre – mortem Workshop

The workshop was held on the 13th February 2017 in Reading. A scenario was posed to attendees imagining a date in the future where a burst had occurred. The question was asked 'what should Thames Water have done differently to prevent this outcome?' The reference for the workshop is WS -001 in the meetings log found in Appendix 3.

Objectives

Identify potential causes and current issues that could lead to a Trunk Main burst

Approach:

Brainstorm what Thames Water should have done differently	Group ideas and summarise key points	Prioritise issues according to business benefit and feasibility

Outputs

A prioritised list of issues which could cause a Trunk Main burst, including business benefit and feasibility of addressing the issue

Root Cause Analysis Workshop 1

The workshop was held on the 21st February 2017 in Reading. The purpose of the session was to identify the root causes from asset planning, operations and maintenance, monitoring and event response activities. The reference for the workshop is WS -002 in the meetings log found in Appendix 3.

Objective:

Identify root causes and appropriate evidence to support the root causes

Approach:

Identify root causes using root cause tree diagrams → Gather evidence to support root causes → Develop suggested recommendations

Outputs:

Root cause tree diagrams. Diagrams from this workshop were combined with those from other workshops to create a summary diagram. Documents for evidence purposes added to data request tracker used in conjunction with other fishbone diagrams to create a summarised set of root causes and impacts

Root Cause Analysis Workshop 2 – Operations Working Sessions

Two working sessions were held on the 22nd of February 2017. The first session was held at the Infrastructure Alliance offices in Darenth, the second at the Infrastructure Alliance offices in Kentish Town. The purpose of the sessions were to engage directly with operations and field teams to identify the root causes from operations, maintenance and event response activities. The reference for the workshop is WS -003 and WS-004 in the meetings log found in Appendix 3.

Objective:

Identify root causes and appropriate evidence to support the root causes with operations staff

Approach:

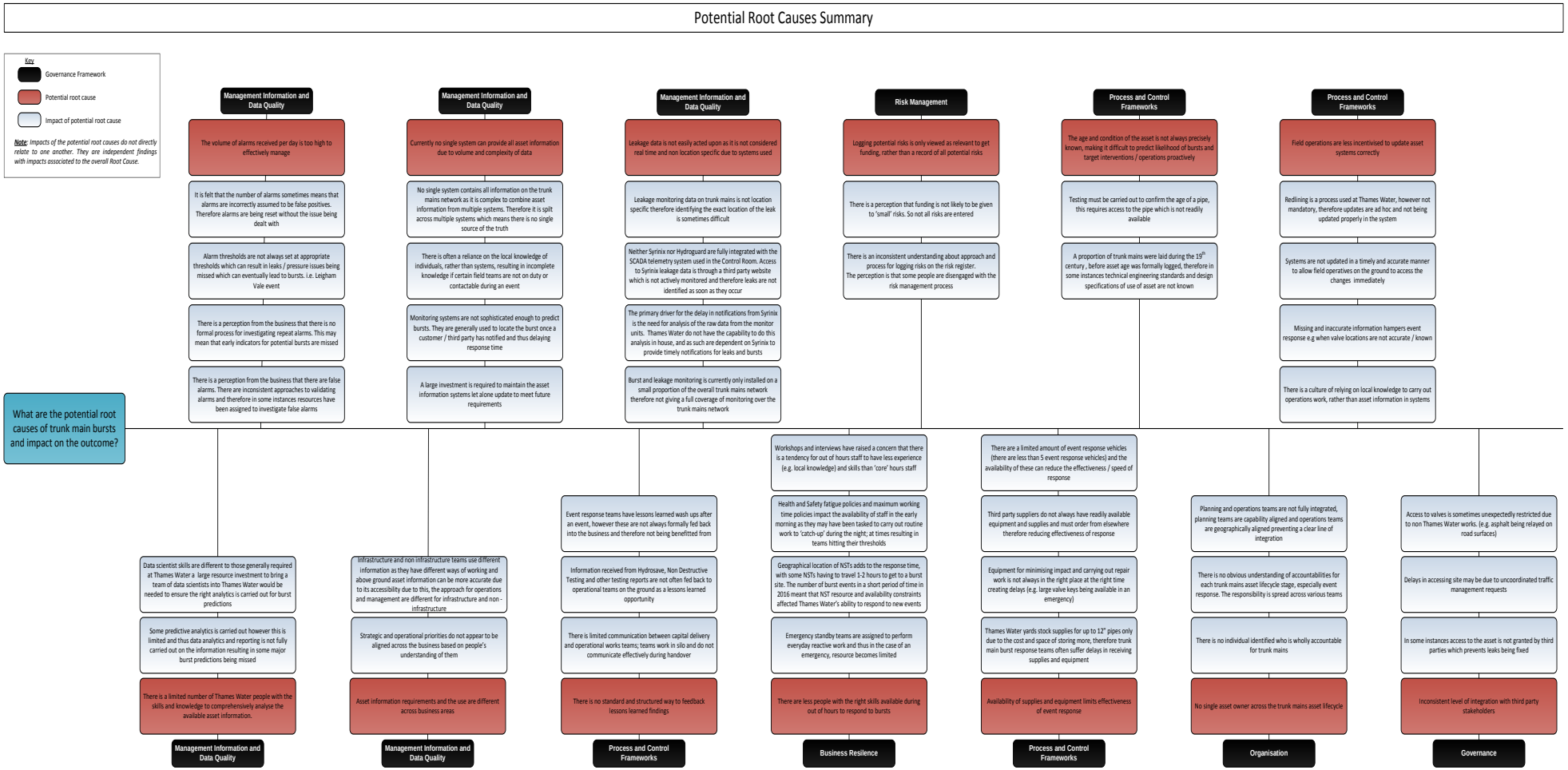
Identify root causes using root cause tree diagrams → Gather evidence to support root causes → Identify links to the 8 high profile events

Output:

Root cause tree diagrams. Diagrams from this workshop were combined with those from other workshops to create a summary diagram. Documents for evidence purposes added to data request tracker used in conjunction with other fishbone diagrams to create a summarised set of root causes and impacts

Appendix 5 – Root Cause Fishbone Diagram

Following the root cause workshops a summary of findings was developed and is presented below. The summary represents a cross business point of view based on anecdotal discussion during workshops. Therefore some content reflects attendee's perceptions. The root causes have been further validated through interviews and data and document analysis before being included in the findings of this report.



Appendix 6 – Performance Outcome Delivery Incentives (ODIs)

Thames Water has a set of performance commitments, as detailed below which have been agreed by the regulator, Ofwat. Thames Water strategic plans are governed by the below performance commitments. Not adhering to these results in a penalty from the regulator.

Table 3 - Thames Water Performance Commitments for Wholesale Water in AMP6

	recalibration	recalibration
WA1: Improve handling of written complaints by increasing 1st time resolution		
WA2: Number of Written complaints per 10,000 connected properties		
WA3: Customer satisfaction surveys (Internal CSAT monitor)		
WA4: Reduced water consumption from issuing water efficiency devices to customers	0.885	
WA5: Provide a free repair service for customers with a customer side leak outside of the property		
WB1: Asset Health Water Infrastructure	4.675	
WB2: Asset Health Water Non Infrastructure	4.675	
WB3: Compliance with drinking water quality standards – Ofwat/DWI KPI	3.915	
WB4: Properties experiencing chronic low pressure		
WB6: Security of Supply Index – Ofwat KPI	2.265	
WB7: Compliance with SEMD advice notes (with or without derogation)	40.94% of annualised costs saved through scope reduction	
WB8: Ml/d of sites made resilient to future extreme rainfall events	0.005	0.005
WC1: Greenhouse gas emissions from water operations		
WC2: Leakage	0.450	0.270
WC3: Abstraction Incentive Mechanism (AIM)		
WC4: We will educate our existing and future customers		
WC5: Deliver 100% of agreed measures to meet new environmental regulations	40.94% of 2015-20 costs reduced through scope reductions	
WD1: Energy imported less energy exported		

Note: Each performance commitment has an annual target associated with it. Some performance commitments have a financial penalty or reward if Thames Water perform below or above the target.

Appendix 7 – Report Author

Paul Cuttill

Paul Cuttill is an independent consultant working in the energy and business development sectors following a 31 year career within the UK Energy Industry across a range of senior appointments with EDF Energy plc, one of the UK's largest energy companies culminating in his appointment as Chief Operating Officer, Networks between October 2002 and June 2008.

The Networks business unit (sold to CK Infrastructure in November 2010) employs around 5500 people, has a regulatory asset value of c. £3.0bn, earnings before interest and tax in excess of £700m per annum and distributes electricity to 7.8m connected customers. In addition the unit is responsible for private, non-regulated network operations such as those serving Heathrow, Gatwick and Stansted airports on behalf of BAA, High Speed 1 (Channel Tunnel Rail Link) on behalf of London and Continental Railways and the HV power system for London Underground.

For 3 years from 1 January 2009 Paul was Managing Director and Board Member of Strategy International Limited trading as The D Group. The D Group is a publicity adverse business-networking organisation with a strong international slant as well as an established national presence throughout government and business as a whole. The D Group has over 70 corporate members ranging from multi-national FTSE 100 companies to small industry-specific organisations. Paul remains as Consultant Adviser to The D Group.

Other appointments include:

- Deputy Chairman, DRENL Ltd – a developer and operator of small scale energy from waste plants.
- Director and Partner, Cleantech HQ – an independent developer of leantech opportunities and solutions.
- Board Member of Spirit of 2012 Trust – a company entrusted to oversee and manage £40m endowment of Big Lottery funds ensure the spirit radiated by the London 2012 Olympic and Paralympic Games is felt by everyone everywhere.
- Between 2004 and 2006 Paul was a Board Member of Energy and Utility Skills SSC, the Sector Skills Council for electricity, gas, waste management and water.
- Between December 2006 and September 2008 Paul was a Founder Member of the Mayor of London's Skills and Employment Board and has been Vice Chair of the Advisory Panel to the UK Government on the issues of Leadership and Management set out in the skills White Paper 'Skills for Productivity' published in March 2005.

In June 2004 Paul was appointed by HRH The Prince of Wales as an Ambassador for Corporate Responsibility in the London Region.

In the 2005 New Year Honours list, Paul was made an Officer of the Order of the British Empire (OBE) for services to the energy industry. He lives in West Sussex is both a Liveryman of the Worshipful Company of Fuellers and a Freeman of the City of London. He enjoys horseracing, all forms of music and the occasional round of golf.

10 Glossary of Terms

AIM	Asset Investment Manager
AMA	Asset Management and Maintenance
AMP	Asset Management Planning period
AMP5	Asset Management Planning period 5, from April 2010 to March 2015 inclusive
AMP6	Asset Management Planning period 6, from April 2015 to March 2020 inclusive
AMP7	Asset Management Planning period 7, from April 2020 to March 2025 inclusive
APR	Annual Performance Report
APS	Asset Planning System
AR	Annual Return
ARRC	Audit, Risk & Regulatory Committee
C&L	Cunningham & Lindsey
Capex	Capital Expenditure
CCTV	Closed Circuit Television
CEO	Chief Executive Officer
CFO	Chief Financial Officer
DEFRA	Department for Environment, Food and Rural Affairs
DMA	Distribution Management Areas
EDF	EDF Energy Networks (Now UK Power Networks)
eight$_2$O Alliance	Alliance partnership to deliver capital investment programmes
ERM	Enterprise Risk Management
FD09	Financial Determination 2009
FTE	Full Time Equivalent
GIS	Geographical Information Services
GLA	Greater London Authority
IAD	Investment Area Document
IAR	Integrated Asset Repository
Infrastructure Alliance (IA)	Alliance partnership to maintain Thames Water's supply network
ISO 55001	The requirements specification for an integrated, effective management system for asset management
JR	June Return
LRG	Local and Regional Government Liaison
MD	Managing Director
MWH Global	A global water and natural resources firm, providing technical engineering, construction services and consulting services who are part of the eight$_2$O alliance.
NDT	Non-Destructive Testing
NMT	Network Maintenance Team
NST	Network Service Technician
ODI	Outcome Delivery Incentive
Opex	Operational Expenditure

PC	Performance Commitments
PIG	Internal material analysis tool
PR	Periodic review conducted by Ofwat for the purpose of determining one or more price controls in accordance with Condition B of the Thames Water Instrument of Appointment
PR14	Price Review 2014 covering the regulatory period from 1 April 2015 to 31 March 2020
PR19	Price Review 2019 covering the regulatory period from 1 April 2020 to 31 March 2025
PTW	Permit to Work
RA6	ODI metric aligned to improving Service Incentive Mechanisms
ROCC	Risk, Opportunities and Controls Committee
RSA	Royal Sun Alliance (Thames Water's Insurance Providers)
SCADA	Supervisory Control and Data Acquisition
SFT	Strategic Field Technicians
SIM	Service Incentive Mechanisms
SLA	Service Level Agreement
SP&A	Strategy, Planning and Assurance
Syrinix	Leak and burst detection system that is installed on Trunk Mains that 'listens' to the acoustics of the water flow. When bursts are detected notifications are sent to the Thames Water Control Room
Sahara	A probe that is placed into the Trunk Mains network, whilst under pressure, that uses acoustics to identify leaks within the internal walls of the pipes
Hydroguard	Units are installed on Trunk Main valves that, through monitoring pressure and flow, can identify bursts. When a burst is identified a notification is sent to the Thames Water Control Room
Hydrosave	An operational consultant and specialist contractor within the water industry
Red Route	Major roads as classified by Transport for London. There are specific rules that govern these roads
MP	Member of Parliament
Ofwat	Regulator for water and sewerage providers in England and Wales
Deep Dives	Detailed documents developed by Thames Water for each of the 8 high profile Trunk Main bursts that occurred between October and December 2016
'no regret' mains	Locations where the consequence of a further burst in the same location is considered too great by the business and rehabilitation should be undertaken
ICS	ICS Consulting provide consultancy and support services to asset intensive businesses
SI4	Unplanned interruptions to customer supply >4 hours.
SI12	Unplanned interruptions to customer supply >12 hours.
LA	Local Authority
WCT	Water Control and Transmission
IBM	A global cloud platform and cognitive solutions company who are part of the eight$_2$O alliance.
Asset Owner Operating Model	A project working to develop and strengthen Asset Owner capabilities across the end-to-end asset maintenance value chain.
Breivoll	A company that specialises in in-line utility pipeline inspection
Terms of Reference (ToR)	Defines the purpose and scope of committees, projects or meetings
Asset Planning	The activities that take place to plan the use, maintenance and replacement of the Trunk Mains network
Asset Operations and Maintenance	The activities that take place as business-as-usual on the Trunk Mains

Asset Monitoring	The activities that are performed to plan, install and use equipment on Trunk Mains to proactively identify potential bursts, and to reactively understand when bursts have happened
Event Response and Aftercare	The activities that take place from burst notification through to closing out all customer aftercare
TfL	Transport for London
Trunk Mains	A classification of larger diameter mains (typically 18” or greater) in a water distribution system
Trunk Mains Strategic Review	A 4-6 month review Thames Water’s Trunk Mains asset network, with participation from Ofwat.
TTA	Thames Technology Alliance composed of Accenture, Bilfinger, Deloitte and IBM
WC2	ODI metric aligned to reducing leakage

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