Review of progress of the Iron Mains Risk Reduction Programme (IMRRP) 2013 to 2023

Prepared by researchers at the

Health and Safety Executive

RR1216 (2024)

Research Report

Prepared 2024

First published 2024

The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains with the risk of injuries, fatalities, and property damage. A review of the IMRP was carried out in 2011 and published as HSE Research Report 888. Following the review, the IMRP was renamed the Iron Mains Risk Reduction Programme (IMRRP) and the HSE Iron Mains Enforcement Policy governing the IMRRP was revised taking into account the review findings.

This report describes research commissioned in 2023 to review the progress of the IMRRP since 2013 to:

- **determine whether over the period 2013-2023 the Iron Mains Enforcement Policy has secured the decommissioning of the highest risk iron mains; and**
- **consider if there should be changes to how the programme is structured as it enters the final six years of the 30-year programme (2026-2032).**

The review found that the number of pipe failures recorded each year per kilometre of remaining iron mains is increasing slightly and identified concerns with the methodology used to prioritise larger diameter pipes for decommissioning. The review also suggests an alternative approach to address weaknesses in the Condition (integrity) Monitoring practices currently used by the Gas Distribution Networks. Based on the findings of our review, we present a number of options for revising HSE's Iron Mains Enforcement Policy as it enters the final six years of the 30-year programme (2026-2032), to ensure that it remains fit for purpose.

DOI: https://doi.org/10.69730/hse.24rr1216

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

Review of progress of the Iron Mains Risk Reduction Programme (IMRRP) 2013 to 2023

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Acknowledgements

The authors would like to thank the Gas Distribution Networks and DNV for providing us with data and documentation for our review, and for answering our queries.

We would also like to thank our HSE colleagues who shared their expertise and provided valuable contributions to the workshops.

Finally, we would like to thank HSE Regulatory Inspector Andrew Cooke for the support and guidance that he has provided throughout this project.

Abbreviations

CF	Consequence Factor
CI	Cast Iron
DESNZ	Department for Energy Security and Net Zero
DI	Ductile Iron
GDN	Gas Distribution Network
GHF	Gas History Factor
GiB	Gas in Building
GIF	Gas Ingress Factor
GTF	Gas Tracking Factor
GSMR	Gas Safety (Management) Regulations 1996
HP	High Pressure
IMRP	Iron Mains Replacement Programme
IMRRP	Iron Mains Risk Reduction Programme
LDZ	Local Distribution Zone
LP	Low Pressure
MCF	Mains Corrosion Factor
MCJF	Mains Corrosion Joint Factor
MFF	Mains Fracture Factor
MP	Medium Pressure
MRPS	Mains Replacement Prioritisation Scheme
NGN	Northern Gas Networks
PAST	Pipes Above Safety Threshold
PE	polyethylene
ppb	parts per billion
ppm	parts per million
PRE	Public Reported Escape
SGN	Scotland Gas Networks and Southern Gas Networks
SI	Spun Iron
SPI	Safety Performance Indicator
WWU	Wales & West Utilities

Key Messages

Iron mains within the natural gas distribution network are subject to corrosion and brittle failure. These failures give rise to gas escapes and the consequent risk of fire and explosion. To address this issue, the Gas Distribution Network operators (GDNs) are undertaking a 30-year programme of iron mains risk reduction.

The current Iron Mains Risk Reduction Programme (IMRRP), also known as the Three-Tier Approach, has been in place since 2013. HSE's Enforcement Policy for the IMRRP requires the GDNs to use a risk-based approach to prioritise iron mains for decommissioning.

A review has been undertaken to assess whether HSE's Enforcement Policy for the IMRRP has secured the decommissioning of the highest risk iron mains. This technical review provides an independent analysis of the safety benefits realised by the decommissioning programme.

The performance of the IMRRP was assessed by reviewing data on fracture and corrosion events and Gas in Building (GiB) events on the iron mains network. To complement this analysis, a detailed review of the methodology used to prioritise pipes for decommissioning was carried out. The review was informed by contributions from HSE Regulatory Inspectors, Pipeline Specialists, engineers and scientists at two internal HSE workshops.

At a pipe-specific level, there is a good correlation between the risk score calculated by the GDNs' risk model and the subsequent number of reported GiB events. However, the good performance of the risk model has not translated into a decrease in the number of pipe failures per km per year at a network level. This may be because the rate of mains decommissioning has failed to keep pace with the deterioration of the network. Alternatively, this may indicate that there are issues with the way in which the risk model outputs are used to prioritise pipes for decommissioning.

This review identified multiple issues with the methodology used to prioritise larger pipes (of diameter greater than 8 inches) for decommissioning. These include a failure to consider cumulative risk from multiple pipes and the sharing of individual risk across multiple people in multiple buildings, contrary to the standard definition of individual risk in HSE's R2P2 (Reducing Risks, Protecting People) guidance.

The conclusions of this review will be used by HSE to inform the next iteration of the Iron Mains Enforcement Policy for the period 2026 to 2032. The primary audiences for this report are HSE and the GDNs. It will also be of interest to Ofgem as the gas economic regulator and organisations within the mains decommissioning supply chain.

Executive Summary

Background

Iron mains within the natural gas distribution network are subject to corrosion and brittle failure. These failures give rise to gas escapes and the consequent risk of fire and explosion. To address this issue, the Gas Distribution Network operators (GDNs) are undertaking a 30-year programme of iron mains risk reduction.

The current Iron Mains Risk Reduction Programme (IMRRP), also known as the Three-Tier Approach, has been in place since 2013. HSE's Enforcement Policy for the IMRRP requires the GDNs to use a risk-based approach to prioritise iron mains for decommissioning and consequently for replacement if required. The GDNs use DNV's MRPS (Mains Replacement Prioritisation Scheme) risk model to inform this approach.

Under the Three-Tier Approach, all Tier 1 pipes (pipes of diameter 8 inches and below) within 30 metres of buildings must be decommissioned by 2032. Larger diameter Tier 2 and Tier 3 pipes are deemed to represent a lower risk to the public than Tier 1 pipes. For Tier 2 pipes, action is therefore only required for pipes that have a risk score above a Risk Action Threshold set by the GDN operator. All Tier 3 pipes and Tier 2 pipes with a risk score above the threshold are subject to condition monitoring.

This report describes a review of the progress of the IMRRP from 2013 to 2023, which will be used by HSE to inform the next iteration of the Iron Mains Enforcement Policy for the period 2026 to 2032. This technical review is focused on safety considerations and provides an independent analysis of the safety benefits realised by the decommissioning programme. This review does not consider the economic case, nor the decommissioning programme in the wider context of the future gas network.

Aims

The aim of this review is to assess whether HSE's Iron Mains Enforcement Policy for the IMRRP has secured the decommissioning of the highest risk iron mains (leading to a significant reduction in the risk of gas escapes from the network) between 2013 and 2023.

Based on the conclusions of this review, HSE will consider whether there are any options for revising HSE's Iron Mains Enforcement Policy (including its timescale) as it enters the final six years of the 30-year programme (2026-2032), to ensure it remains fit for purpose.

Methods

The performance of the IMRRP was assessed by reviewing data on fracture and corrosion events and Gas in Building (GiB) events across the whole iron mains network. In addition, a detailed analysis of pipe-specific data was performed, to assess whether the MRPS risk score for a pipe is a good predictor of the number of GiB events and pipe failures observed on that pipe.

To complement this analysis, a review of the methodology used to prioritise pipes for decommissioning was carried out. Two internal HSE workshops were held, to discuss particular aspects of the methodology in more detail. These workshops brought together HSE Regulatory Inspectors, Pipeline Specialists and scientists with expertise in mechanical engineering, materials science and risk assessment.

The first workshop reviewed current condition monitoring techniques and discussed possible alternative approaches that would provide an effective means of identifying the remaining high-risk pipes in Tiers 2 and 3. The second workshop reviewed the risk factors currently considered in the prioritisation methodology and discussed additional risk factors that could be included.

Findings

The number of pipe failures per year on the iron mains network is decreasing as the length of iron mains decreases. However, the number of pipe failures recorded each year per kilometre of remaining iron mains shows a slight (but statistically significant) increase. This could be a result of either incorrect prioritisation of pipes for decommissioning (i.e. a failure to remove the highest-risk iron mains) or network deterioration.

The analysis of pipe-specific data shows a good correlation between the risk score calculated by the MRPS for a specific pipe and the number of GiB events that are observed on that pipe. This suggests that the MRPS risk scores are an appropriate measure by which to prioritise pipes for decommissioning.

The good performance of the MRPS has not translated into a decrease in the number of pipe failures per km per year at a network level. This may be because the rate at which mains are decommissioned has failed to keep pace with the deterioration of the network. Alternatively, this may indicate that there are flaws in the methodology used to prioritise pipes for decommissioning.

This review has identified multiple issues with the approach used to prioritise Tier 2 pipes for decommissioning or other appropriate attention. In this methodology, the individual risk of fatality is calculated from the MRPS score and compared to a Risk Action Threshold, to determine what action is required. The following points are of particular concern:

- The MRPS outputs are being used as a measure of absolute risk, rather than a measure of relative risk.

- Individual risk is being shared across multiple people in multiple buildings. This is not consistent with the definition of individual risk used in HSE’s R2P2 (Reducing Risks, Protecting People) guidance.

- Cumulative risk from multiple pipes is not considered.
- No action is required for Tier 2 pipes with risk scores below threshold.

In the workshops, concerns were raised about the quality of the historical and survey data that are input to the MRPS. The workshop participants also noted that most pipe failures have a corrosion element, so corrosion should be included for all pipes in the MRPS. Corrosion is not currently considered for cast and spun iron pipes, but DNV has confirmed that corrosion will be modelled for all pipe types in the next release of the MRPS.

Workshop participants also identified a number of concerns about the use of leakage surveys for condition monitoring. It was observed that issues with staff competency and the ability to follow processes accurately may limit the quality of the data obtained from leakage surveys. The use of advanced leakage detection systems, such as Picarro (currently being trialled by two of the GDNs) would address many of the concerns raised.

Participants felt it would be preferable to base condition monitoring on pipe integrity measurements (a leading indicator) rather than leakage surveys (a lagging indicator). It was noted that this approach may be hampered by a lack of historic condition data.

Options for revising the Iron Mains Enforcement Policy

Based on the findings of our review, we present a number of options for revising HSE's Iron Mains Enforcement Policy as it enters the final six years of the 30-year programme (2026-2032), to ensure that it remains fit for purpose.

The current Enforcement Policy gives the GDNs flexibility about how Tier 1 pipes are prioritised for decommissioning. Tier 1 decommissioning programmes in which only the pipes with the very highest risk scores are mandatory would give networks more flexibility to decommission all the pipes in a given geographical area and may facilitate the transition to natural gas alternatives such as hydrogen in a given region. A revised Enforcement Policy could more strongly encourage GDNs to take advantage of this flexibility and carry out more decommissioning on a geographical basis.

This review raised multiple concerns about the methodology currently used to prioritise Tier 2 pipes for decommissioning or other appropriate attention. One particular concern was the fact that no action is required for Tier 2 pipes with risk scores below the Risk Action Threshold. This could be addressed in a revised Enforcement Policy.

Our data analysis showed that there is a good correlation between the risk scores for Tier 2 pipes and the observed number of GiB events. It may therefore be appropriate to introduce a programme for addressing high-scoring Tier 2 mains.

Many of the concerns raised about the use of leakage surveys for condition monitoring would be addressed by the use of advanced leakage detection systems. A revised Enforcement Policy could encourage a move to such systems.

Contents

1 Introduction

1.1 Background

Iron mains within the natural gas distribution network are subject to corrosion and brittle failure. These failures give rise to gas escapes and the consequent risk of fire and explosion.

In response to this issue, the Iron Mains Replacement Programme (IMRP) was introduced in 2002 and was adopted by the Gas Distribution Networks (GDNs). Under the IMRP, the GDNs were required to replace all ‘at risk’ iron mains (those within 30 metres of buildings) by 2032.

In 2010, HSE and Ofgem commissioned a 10-year review of the IMRP [1]. In response to the review findings, the IMRP was modified to become the current Iron Mains Risk Reduction Programme (IMRRP), which is also known as the Three-Tier Approach.

Each GDN Operator must include an iron mains risk reduction programme in its Gas Safety (Management) Regulations (GSMR) safety case, describing how a risk-based approach will be used to prioritise the iron mains for decommissioning. This programme must be submitted to HSE for approval [2]. HSE’s Enforcement Policy for the IMRRP [2] sets the framework for the Approved Programmes and must be periodically reviewed to ensure that it provides an appropriate basis for the Approved Programmes.

This report describes a review of the progress of the Iron Mains Risk Reduction Programme from 2013 to 2023, which will be used by HSE to inform the next iteration of the Iron Mains Enforcement Policy for the period 2026 to 2032. This technical review is focused on safety considerations, to complement a review by Ofgem, DESNZ and HSE of the wider economic, environmental and operational aspects of the IMRRP. It provides an independent analysis of the safety benefits realised by the decommissioning programme.

1.1.1 The Three-Tier Approach

The Iron Mains Enforcement Policy [2] requires the Gas Distribution Network operators (GDNs) to use a risk-based approach to prioritise iron mains for decommissioning and consequently for replacement if required. The GDNs use DNV’s MRPS (Mains Replacement Prioritisation Scheme) risk model to inform this prioritisation [3-5].

For the purposes of the Iron Mains Risk Reduction Programme, iron mains are split into three tiers by diameter [2]:

- Tier 1: 8 inches and below
- Tier 2: above 8 inches and below 18 inches
- Tier 3: 18 inches and above

The HSE Iron Mains Enforcement Policy requires all Tier 1 pipes within 30 metres of buildings to be decommissioned by 2032 [2].

The 10-year review of the IMRP [1] concluded that larger diameter pipes represent a lower risk to the public than Tier 1 pipes. Under the current HSE Enforcement Policy, Tier 2 pipes that have a risk score above a Risk Action Threshold set by the GDN operator will be selected to receive appropriate attention (either decommissioned or assessed for continued use if found to be in good condition or remediated to allow for lifetime extension) [2]. All Tier 3 pipes and Tier 2 pipes with a risk score above the threshold are subject to condition monitoring.

1.2 Aims

The first aim of this review is to assess whether HSE's Iron Mains Enforcement Policy for the IMRRP has secured the decommissioning of the highest risk iron mains (leading to a significant reduction in the risks of gas escapes from the network) over the period 2013 to 2023.

Based on the conclusions of this review, we will consider whether there are any options for revising HSE's Iron Mains Enforcement Policy (including its timescale) as it enters the final six years of the 30-year programme (2026-2032), to ensure that it remains fit for purpose.

A further aim of this review is to consider how the IMRRP could be developed so that it is linked to the wider strategic needs of the network, such as the transition to potential natural gas alternatives such as hydrogen.

1.3 Approach

In this review we seek to answer the following questions, to inform our assessment of the performance of the IMRRP.

Has the decommissioning programme been targeted at the remaining highest risk pipes? Has the Mains Replacement Prioritisation Scheme (MRPS) been successful in identifying the highest risk 'at risk' mains, including those in Tier 2 and Tier 3?

We have analysed pipe failure and GiB (Gas in Building) event data relating to iron mains provided by the GDNs at network level. Our analysis studied the link between the number of pipe failures and GiB events and the remaining length of pipe in scope of the Iron Mains Risk Reduction Programme, for pipes in Tiers 1, 2 and 3. Regression analysis was carried out to determine whether the trends were statistically significant.

We also carried out a detailed analysis of pipe-specific data provided by the GDNs, to assess whether the MRPS risk score for a pipe is a good predictor of the number GiB events and pipe failures observed on the pipe.

If not, what needs to be done to ensure the remaining high-risk pipes are decommissioned?

The Iron Mains Enforcement Policy [2] requires all Tier 1 pipes within 30 metres of buildings to be decommissioned by 2032. Our review has therefore focused on identifying what needs to be done to ensure that the remaining high-risk pipes in Tiers 2 and 3 are decommissioned.

All Tier 3 pipes and Tier 2 pipes with a risk score above a threshold set by the GDN operator are subject to condition monitoring [2]. Current condition monitoring regimes consist of walking or vehicle surveys using standard gas detection equipment to identify leaks [6,7], although more sensitive monitoring devices are being trialled [8]. We held an internal HSE workshop to review current condition monitoring techniques and discuss possible alternative approaches that would provide an effective means of identifying the remaining high-risk pipes in Tiers 2 and 3. This workshop was attended by HSE Regulatory Inspectors, Pipeline Specialists and scientists with expertise in mechanical engineering and materials science.

We have also carried out a detailed review of the methodology used to prioritise Tier 2 pipes for decommissioning or other appropriate attention and have identified some concerns and proposed possible revisions.

To what extent has the decommissioning programme (and the requirements of HSE’s wider Iron Mains Enforcement Policy 2013-21) kept pace with the deteriorating ‘at risk’ population of iron mains (including Tier 2 and Tier 3)?

On behalf of all networks, SGN (Scotland and Southern Gas Network) commissioned DNV to carry out a technical assessment of Iron Mains risk to understand current asset degradation rates [9]. To inform this work, DNV developed a statistical model of network deterioration.

We have carried out a review of the DNV study, to assess whether the statistical model is an appropriate tool for predicting the deterioration of the network. We also discuss whether the model is a suitable basis for developing alternative replacement scenarios for mains and services in the Ofgem RIIO-GD3 price-control period (April 2026 to March 2031) and beyond.

Are any areas of known risk currently included within the programme being overlooked or delayed? Are any areas of known risk currently excluded from the programme in need of reconsideration?

We have reviewed and summarised information describing the MRPS [3-5] and the other risk factors and methodologies that are used to prioritise iron mains for decommissioning [10-13].

An internal HSE workshop was held to discuss the risk factors currently considered in the risk reduction programme and identify any further risk factors that should be included. The workshop brought together HSE experts from a range of relevant fields including Regulatory Inspectors and specialists in materials, pipelines, mechanical engineering and risk assessment.

Does the rate of steel service pipe replacement need to be increased in order to prevent the service pipe risk profile deteriorating?

Steel service pipes are not within scope of the Iron Mains Enforcement Policy, but the risk they present is in part being managed through the iron mains programme because steel services are replaced by PE (polyethylene) when a new PE main is installed.

To assess whether the rate of steel service pipe replacement needs to be increased in order to prevent the service pipe risk profile deteriorating, we have analysed incident data relating to steel service pipes provided under GSMR (Gas Safety (Management) Regulations 1996) and data on GiB events from services provided by the GDNs.

1.4 Structure of the report

The remainder of this report is structured as follows:

- In Section 2, we present the analysis of pipe failure and GiB (Gas in Building) event data relating to iron mains, provided by the GDNs at network level.
- In Section 3, we describe the MRPS risk model and the methodologies used by the GDNs to prioritise pipes for decommissioning based on the outputs of the MRPS.
- Our analysis of pipe-specific failure data and MRPS risk scores is described in Section 4.
- The workshop to discuss the risk factors considered in the risk reduction programme is reported in Section 5.
- The workshop to discuss condition monitoring techniques is described in Section 6.
- In Section 7, we present our review of the DNV study on network deterioration.
- Our analysis of steel service pipe failure data is described in Section 8.
- In Section 9, we discuss modifications to the prioritisation programme that would facilitate the transition from natural gas to alternatives such as hydrogen in the distribution network.
- The conclusions of our review are summarised in Section 10.

2 Performance at a network level

2.1 Methodology

The purpose of this systematic review was to assess whether HSE's Iron Mains Enforcement Policy for the IMRRP has secured the decommissioning of the highest risk iron mains, leading to a significant reduction in the risk of gas escapes from the network over the period 2013 to 2023. Our assessment was carried out using network performance data provided by the GDNs.

We have used the following performance indicators to assess the progress of the IMRRP:

- Length of iron mains remaining
- Number of fractures and corrosion events
- Number of Gas in Building (GiB) events
- Number of fracture and corrosion events per kilometre of iron mains
- Number of GiB events per kilometre of iron mains

Historical data on fractures and corrosion events (and the resulting GiB events) are used in the calculation of pipe risk scores. Therefore, analysing trends in these data should give a good measure of how the GDN's risk model and the risk reduction programme are performing.

The analysed data spanned 10 years, from 2013/14 to 2022/23 (starting at beginning of the Ofgem RIIO-GD1 price-control period and including the first two years of the RIIO-GD2 price-control period).

For the purposes of the IMRRP, iron mains are split into three tiers by diameter [2]. The HSE Iron Mains Enforcement Policy requires all Tier 1 pipes within 30 metres of buildings to be decommissioned by 2032 but does not require all Tier 2 and Tier 3 pipes within 30 metres of buildings to be decommissioned. The data have been analysed by tier to investigate the impact of this policy.

2.2 Data sources

All GDNs provided the length of iron mains remaining in each tier by year. The number of pipe failures (fractures or corrosion events) and the number of GiB events for each tier by year were provided by Cadent, NGN and SGN in response to an earlier request for information by the Department for Energy Security and Net Zero (DESNZ). The data provided by WWU were not broken down by tier, so were not included in our analysis.

The data were provided by financial year. In the figures presented in this section, the x-axis labels refer to the start of the relevant financial year (so ‘2013’ denotes the financial year from April 2013 to March 2014).

We cross-checked the data summed over all tiers against the data provided by the GDNs in their annual SPI (Safety Performance Indicator) returns.

2.3 Data analysis

We have plotted the variation in the performance indicators over the 10-year time period of interest, to allow trends in the data to be visualised. To quantify the trends, we carried out a statistical analysis using Quasi-Poisson regression. Poisson regression is a method to fit a trend line to data that express counts of events (such as the number of GiB events in a given year), and hence cannot fall below zero. In this analysis we assume that the only factor systematically affecting the count is time, i.e. the year. Even if we had data from multiple fundamentally identical systems, the number of events in a given time period might be expected to vary between the systems about some average value, due to processes that are not included in the model, i.e. factors other than time: we model those variations as random fluctuations. Random variation in count data is typically modelled using a Poisson probability distribution which only generates non-negative whole numbers (rather than a Normal distribution that is often assumed for measurements that can take any non-integer number). However, the number of GiB and failure events was found to have larger year-to-year deviations about the trend line than would be expected from a Poisson distribution, hence we used Quasi-Poisson regression, which allows for larger deviations about the trend line.

In the figures presented in this section, a solid line represents the absolute number of events recorded by the networks and a dashed line represents the prediction based on the regression model. The shaded area represents the 95% confidence interval of the prediction of the regression model. A statistically-significant increase or decrease in a performance indicator is represented by an upward or downward arrow in the legend, respectively. If a trend is not statistically significant, it is represented by a horizontal arrow. A statistically-significant trend is defined as a trend for which the p-value is lower than 0.05. A p-value is the probability that the observed trend in the data (or a more extreme trend) could have occurred by chance alone if, in fact, there is no underlying systematic change in the system that generates the data. Hence if a p-value is below 0.05, there is less than 5% chance that the trend in the observed number of events could be due to chance alone.

2.4 Results

2.4.1 Iron mains population

Figure 1 presents the length of iron mains remaining by network, summed over all tiers. These lengths include all iron mains, regardless of proximity to a building. Figure 1 shows that Cadent has by far the largest network. The rate of decrease in the length of iron mains remaining is similar for all networks.

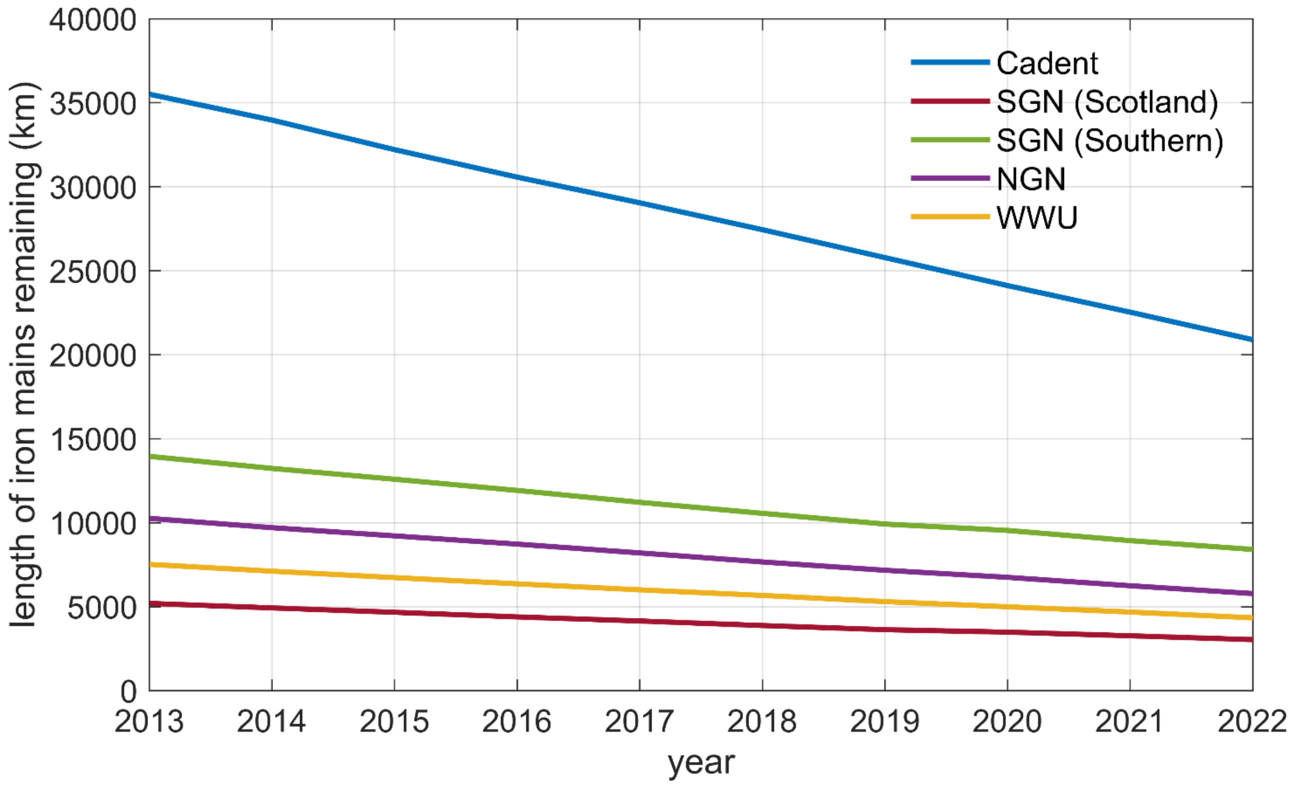

Figure 1 The length of iron mains remaining by network, summed over all tiers.

Figure 2 shows the length of iron mains remaining by tier, summed over all networks. These lengths include all iron mains, regardless of proximity to a building.

There has been a significant reduction in the length of Tier 1 iron mains since 2013, but the rate of decommissioning of Tier 2 and Tier 3 mains is much lower. Similar trends are observed for the individual networks.

These trends show the impact of the Iron Mains Enforcement Policy [2]. This requires all Tier 1 pipes within 30 metres of buildings to be decommissioned by 2032 but does not require the decommissioning of all Tier 2 and Tier 3 pipes within 30 metres of buildings. Consequently, decommissioning work in the GD1 and GD2 periods has focused on Tier 1 mains.

Regression analysis of the data shows that the overall population of iron mains (summed over all networks and all tiers) has decreased by an average of 5.7% each year between 2013 and 2023.

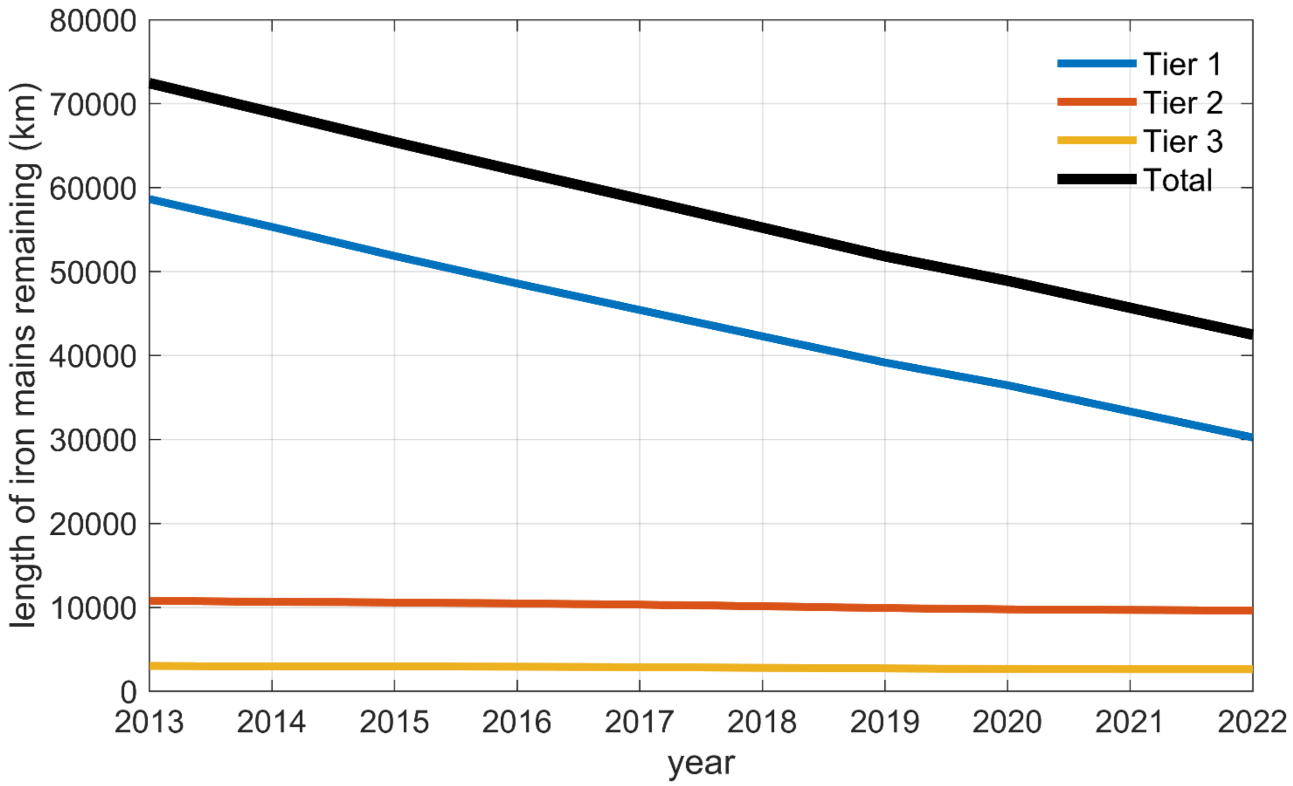

Figure 2 The length of iron mains remaining by tier, summed over all networks.

2.4.2 Fracture and corrosion events

Figure 3 shows the number of fracture and corrosion events associated with Tier 1 pipes in each year from April 2013 to March 2023. As indicated in Figure 1, Cadent has the largest network, so it is to be expected that it also has the largest number of fracture and corrosion events.

The data summed over all networks show a statistically significant decrease in the number of fraction and corrosion events with time. This is to be expected, as the population of Tier 1 iron mains has almost halved over the time period of interest (excluding the WWU network, there were 52,559 km of Tier 1 mains remaining in March 2014, which had decreased to 27,056 km by March 2023). From these data alone, we cannot determine whether the decrease in fraction and corrosion events is simply a function of the decrease in the Tier 1 population, or whether the targeting of higher-risk pipes for decommissioning has also contributed to the decrease.

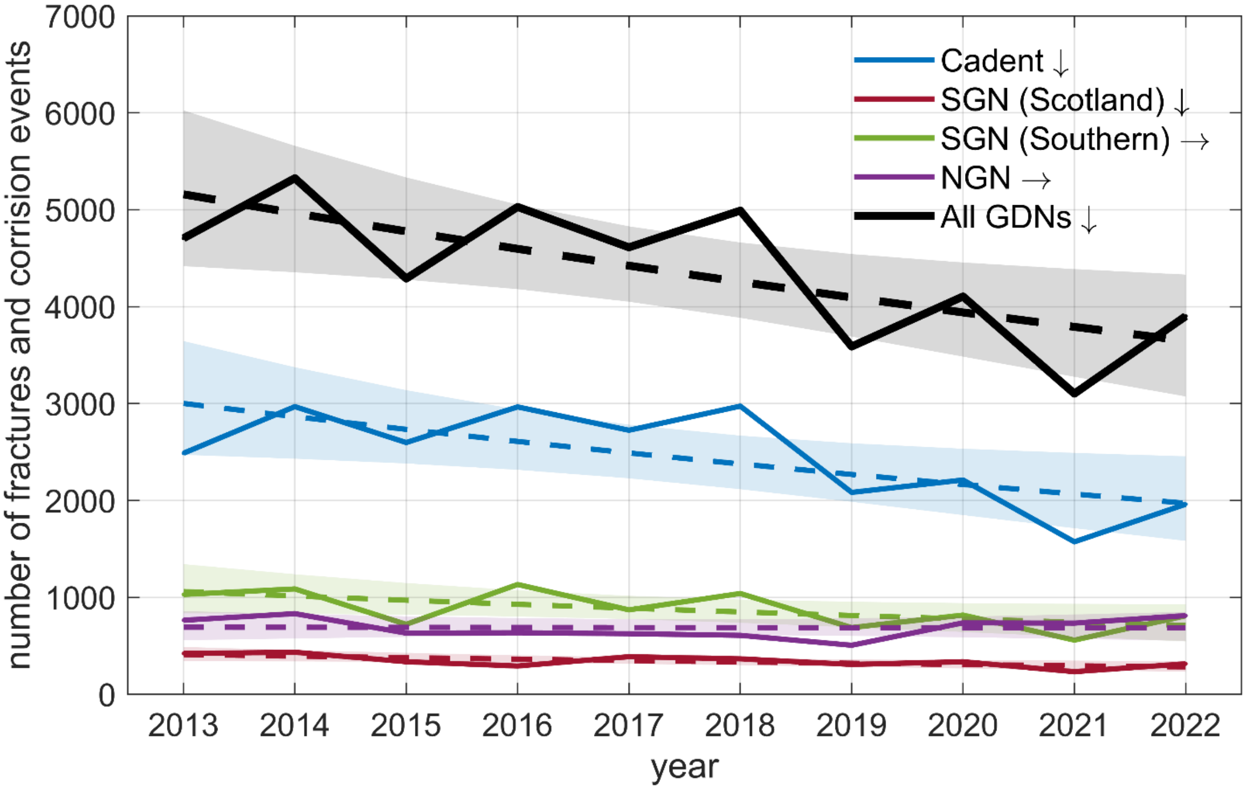

Figure 3 The number of fracture and corrosion events associated with Tier 1 pipes, showing the Quasi-Poisson regression analysis.

The number of fracture and corrosion events associated with Tier 2 pipes in each year from April 2013 to March 2023 is presented in Figure 4. When the data are summed over all networks, there appears to be a slight increase in the number of fracture and corrosion events with time, but this is not statistically significant. The population of Tier 2 iron mains did not change appreciably over the ten-year period (excluding the WWU network, there were 9507 km of Tier 2 mains remaining in March 2014, which had decreased to 8613 km by March 2023), so we would not expect to see as large a decrease in the number of fracture and corrosion events as was seen for Tier 1 mains.

The equivalent data for Tier 3 mains are shown in the appendices in Section 12. The Tier 3 data show no statistically significant trends.

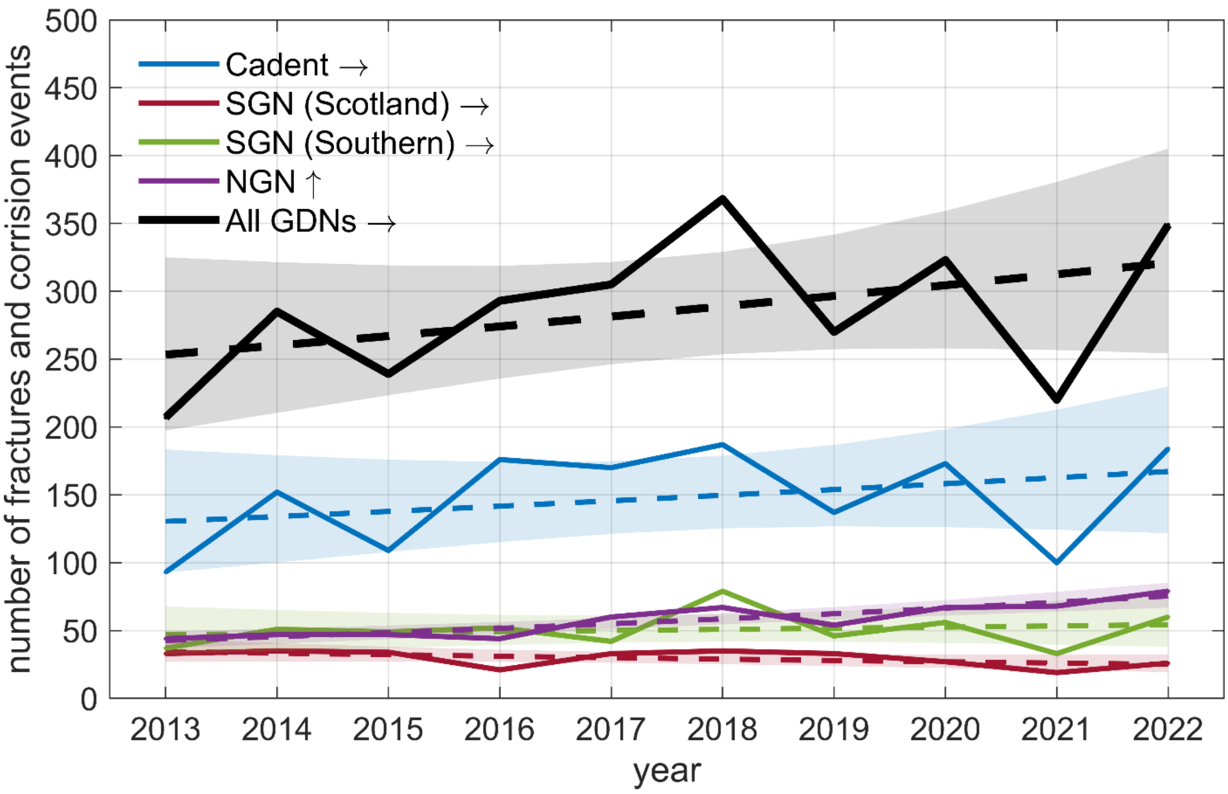

Figure 4 The number of fracture and corrosion events associated with Tier 2 pipes, showing the Quasi-Poisson regression analysis.

2.4.3 Fracture and corrosion events per kilometre

There are several factors that may influence trends in the number of fracture and corrosion events. These include changes in the iron mains population, network deterioration and efficient targeting of higher-risk pipes. To distinguish the impact of changes in the iron mains population from the impact of the other factors, the number of fracture and corrosion events for each year has been divided by the length of iron mains remaining in that year, to give the number of fracture and corrosion events per kilometre.

The number of fracture and corrosion events per kilometre associated with Tier 1 pipes is shown in Figure 5 for the individual GDNs. No network shows a decrease in the number of fracture and corrosion events per kilometre with time, and for NGN, there is a statistically significant increase in the number of fracture and corrosion events per kilometre. The Tier 1 data summed over all networks are shown in Figure 6 and show a statistically significant increase with time.

The number of fracture and corrosion events per kilometre associated with Tier 2 pipes is shown in Figure 7 for the individual GDNs. As for Tier 1, no network shows a statistically significant decrease in this measure, and for NGN, there is a statistically significant increase. The Tier 2 data summed over all networks are shown in Figure 8 and show no statistically significant trend.

The equivalent data for Tier 3 mains are shown in the appendices in Section 12. The Tier 3 data show no statistically significant trends.

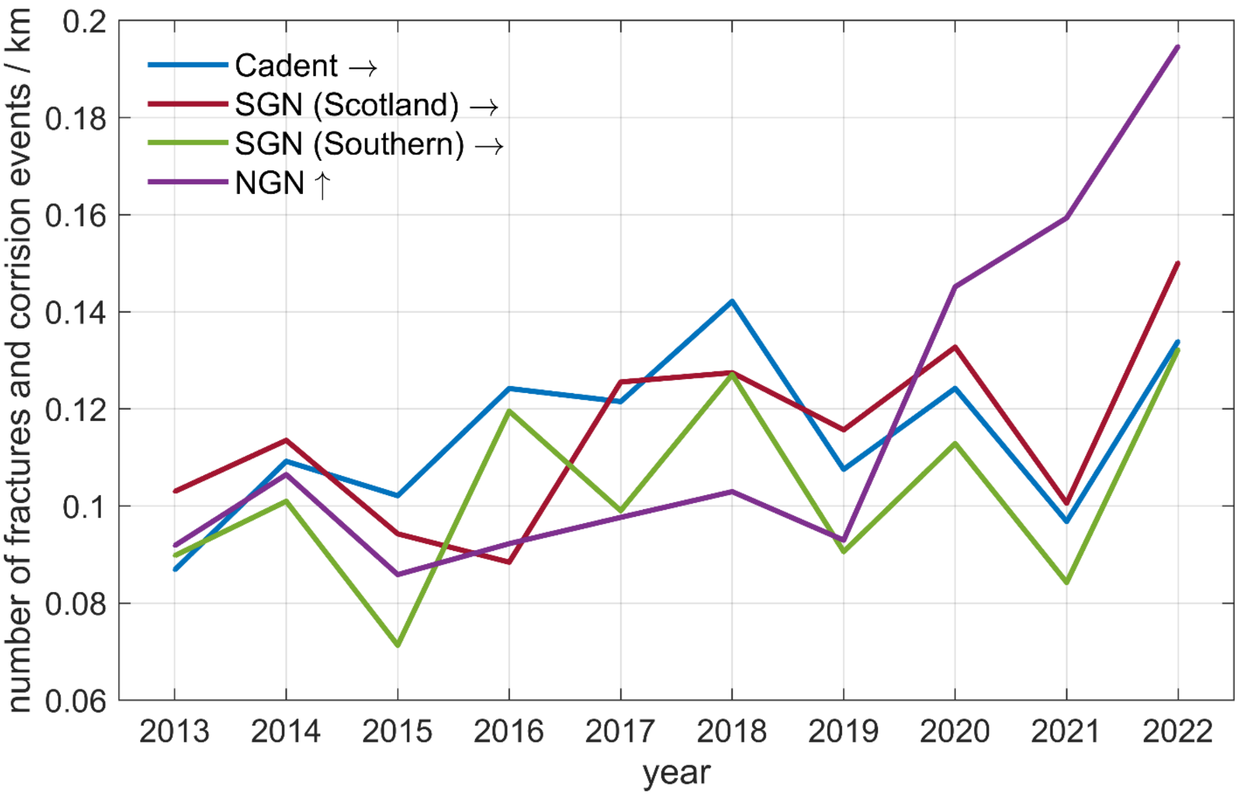

Figure 5 The number of fracture and corrosion events per km associated with Tier 1 pipes, for individual GDNs.

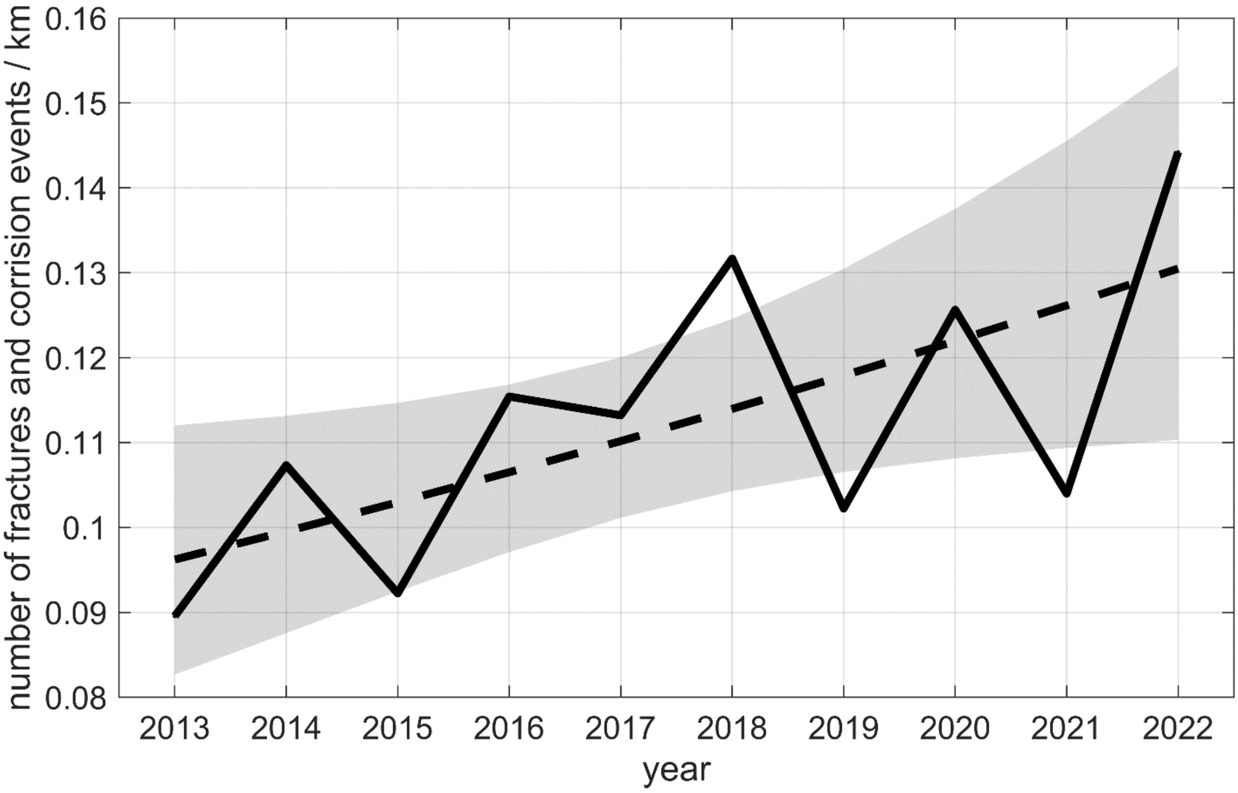

Figure 6 Quasi-Poisson regression of the number of fracture and corrosion events per km associated with Tier 1 pipes, summed over all GDNs. The data show a statistically significant increase with time.

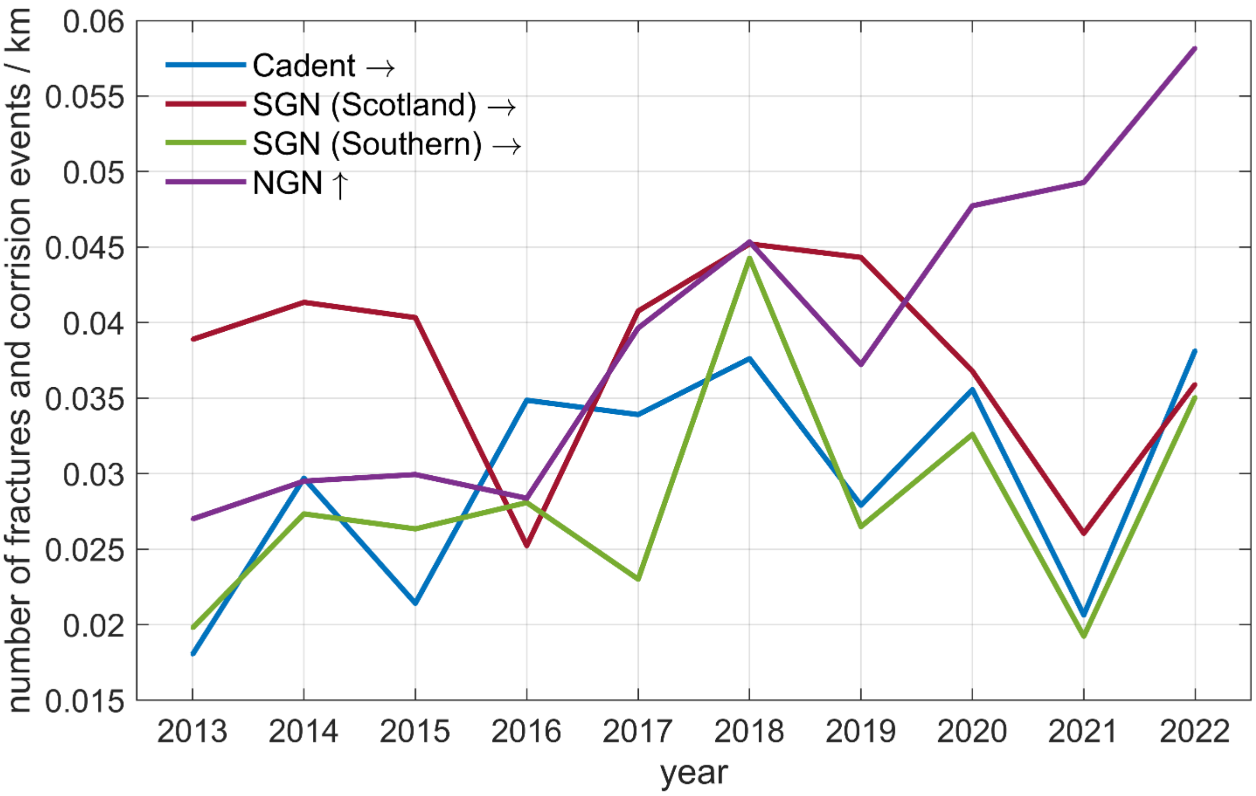

Figure 7 The number of fracture and corrosion events per km associated with Tier 2 pipes, for individual GDNs.

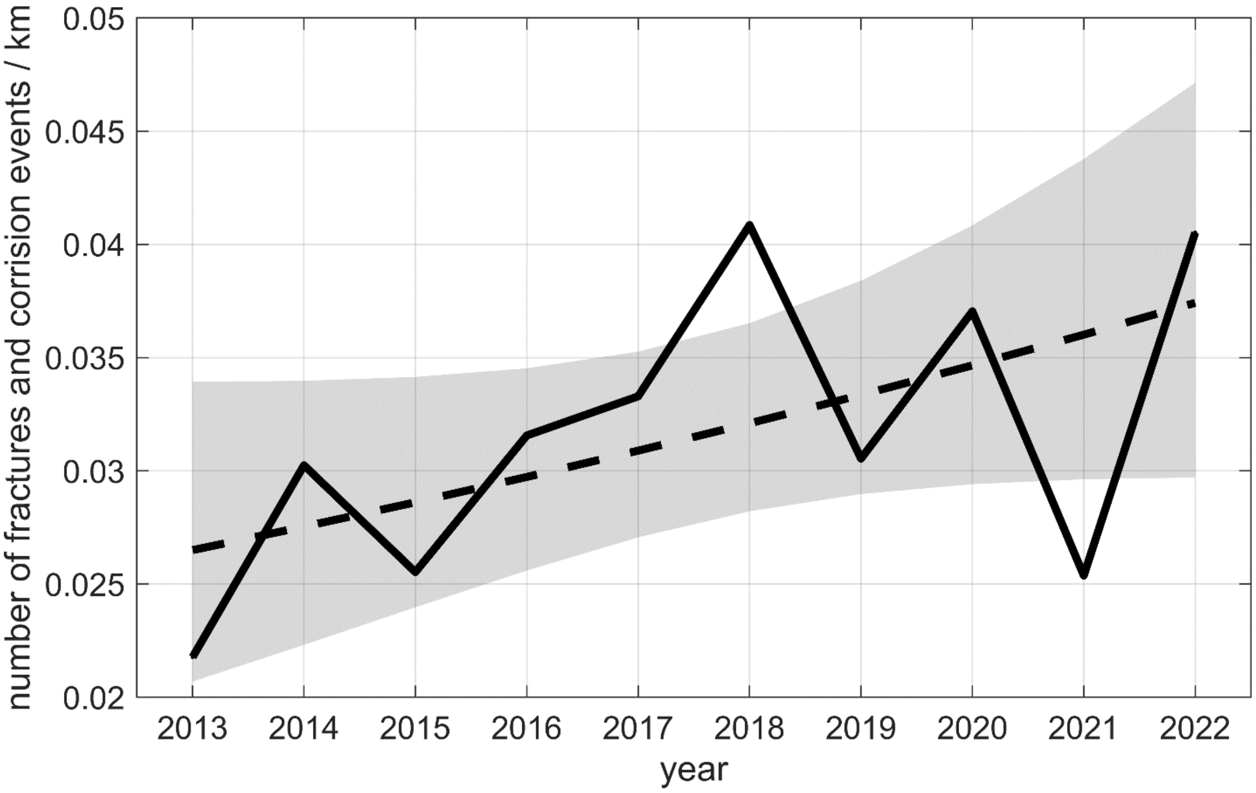

Figure 8 Quasi-Poisson regression of the number of fracture and corrosion events per km associated with Tier 2 pipes, summed over all GDNs. The data do not show a statistically significant trend.

A statistically significant decrease in the number of fracture and corrosion events per km is not seen for any tiers or any networks. This may indicate that the pipes that pose the highest risk of failure have not been effectively targeted, or it could be a sign that the risk reduction programme is not keeping pace with the rate of deterioration of the network. It is possible that both these factors play a role.

2.4.4 Gas in Building events

Figure 9 shows the number of Gas in Building events associated with Tier 1 pipes in each year from April 2013 to March 2023. Cadent, with the largest network, reported the largest number of GiB events. The data appear to show a decrease in the number of Tier 1 GiB events with time, but this decrease is only statistically significant for the SGN (Southern) and NGN networks.

The number of Gas in Building events associated with Tier 2 pipes in each year from April 2013 to March 2023 is presented in Figure 10. Lower numbers of GiB events are seen for Tier 2 than for Tier 1, due to the lower population of Tier 2 iron mains. When the data are summed over all networks, there appears to be a slight increase in the number of Tier 2 GiB events with time, but this is not statistically significant.

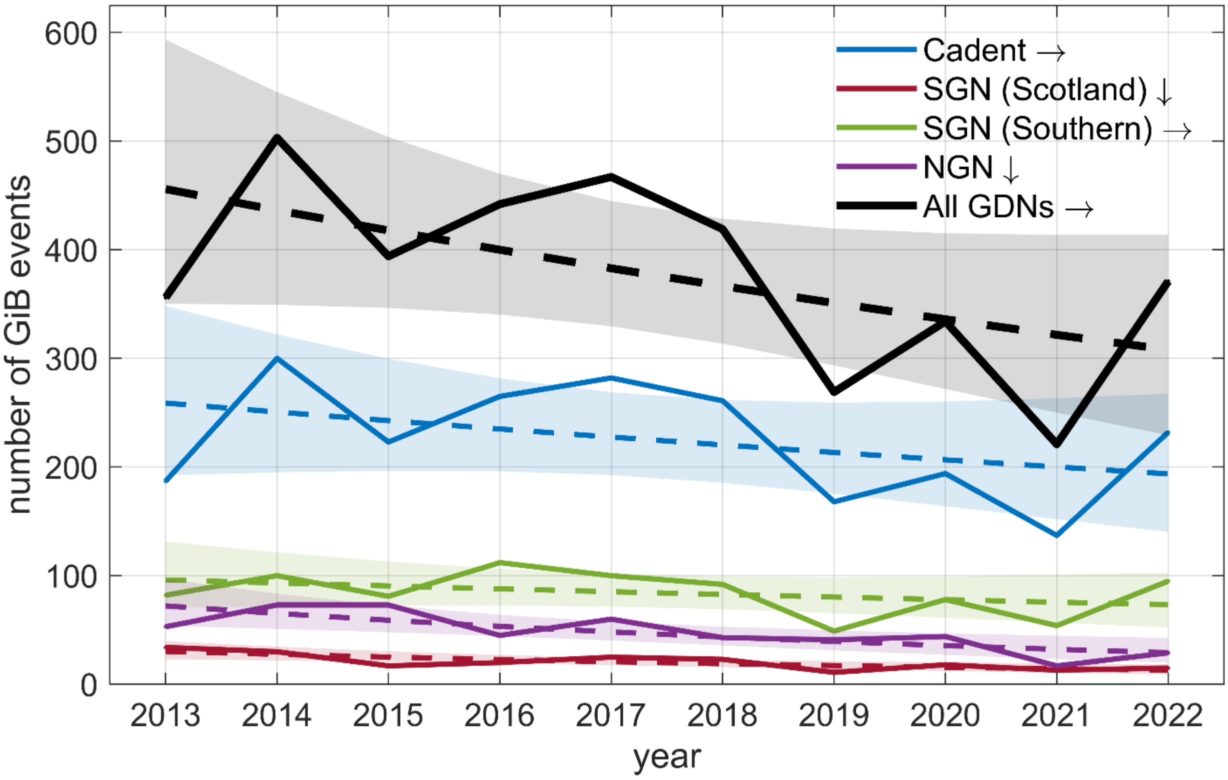

Figure 9 Gas in Building events associated with Tier 1 pipes, showing the Quasi-Poisson regression analysis.

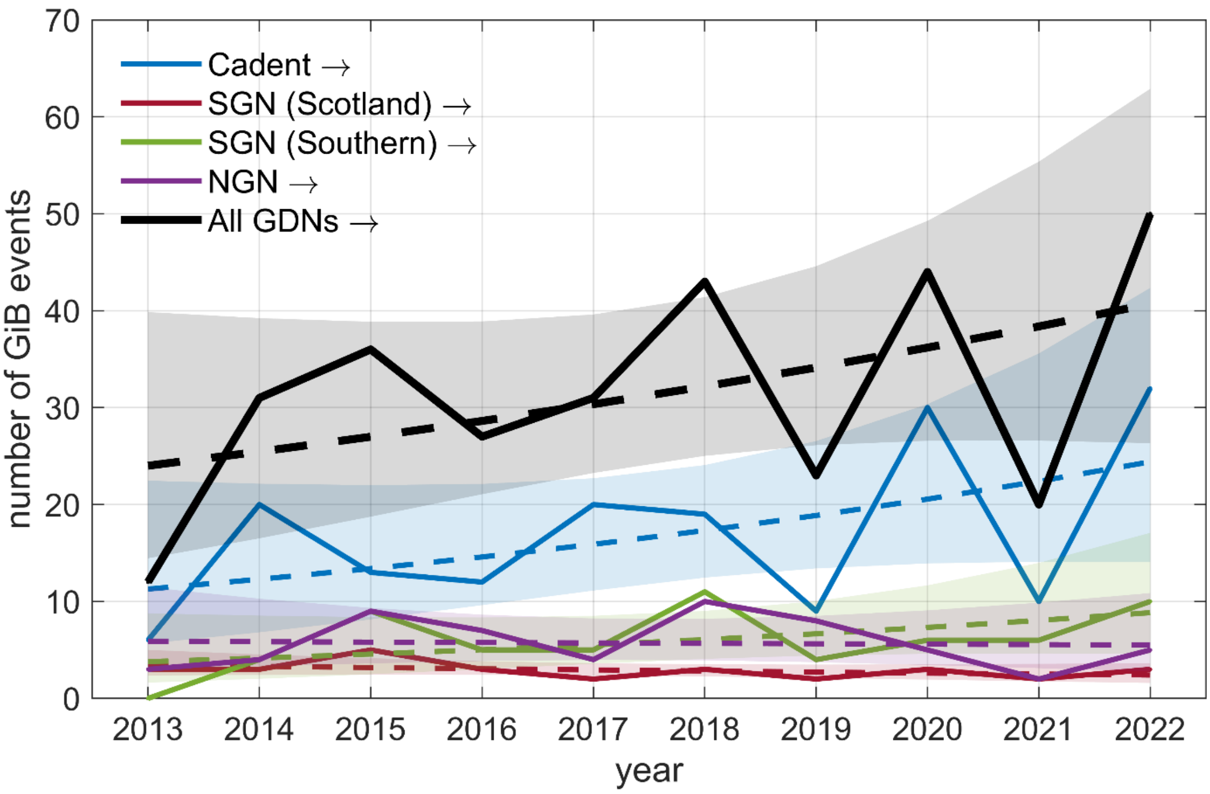

Figure 10 Gas in Building events associated with Tier 2 pipes, showing the Quasi-Poisson regression analysis.

Too few GiB events were recorded for Tier 3 pipes for any meaningful analysis to be undertaken, but the data are shown in the appendices in Section 12 for completeness.

2.4.5 Gas in Building events per kilometre

The number of Gas in Building events per kilometre associated with Tier 1 pipes is shown in Figure 11 for the individual GDNs and in Figure 12 summed over all networks. No network shows a statistically significant trend in the number of GiB events per kilometre with time. The data summed over all networks appear to show a slight increase in this measure with time, but this is not statistically significant. The data reported by Cadent and SGN (Southern) show similar fluctuations, but we have not been able to identify an external factor (such as weather conditions) that would explain this.

The number of Gas in Building events per kilometre associated with Tier 2 pipes is shown in Figure 13 for the individual GDNs and in Figure 14 summed over all networks. As for Tier 1, the data summed over all networks appear to show a slight increase in this measure with time, but this is not statistically significant.

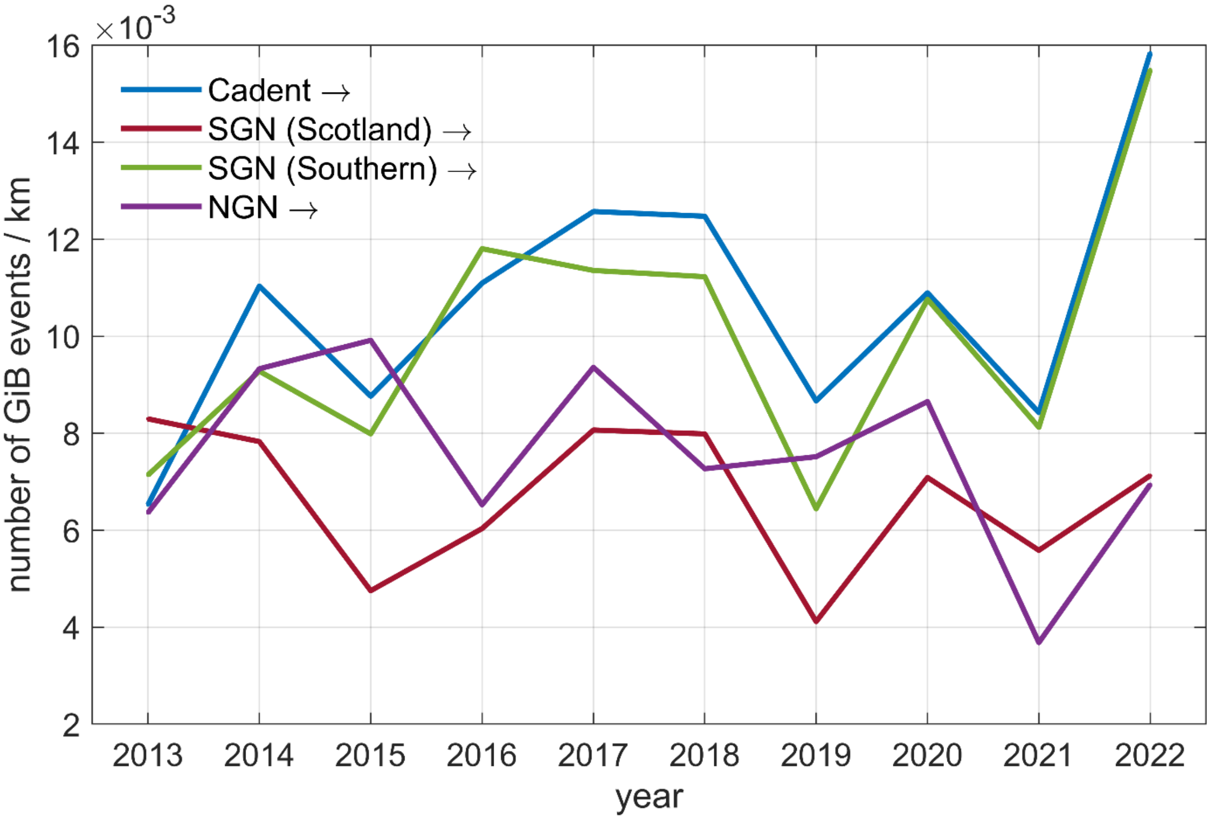

Figure 11 The number of Gas in Building events per km associated with Tier 1 pipes, for individual GDNs.

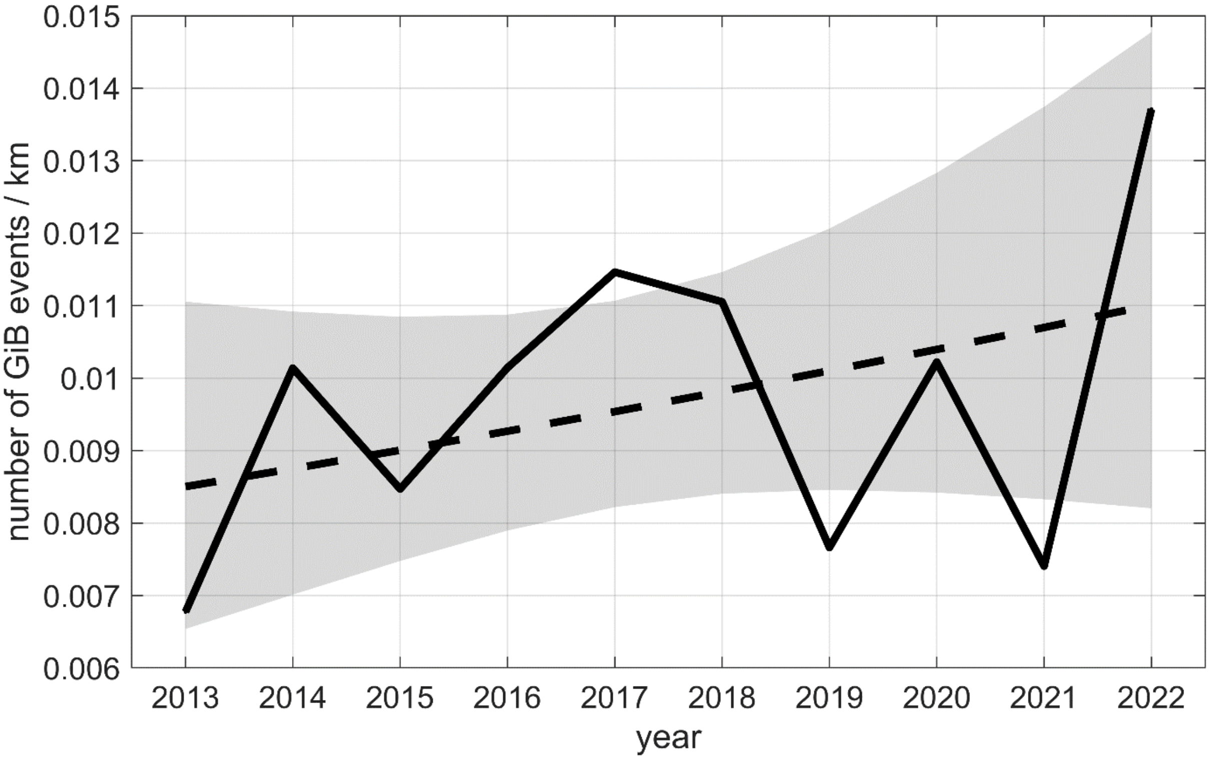

Figure 12 Quasi-Poisson regression of the number of Gas in Building events per km associated with Tier 1 pipes, summed over all GDNs. The data do not show a statistically significant trend.

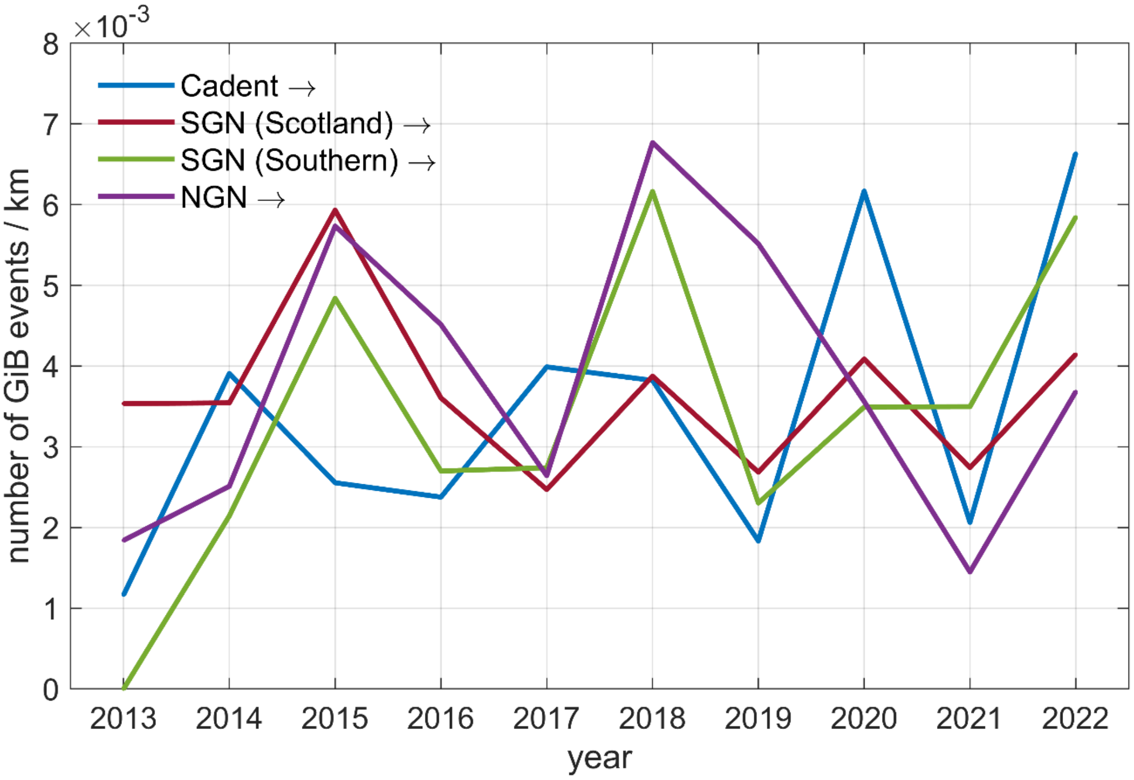

Figure 13 The number of Gas in Building events per km associated with Tier 2 pipes, for individual GDNs.

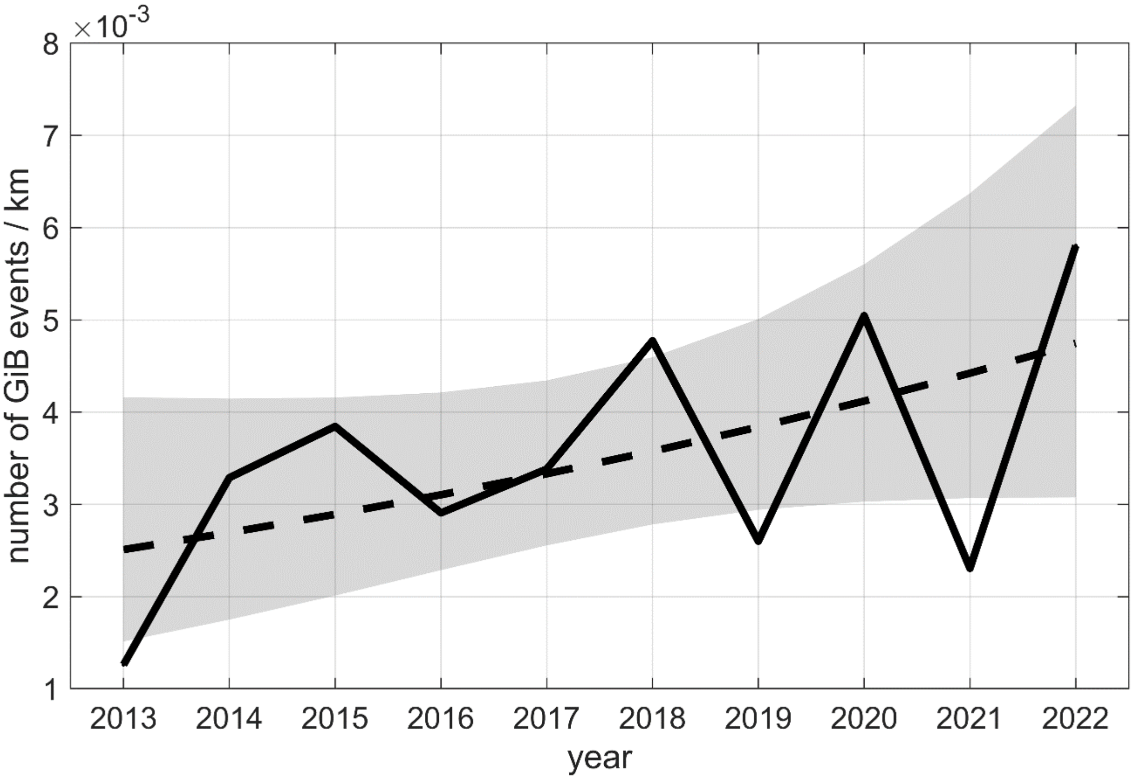

Figure 14 Quasi-Poisson regression of the number of Gas in Building events per km associated with Tier 2 pipes, summed over all GDNs. The data do not show a statistically significant trend.

2.5 Discussion

The length of Tier 1 iron mains remaining in the network almost halved in the ten years from 2013. Over this period, the reported number of Tier 1 fracture and corrosion events also decreased. However, the number of Tier 1 fracture and corrosion events per km of remaining iron mains increased. This may indicate that the pipes that pose the highest risk of failure have not been effectively targeted, or it could be a sign that the risk reduction programme is not keeping pace with the rate of deterioration of the network. It is also possible that both these factors play a role.

Far fewer Tier 2 iron mains have been decommissioned since 2013 (the length of Tier 2 iron mains only decreased by 10% in the ten years from 2013) and there has been little change in the number of Tier 2 fracture and corrosion events reported each year over this time period. There has not been a statistically significant change in the number of fracture and corrosion events per km associated with Tier 2 pipes.

The reported number of Gas in Building events per km of remaining iron mains appears to show a slight increase for both Tier 1 and Tier 2 mains, but these trends are not statistically significant. The fact that the number of Gas in Buildings events per km has not decreased is a further indication that the highest-risk pipes have not been effectively targeted or that the condition of the network is deteriorating.

3 Pipe prioritisation using a risk-based approach

The Iron Mains Enforcement Policy [2] requires the Gas Distribution Network operators (GDNs) to prioritise iron mains decommissioning based on risk.

The GDNs use the MRPS (Mains Replacement Prioritisation Scheme) risk model to inform this prioritisation [3-5]. This model was developed for the networks by DNV at the start of the iron mains decommissioning programme and is used to assign a risk score to all ‘at risk’ iron pipes, where ‘at risk’ pipes are defined as those within 30 metres of a building.

The risk score gives the probability of an explosion incident per km per year for each pipe.

For an explosion incident to occur, gas must escape from a pipe, enter a property and find an ignition source. The MRPS therefore calculates:

- the likelihood of failure by fracture or corrosion or joint leak,
- the likelihood of gas ingress and
- the likelihood of ignition.

These likelihoods are combined to calculate a risk score. The factors considered in the MRPS are shown in Figure 15 below, which has been reproduced from a document provided by DNV [3].

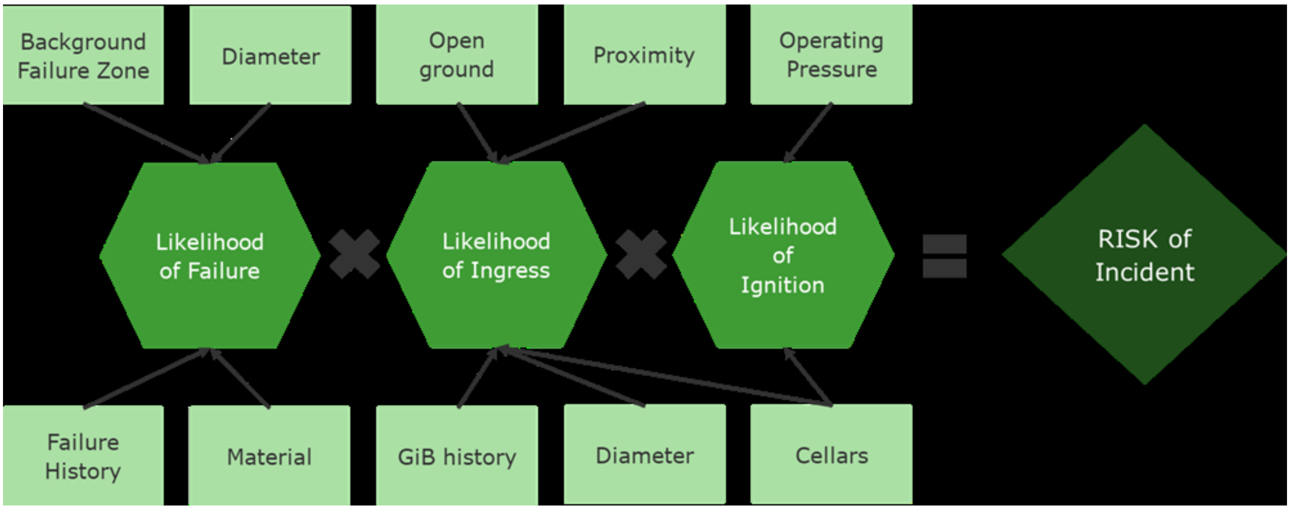

Figure 15 Schematic of the Mains Replacement Prioritisation Scheme (MRPS) risk model, reproduced from [3].

3.1 The Mains Replacement Prioritisation Scheme (MRPS) model

The MRPS has separate models for cast and spun iron, ductile iron and steel [3-5]. For cast iron, fractures have historically been the primary cause of Gas in Building (GiB) events, so are the only failure mode currently included in the cast and spun iron model. In the ductile iron model, the primary failure modes are corrosion and joint leakage. In the steel model, it is assumed that pipes will fail by corrosion.

The risk score for each pipe is dependent on the number of previous failures and GiB events that have occurred on the pipe. For pipes which have not previously suffered a GiB event, scaling factors are used in place of historical failure data. These scaling factors depend on the pipe material and surroundings.

For cast iron and spun iron mains with no previous GiB occurrences, the MRPS risk score is calculated by multiplying factors as follows:

$$\text{Risk score} = \text{MFF} \cdot \text{GIF} \cdot \text{GHF} \cdot \text{CF}$$

where MFF is the Mains Fracture Factor, GIF is the Gas Ingress Factor, GHF is the Gas History Factor and CF is the Consequence Factor. For cast iron and spun iron mains that have previously sustained any failures (except those caused by interference damage) that have resulted in GiB events, the following equation is used:

$$\text{Risk score} = \text{MFF} \cdot \text{GTF} \cdot \text{CF}$$

where GTF is the Gas Tracking Factor. For ductile iron mains with no previous GiB occurrences, the MRPS risk score is calculated as follows:

$$\text{Risk score} = \text{MCJF} \cdot \text{GIF} \cdot \text{GHF} \cdot \text{CF}$$

where MCJF is the Mains Corrosion Joint Factor. For ductile iron mains that have previously had any failures (except those caused by interference damage) that have resulted in GiB events, the following equation is used:

$$\text{Risk score} = \text{MCJF} \cdot \text{GTF} \cdot \text{CF}$$

For steel mains with no previous GiB occurrences, the MRPS risk score is calculated as follows:

$$\text{Risk score} = \text{MCF} \cdot \text{GIF} \cdot \text{GHF} \cdot \text{CF}$$

where MCF is the Mains Corrosion Factor. For steel mains that have previously had failures (except those caused by interference damage) that have resulted in GiB events, the following equation is used:

$$\text{Risk score} = \text{MCF} \cdot \text{GTF} \cdot \text{CF}$$

Referring back to Figure 15, the likelihood of failure is calculated as the Mains Fracture Factor, the Mains Corrosion Joint Factor or the Mains Corrosion Factor. The likelihood of ingress is calculated from the Gas Ingress Factor and the Gas History Factor for mains with no previous GiB occurrences, and from the Gas Tracking Factor for mains that have previously had a GiB occurrence. The likelihood of ignition is calculated from the Consequence Factor.

These terms are considered in more detail in the following sections.

3.1.1 Mains Corrosion Factor

The Mains Corrosion Factor is the number of corrosion leaks per km per year and is applicable to the models for ductile iron and steel only. It is dependent on the following parameters [3]:

- **The Corrosion History coefficient**, whose value is based on the number of previous corrosion failures of the specific pipe for which a risk score is being calculated. The pipe is assigned to one of three Corrosion History categories (corresponding to no previous barrel corrosions, one previous barrel corrosion and more than one previous barrel corrosion). Each category is associated with a different Corrosion History coefficient.
- **The Background Corrosion Zone coefficient**, whose value is based on the number of corrosion failures sustained by other pipes within 50 m. The pipe is assigned to one of four Background Corrosion Zone categories (Low 1, Low 2, Medium or High). Each category is associated with a different Background Corrosion Zone coefficient.

The Mains Corrosion Factor may also be dependent on the age of the pipe, depending on the number of mains in each Corrosion History and Background Corrosion Zone category when a coefficient update is undertaken; the pipe age is used as a further differentiator when the majority of mains are in a single category [3].

Values for the Corrosion History coefficient and Background Corrosion Zone coefficient are based on historical data on pipe failures that are compiled by the GDNs. They do not depend on soil corrosivity or other factors that could promote pipe corrosion. However, the impact of soil moisture and pH on corrosion may be implicitly included in the Background Corrosion Zone coefficient.

3.1.2 Mains Corrosion Joint Factor

The Mains Corrosion Joint Factor is the number of corrosion and joint leaks per km per year and comprises the Mains Corrosion Factor, as described above, combined with the Mains Joint Factor and a weighting factor. It is applicable to the model for ductile iron only. The Mains Joint Factor is dependent on the following parameters [3]:

- **The Joint History coefficient**, whose value is based on the number of previous joint failures of the specific pipe for which a risk score is being calculated. The pipe is assigned to one of three Joint History categories (corresponding to no previous

joint failures, one previous joint failure and more than one previous joint failure). Each category is associated with a different Joint History coefficient.
- **The Background Joint Zone coefficient**, whose value is based on the number of joint failures sustained by other pipes within 50 m. The pipe is assigned to one of three Background Joint Zone categories (Low, Medium or High). Each category is associated with a different Background Joint Zone coefficient.

The Mains Joint Factor may also be dependent on the age of the pipe, depending on the number of mains in each Joint History and Background Joint Zone category when a coefficient update is undertaken; the pipe age is used as a further differentiator when the majority of mains are in a single category [3].

Values for the Joint History coefficient and Background Joint Zone coefficient are based on historical data on pipe failures that are compiled by the GDNs.

3.1.3 Mains Fracture Factor

The Mains Fracture Factor is the number of fractures per km per year and is applicable to the models for cast iron and spun iron only. It is dependent on the following parameters [3]:

- **The Breakage History coefficient**, whose value is based on the number of previous breakages per km per year sustained by the specific pipe for which a risk score is being calculated in the previous 10 years. The pipe is assigned to one of four Breakage History categories (corresponding to no previous breakages, ≤ 2 breakages per km per year, 2 to 4 breakages per km per year and > 4 breakages per km per year). Each category is associated with a different Breakage History coefficient.
- **The Background Breakage Zone coefficient**, whose value is based on the number of fracture failures sustained by other pipes within 50 m. The pipe is assigned to one of five Background Breakage Zone categories (Low 1, Low 2, Low 3, Medium or High). Each category is associated with a different Background Breakage Zone coefficient.
- **The Diameter Band**, which is dependent on the pipe diameter in inches.

Values for the Breakage History coefficient and Background Breakage Zone coefficient are based on historical data on pipe failures that are compiled by the GDNs. The role of traffic loading and local ground subsistence in promoting fractures may be implicitly included in the Background Breakage Zone coefficient.

3.1.4 Gas Ingress Factor

The Gas Ingress Factor is used to predict the likelihood that a leak from a main will lead to gas ingress at a nearby dwelling, for mains where gas ingress has not previously occurred. It has units of GiBs/leak.

For cast and spun iron, the Gas Ingress Factor is dependent on the following parameters [4]:

- The nominal diameter of the main.
- The percentage of the main length with proximity to a dwelling ≤ 5 m.
- The percentage of the main length with proximity to a dwelling between 5 m and 10 m.
- The percentage of the main length with proximity to a dwelling from 10 m to ≤ 30 m.

The parameters are given different weightings depending on whether the properties in the vicinity of the main have cellars and whether the ground between the main and the nearest property has been built on.

The Gas Ingress Factor is dependent on the diameter of the main because a fracture on a larger diameter main has the potential to release a larger quantity of gas that a fracture on a smaller diameter main. There is therefore a greater likelihood that a release from the larger diameter main will enter a building.

For ductile iron and steel, the Gas Ingress Factor is not dependent on the diameter of the main because most leaks from these types of pipes come from small corrosion holes or joints. The Gas Ingress Factor for ductile iron and steel is dependent on the following parameters [4]:

- The percentage of the mains length adjacent to a cellared property.
- The percentage of mains length with less than 2 metres of open ground (such as grass or soil) between the main and a nearby property.
- The percentage of the main length with proximity to a dwelling ≤ 5 m.
- The percentage of the main length with proximity to a dwelling between 5 m and 10 m.
- The percentage of the main length with proximity to a dwelling from 10 m to ≤ 30 m.

Values for these parameters are obtained from survey data.

3.1.5 Gas History Factor

The Gas History Factor is a scaling factor for pipes with no previous history of Gas in Building events [4]. It is based on historical data showing how likely it is that a leak on a pipe with no previous GiB occurrences will cause a GiB event. Its value is dependent on the pipe material. In the most recent coefficient update, the Gas History Factor has a larger value for cast and spun iron than for ductile iron.

3.1.6 Gas Tracking Factor

The Gas Tracking Factor is used to predict the likelihood of a GiB event occurring, based on the number of GiB events that have previously occurred on the pipe [4]. GiB events caused by third party damage are excluded from the analysis. Previous GiB events indicate the presence of tracking routes, which increases the likelihood of future GiB events occurring. The Gas Tracking Factor is not dependent on the pipe material or the failure mode, as these factors will not play a role in determining whether a tracking route is present.

3.1.7 Consequence Factor

The Consequence Factor is the number of incidents per Gas in Building occurrence [5]. It is the same for the Cast Iron, Ductile Iron and Steel Risk Models. The Consequence Factor is dependent on the average number of incidents per GiB event, which is derived from historical data from the previous 10 years for cast and spun iron fractures only. It is also dependent on the pressure of the main and the percentage of the mains length that has cellars in close proximity. The percentage of the mains length that has cellars in close proximity is obtained from survey data.

3.1.8 Summary

The input data required by the MRPS can be split into two categories: historical data and properties of the pipe and its surroundings. The model uses the following historical data:

- Number of previous corrosion failures on the pipe for which a risk score is being calculated.
- Number of corrosion failures in the past five years on other pipes within 50 m.
- Number of previous joint failures on the pipe for which a risk score is being calculated.
- Number of joint failures in the past five years on other pipes within 50 m.
- Number of previous breakages (i.e. fractures) on the pipe for which a risk score is being calculated.
- Number of breakages in the past five years on other pipes within 50 m.
- Number of GiB (Gas in Buildings) events that have already occurred on the pipe for which a risk score is being calculated (excluding interference damage).

The model requires the following properties of the pipe and its surroundings:

- Pipe material (different submodels are used for different materials; the scaling factors used for pipes that have not previously experienced a GiB event depend on the material of pipe).
- Age of main (in cases where there have been no previous corrosion or joint failures).
- Pipe diameter.
- Proximity of buildings.

- Percentage of the main length with less than 2 metres of open ground between the main and a nearby property. (Open ground is ground that has not been built on, such as grass. A pavement would not count as open ground.)
- Proportion of adjacent buildings that have cellars.
- Mains pressure (low or medium).

The proximity of buildings, the amount of open ground and the presence of buildings with cellars are recorded during dedicated MRPS surveys of the network. Cadent undertakes these surveys every five years for cast iron and ductile iron in a rolling programme [14].

3.2 Prioritisation of pipes for decommissioning in GD2 using the outputs of the MRPS

3.2.1 Tier 1

The 2013 to 2021 HSE Enforcement Policy for the iron mains risk reduction programme (covering the Ofgem RIIO-GD1 price-control period) [15] included the following requirement:

‘Twenty percent of the Tier 1 set length of pipes to be decommissioned will be drawn from the highest risk pipes identified by the risk model. The remaining 80% of the set of pipes to be decommissioned will be drawn from any part of the remaining Tier 1 population.’

The 2021 to 2026 HSE Enforcement Policy (which covers the Ofgem GD2 price-control period) [2] removed this requirement, instead stating:

‘The approach for Tier 1 pipes shall prioritise the efficient decommissioning of pipes with a higher risk throughout the period of their Approved Programme. Gas Distribution Networks (GDN) operators are expected to make effective use of the risk models available to them and to make improvements where appropriate.’

The change to the Enforcement Policy was motivated by the fact that the range of risk scores predicted by the MRPS has reduced over the course of the IMRRP, as pipes with higher risk scores have been decommissioned. Assigning 20% of pipes as mandatory for decommissioning, based on small differences in MRPS risk scores, may not be the most efficient way of reducing the overall risk posed by the iron mains network.

Therefore, although HSE’s current Enforcement Policy for the IMRRP requires the GDNs to use a risk-based approach to prioritise iron pipes for decommissioning, it allows the GDNs some flexibility in how this is implemented.

All the GDNs use the risk scores output by the MRPS to inform their Tier 1 decommissioning programmes, but there are some differences in their chosen approaches. The approaches adopted by the GDNs are summarised in the following sections.

NGN and WWU

NGN [11] and WWU [13] still follow the 20:80 model required by the 2013 to 2021 HSE Enforcement Policy [15], in which twenty percent of the length of Tier 1 pipe to be decommissioned is drawn from the highest risk pipes identified by the MRPS risk model.

At the start of the current enforcement policy (2021), WWU ranked all remaining Tier 1 pipes top down by MRPS risk score, having removed all pipe lengths below 3 m. A mandatory pipe risk threshold was set by moving down the list until a pipe length totalling 20% of the five-year (2021-2026) workload was reached [13]. The MRPS risk score of the pipe at this point on the list was set as the mandatory pipe risk threshold. The approach adopted by WWU requires all pipes with a risk score at or above the mandatory pipe risk threshold to be decommissioned within the five-year period.

The remaining 80% of the pipe length for decommissioning was selected from pipes with risk scores below the mandatory pipe risk threshold, based on criteria such as geography and leakage and maintenance history [13].

SGN

At the start of the GD2 period (2021), SGN set a Risk Action Threshold for Tier 1 that was based on the risk score of the lowest scoring mandatory pipe from the GD1 period (2013-2021) [12]. The approach adopted by SGN requires all pipes scoring above the Risk Action Threshold to be decommissioned during the GD2 period. SGN uses external risk factors in conjunction with the MRPS model output to select the remaining pipe length for decommissioning from pipes with scores below the Risk Action Threshold.

Cadent

Cadent has adopted a more complex approach than the other GDNs. The risk score output by the MRPS is converted into the risk of fatality for an individual for a specific pipe [10]. In its analysis, Cadent assumes that an individual risk of fatality of less than one in a million per annum is broadly acceptable, and uses this as the pipe-specific individual risk threshold. This threshold is consistent with HSE guidance [16] and was set following discussions involving HSE, Ofgem and all GDNs.

The MRPS risk score gives the probability of an explosion incident per km per year for a specific pipe. Cadent uses the property density and a fatality factor to convert this to the individual risk of fatality [10].

A value for the property density in the vicinity of the pipe is obtained from MRPS survey data. In Cadent’s methodology, the higher the property density, the lower the individual risk. This is because only one building is assumed to be affected by the incident, so the chance of being in the particular building in which the incident occurs decreases as the number of properties in the vicinity increases.

The fatality factor is calculated from the average number of fatalities in an incident and the average number of people in a household. Between the start of 1990 and the end of 2010, there were 86 incidents relating to distribution gas pipes, resulting in 21 fatalities [17]. This gives an average number of deaths per incident of about 0.25. However, Cadent assumes a cautious value of 0.45 in its analysis [10], based on advice from the Industrial Statistics Research Unit at Newcastle University (ISRU) [17].

Cadent converts the number of fatalities per incident into the number of fatalities per person per incident by dividing by the average number of people per household in the UK (assumed to be 2.38 [10] based on Office of National Statistics data on household size from 2018). The resulting fatality factor of 0.19 fatalities per person per incident is used, together with the property density, to convert the MRPS risk score into the individual risk of fatality.

As noted above, in areas with high property densities, Cadent's methodology predicts that the individual risk of fatality will be low, even if the MRPS predicts a high incident risk. Cadent therefore also considers societal risk in its analysis. Societal risk is a measure of the total risk to a population based on the incident frequency and the total number of people affected. Assuming 0.45 fatalities per incident, Cadent calculates the MRPS risk score that corresponds to the acceptable risk level for societal risk, as defined by the BSI (British Standards Institution) [18]. This is set as the societal risk threshold [10]. It is not dependent on the property density so applies to all pipes in the network.

Cadent defines pipes with risk scores that exceed either the pipe-specific individual risk threshold or the societal risk threshold as PAST (Pipes Above Safety Threshold) pipes [10]. All PAST pipes are prioritised for decommissioning. The remaining required volume of work is made up of Tier 1 pipes below the risk thresholds.

Cadent also considers other risk factors qualitatively, to allow pipe-specific factors to be accounted for in the risk assessment process. These factors include [10]:

- Whether the pipe has previously caused an incident or 'near-miss'.
- Whether the pipe has previously caused a RIDDOR (The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013) GiB. A RIDDOR GiB is a GiB event that results in evacuation and has an atmosphere closer to ignition than a typical GiB event. The MRPS does not distinguish between RIDDOR GiBs and typical GiB events.
- The overall condition of the pipe, as measured by the total number of gas escapes that have previously occurred on the pipe, irrespective of cause.
- The types of properties within 30 m of the pipe. Are the buildings in the vicinity of the pipe designed to withstand an explosion (such as steel-framed high-rise buildings) or are they vulnerable to explosion damage?
- The nature of the population exposed to risk. Is the local population vulnerable and therefore more difficult to evacuate (e.g. hospital inpatients or care home

residents)? Are there any houses in multiple occupation with a higher population density than is typical for houses in Britain?

3.2.2 Tier 2

Under HSE's Enforcement Policy for the iron mains risk reduction programme 2021-2026 [2], Tier 2 pipes (pipes of diameter between 8" and 18") that have a risk score above a Risk Action Threshold set by the GDN operator will be selected to receive appropriate attention (either decommissioned or, where a suitable and sufficient technique exists, assessed for continued use if found to be in good condition or remediated to allow for lifetime extension). These pipes will also be subject to condition monitoring.

No action is required for Tier 2 pipes that have a risk score below the Risk Action Threshold [2], although pipes with a risk score below threshold may receive appropriate attention if a Cost Benefit Analysis is agreed with Ofgem.

NGN, SGN and WWU set the Tier 2 Risk Action Threshold to be the MRPS risk score that is equivalent to an individual risk of fatality of one in a million per annum (following the methodology used by Cadent for Tier 1, as described above) [10,13,19,20].

As for Tier 1, Cadent uses both an individual risk threshold and a societal risk threshold [10]. A pipe is considered to be above threshold if its risk score exceeds either threshold.

SGN and NGN use the property density averaged over each Local Distribution Zone (LDZ), so the same Tier 2 Risk Action Threshold is used for all pipes within an LDZ [19,20]. WWU and Cadent use pipe-specific property density information to calculate pipe-specific individual risk thresholds [10,13].

3.3 Review of the methodology used to prioritise Tier 2 pipes

Under the current HSE Enforcement Policy [2], no action is required for Tier 2 pipes that have a risk score below the Tier 2 Risk Action Threshold. It is therefore particularly important that the Tier 2 Risk Action Threshold has been calculated in an appropriate way. We have reviewed the methodology used to prioritise Tier 2 pipes for decommissioning or other appropriate attention and identified some concerns.

3.3.1 Absolute and relative risk

The methodology for setting the Tier 2 Risk Action Threshold uses the MRPS outputs as an *absolute* measure of risk. This is in contrast to the approaches used by NGN, SGN and WWU to prioritise Tier 1 pipes for decommissioning, in which the MRPS risk score is used as a measure of *relative* risk. That is, a Tier 1 pipe is chosen for decommissioning based on the size of its risk score relative to the risk scores for other Tier 1 pipes.

The MRPS was not originally designed to calculate the absolute risk and the 10-year review of the IMRP [1] raised concerns about using the MRPS risk scores in this way, stating that this bestows a level of accuracy on them which cannot be justified. This is particularly significant because our current review has raised concerns about the quality of data used to derive the MRPS coefficients (see Section 5.1.1 for further discussion on this topic).

Our review has also raised concerns that the approach used to calculate the MRPS risk scores is not as well suited to Tier 2 pipes as it is to Tier 1 pipes. For example, corrosion may play a more important role in failure mechanisms for larger pipes, but this is currently only considered for ductile iron, not cast or spun iron. DNV has informed us that corrosion will be considered for all pipe types in the next release of the MRPS (DNV communication, June 28, 2024).

3.3.2 The relationship between the MRPS risk score and the individual risk

The methodology used by the GDNs to prioritise Tier 2 pipes assumes that only one building is affected by an incident. As a result, the higher the property density, the lower the individual risk of fatality, as the chance of being in the building in which an incident occurs is reduced. The individual risk of fatality is therefore predicted to be lower in urban areas.

The methodology further divides the number of fatalities per incident by the average number of people per household, to give the number of fatalities per person per incident. This is equivalent to sharing the individual risk between all occupants of a building.

These assumptions are not consistent with the definition of individual risk used by HSE [16], which considers the risk of fatality to any individual in any building, rather than the risk of fatality to a particular individual in a particular building. The HSE definition can be thought of as the individual risk of fatality to a hypothetical person who could be present in any of the properties.

The risk calculation carried out by the GDNs does not take into account cumulative risk from multiple pipes. It is particularly important to consider cumulative risk in urban areas, where there may be many iron pipes in close proximity. The individual risk of fatality posed by a specific pipe may be below threshold, but when combined with the risk posed by other pipes in the vicinity, the cumulative risk may exceed the threshold.

3.3.3 Length of Tier 2 pipe with a risk score exceeding the Risk Action Threshold

In June 2020, the coefficients in the MRPS risk model were recalibrated, resulting in a significant reduction in the risk scores predicted by the model. The update was motivated by the fact that the model was overpredicting the number of incidents by a factor of approximately 10 (NGN communication, March 14, 2024). Most of the changes in the coefficients related to the Consequence Factor, which predicts the number of incidents per Gas in Building occurrence.

The Tier 2 Risk Action Thresholds have not (in general) decreased, as they are independent of the MRPS output and depend only on the property density and the number of inhabitants per property. The MRPS risk scores corresponding to the Tier 2 Risk Action Thresholds in GD1 and GD2 are shown in Table 1 for selected GDNs [12,19,20].

Table 1 Tier 2 Risk Action Thresholds in GD1 and GD2 for selected GDNs.

GDN	Tier 2 threshold in GD1 (2013 to 2021)	Tier 2 threshold in GD2 (2021 to 2026)
NGN	142.88	117.4
SGN(Scotland)	185	185
SGN (SE)	232	232
SGN (South)	232	232

We determined the length of Tier 2 pipe with an MRPS risk score exceeding the Tier 2 Risk Action Threshold from pipe specific MRPS risk score data sets provided by the GDNs (see Section 4.3 for further details). The MRPS risk score data were provided for one year within the GD1 period (2017/2018) and one year within the GD2 period (2022/2023). Table 2 shows the length and percentage of Tier 2 pipe above threshold for each of these years for selected GDNs. The length of Tier 2 pipe below threshold is shown in Table 3.

Table 2 Length and percentage of Tier 2 pipe with an MRPS risk score exceeding the Tier 2 Risk Action Threshold for selected GDNs.

GDN	Length (km) and % above threshold in 2017/2018	Length (km) and % above threshold in 2022/2023
NGN	34 (2.6%)	3 (0.2%)
SGN (Scotland)	3 (0.4%)	0 (0%)
SGN (SE)	10 (1%)	0 (0%)
SGN (South)	14 (2.7%)	0 (0%)

Table 3 Length of Tier 2 pipe with an MRPS risk score below the Tier 2 Risk Action Threshold for selected GDNs.

GDN	Length (km) below threshold in 2017/2018	Length (km) below threshold in 2022/2023
NGN	1269	1157
SGN (Scotland)	683	612
SGN (SE)	1008	990
SGN (South)	521	497

For all networks shown, the length of Tier 2 pipe with a risk score exceeding the Tier 2 Risk Action Threshold greatly reduced following the recalibration of the MRPS model coefficients in 2020. In 2022/2023, some networks had no Tier 2 pipes with a risk score exceeding the Tier 2 Risk Action Threshold and were therefore not required to take any action on Tier 2 pipes by the 2021 to 2026 HSE Enforcement Policy.

3.3.4 Comparison of Tier 1 and Tier 2 Risk Action Thresholds

Three of the four GDNs use different methodologies to set their Tier 1 and Tier 2 Risk Action Thresholds [11-13,20]. As a result, their Tier 1 Risk Action Thresholds can differ greatly from their Tier 2 Risk Action Thresholds.

The current SGN Risk Action Thresholds are shown in Table 4 [12,20]. In the South LDZ, a Tier 1 pipe with a risk score of 40.1 must be decommissioned, but no action is required for a Tier 2 pipe with a risk score of 231.

Table 4 SGN Tier 1 and Tier 2 Risk Action Thresholds for GD2.

Local Distribution Zone (LDZ)	Tier 1 Risk Action Threshold	Tier 2 Risk Action Threshold
SGN (Scotland)	72.4	185
SGN (SE)	64.7	232
SGN (South)	40.1	232

As a consequence of the differing approaches adopted for Tier 1 and Tier 2 risk reduction, Tier 2 pipes that are predicted by the MRPS to pose a high risk can be disregarded, whilst Tier 1 pipes that are predicted to pose a much lower risk must be decommissioned.

It should also be noted that the risk score output by the MRPS corresponds to the probability of an explosion incident per km per year. The consequences of an explosion incident could be greater for Tier 2 pipes than for Tier 1 pipes, as failure of a larger pipe may result in the release of a larger quantity of gas.

4 Pipe object MRPS risk scores

In the 10-year review of the IMRP [1], analysis by Advanced Engineering Solutions Limited (AESL) found the MRPS risk score to be a good predictor of GiB events in 2007 and 2008, and hence an effective tool for targeting replacement of iron mains. As pipes associated with the highest risk scores are removed, the risk profile flattens, unless the scores on remaining pipes increase due to recalibration of the model. However, this does not necessarily mean that the MRPS model is no longer an effective predictor of failures or GiB events: indeed, if the risk score was an ideal metric of failure likelihood, such that the pipe with the highest risk score failed more frequently than all others, then even after removing the highest risk pipes, risk scores assigned to the remaining pipes could still be perfectly correlated with the number of failures that pipes experience in the subsequent years.

To assess the performance of the risk score as a predictor of failures and GiB events, and to determine the number of pipes above/below threshold values of risk, we analysed pipe-level data supplied by the GDNs.

4.1 Data

While the SPI data analysed in Section 2 are pooled over each network, or LDZ, the risk-score data analysed by AESL [1] were given at the level of pipe object. A pipe object corresponds to a length of pipe without junctions or changes to properties such as diameter or material. Pipe objects span a large range of lengths: the median length in 2022/2023 was 45 m, while about 5% of pipe objects are below 2 m and 5% are above 329 m. The maximum length of a pipe object was 3.8 km.

For each pipe object, we requested the following data for each of the years 2012/2013, 2017/2018 and 2022/2023:

- Pipe object ID
- Diameter or tier
- Material: Cast Iron (CI), Spun Iron (SI), Ductile Iron (DI)
- Pressure category: Low Pressure (LP), Medium Pressure (MP)
- Length
- Risk score at the start of the year
- The number of failures associated with the pipe object during the year
- The number of GiB events associated with the pipe object during the year

The request did not include the full specification or restrictions associated with the SPI data and hence the total length of the network pipes and the number of failures and GiB events calculated from pipe object data may differ from that in the SPI data. In particular, the events (failures and GiBs) may include modes of failure not included in the SPI data, such as joint failures.

While the data from all GDNs are believed to be broadly equivalent, some networks have provided further information that is indicative of potential differences between networks, and differences from the SPI data:

- SGN informed us (SGN communication, February 26, 2024) that pipe object GiB events relate to ‘live’ assets, so do not include pipes decommissioned during the year (associated with typically 20 GiB events), whereas the SPI data set is generated from live and decommissioned pipes for each year.

- SGN further informed us (SGN communication, February 26, 2024) that as well as fracture and corrosion events, the data include events associated with other modes of failure, including failures of joints, line valves, and fittings. In contrast, SPI data include GiB events from just fractures (for cast iron and spun iron) and corrosion (for ductile iron).

- NGN informed us (NGN communication, March 1, 2024) that pipe-object data include GiB events from all types of repairs (each repair being associated with an event), with interference-associated repairs removed. In contrast, SPI data only count GiB events from repairs to the pipe barrel.

Before cleaning, the data set pooled across all GDNs comprised 1,937,287 records, corresponding to 862,844 unique pipe objects, each with records for one, two or three years specified in the request.

4.2 Data pre-processing

In the data sets provided by SGN and Cadent, we converted the diameter in inches or mm to Tier according to the definitions in Section 1.1.1. In the data set provided by Cadent, the pressure was reported using free text: we assigned the pressure category, LP or MP, depending on whether the free-text description of pressure (after conversion to upper case) contained ‘LP’ or ‘MP’. If neither could be assigned it was categorised as ‘unknown’.

For pipe objects with records in two or three of the requested years, we can check whether the material, diameter and pressure category are consistent across the years. Out of 862,844 unique pipe objects, 180,524 had entries for two years, out of which 339 (0.2%) were inconsistent, and 447,061 had entries for three years, out of which 1406 (0.3%) were inconsistent. Material, tier, and pressure were inconsistent for 1410, 373 and 9 pipe objects, respectively, with some pipe objects being inconsistent in more than one property. The 1745 pipe objects with inconsistent data were removed before further analysis.

Pipe objects with zero risk score, corresponding to pipes over 30 m from a building (104,078 records) or negative values of risk score, corresponding to pipes awaiting reassessment of the risk score (36,036 records) were removed, as were records for pipe objects with a length recorded as zero (89 pipe objects).

After cleaning, the data set comprised 1,792,240 records, corresponding to 812,432 unique pipe objects.

4.3 Analysis

To assess the use of Risk Action Thresholds for risk reduction strategy, we selected subsets of the data corresponding to GDN and Tier, and summed the length of pipe objects above/below specified threshold values of the MRPS risk score (Section 3.3.3).

To assess the predictive ability of the MRPS risk score for a subset of the data (e.g. the 608,341 records for Tier 1 pipes for the year 2017/2018, pooled over materials, pressure and GDN), we sorted the subset of records by the risk score (highest risk first, lowest risk last), then calculated the cumulative sum of the pipe object lengths and cumulative sum of the number of events (either failures or GiB events). Table 5 illustrates the process for a hypothetical data set, while Figure 16 plots the cumulative sum of GiB events against the cumulative length for three subsets of real data corresponding to the three years, for Tier 1 pipes pooled over materials, pressure and GDN.

Table 5 The first six and last three values of cumulative length and cumulative number of GiB events calculated from a hypothetical data subset sorted by risk score. Typical data subset tables contain several hundred thousand rows: missing rows are indicted by vertical ellipses.

Risk score	Length (m)	#GiBs	Cumulative length (m)	Cumulative #GiBs
9889	23	0	23	0
8264	49	2	72	2
6595	62	0	134	2
3919	10	0	144	2
2728	63	5	207	7
2669	40	1	247	8
⋮	⋮	⋮	⋮	⋮
0.2	34	0	40,712,814	563
0.1	7	0	40,712,821	563
0.1	30	0	40,712,851	563

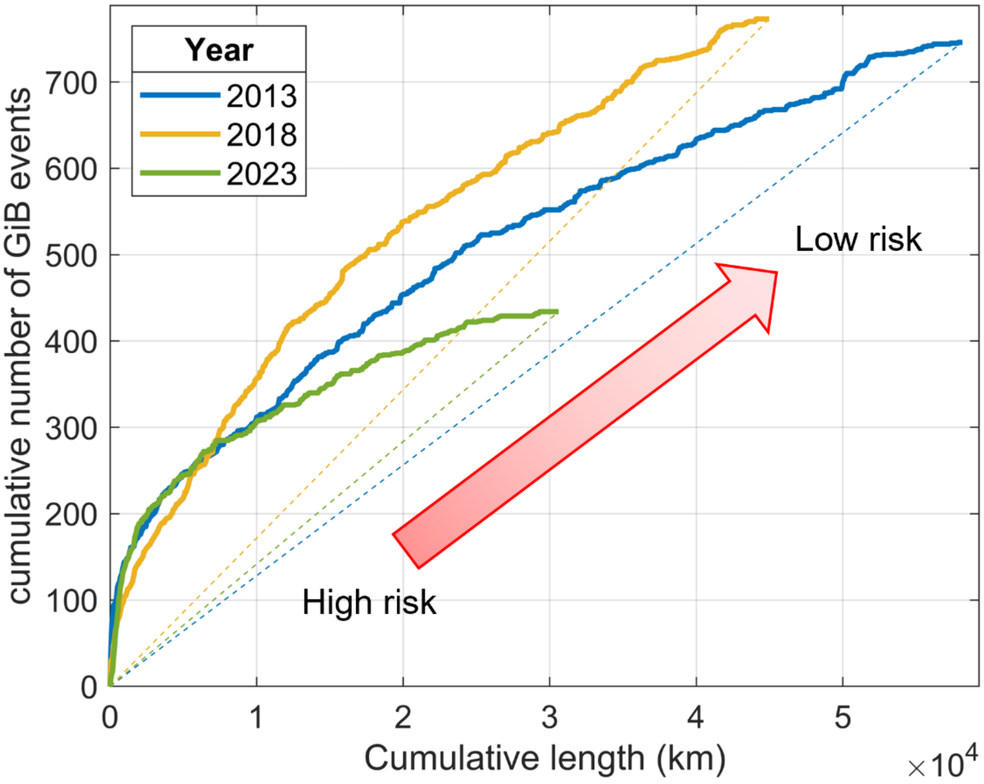

Figure 16 Tier 1 pipe object data sorted by risk score, pooled over materials, pressure and GDN.

The gradient of the dashed lines in Figure 16 gives the mean number of events per km. For ease of comparison between different data sets, we scale the cumulative sums to give the percentage of events in a given year as a function of the percentage of the length of the network, or rather the portion of the network in the selected subset of data (Figure 17, left). The dashed line in Figure 17 (left) indicates chance performance: if the risk score had no predictive ability the data would approximately follow this line: the 20% of pipes (by length) with the lowest risk scores would be associated with 20% of events in the following year, and the 20% of pipes (by length) with the highest risk scores would also be associated with the same number of events in the following year: any selection of 20% of the pipes by length would contain roughly 20% of the events in the following year. The height of the curve above the dashed line gives a measure the predictive ability of the risk score: Figure 17 (right) shows that if the highest risk 5, 10, 15, 20 or 25% of the Tier 1 cast iron and spun iron pipes (pooled over all other factors: material, pressure and GDN) had been removed at the start of 2012/2013, roughly 27, 35, 40, 45 or 52% of GiB events that actually occurred would have been prevented. However, this calculation does not take into account the time it would take to remove the pipes (it assumes that pipes would all be removed at the start of the year) and cannot take into account the number of events that actually were prevented by removing other pipes that formed part of a wider decommissioning work package, hence it should not be interpreted as ‘missed opportunities’ or incorrect targeting of pipes for decommissioning: it is intended only as a comparison of the performance of the MRPS risk score model to a non-targeted selection of pipe objects.

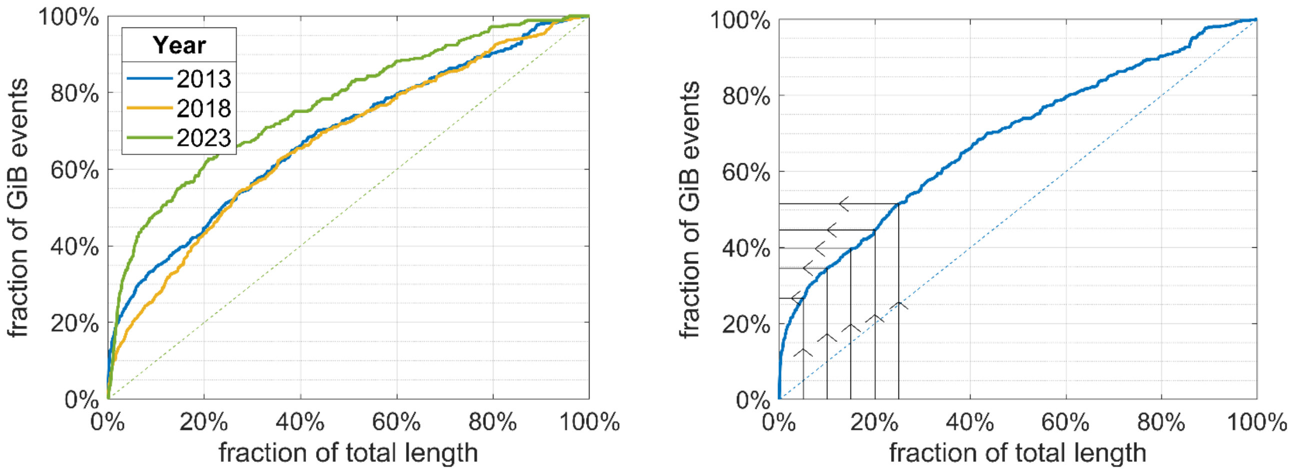

Figure 17 Cumulative GiB events and length from Figure 16 scaled by the grand totals (left), and schematic illustration on the use of linear interpolation to give the predictive ability of the MRPS risk score for specified values of relative cumulative length (right).

The same methodology can be used to assess the performance of the MRPS risk score as a predictor of pipe failures, regardless of whether the failure resulted in a GiB event. Figure 18 illustrates the application to Tier 1 failures in the 2012/2013 data set, pooled over materials, pressure and GDN. Figure 18 also shows the performance of an ideal risk score model given the historic events, calculated by sorting the data by the number of events per kilometre and then calculating the cumulative sums as before. This would be the performance of a model that assigned the highest risk score to the pipe with that went on to have the greatest number of events per kilometre in the following year, down to the lowest risk score being assigned to the pipe that had the smallest number of events per kilometre in the following year. An alternative measure of performance, that takes into account the theoretical upper bound, could be calculated by scaling the fraction of failures predicted by the MRPS model by the fraction predicted by the ideal model (which can also be determined using linear interpolation). However, this alternative metric is more difficult to interpret so in this report we give only the fraction of events predicted at specified fractions of the total length of pipes in the selected subset of data.

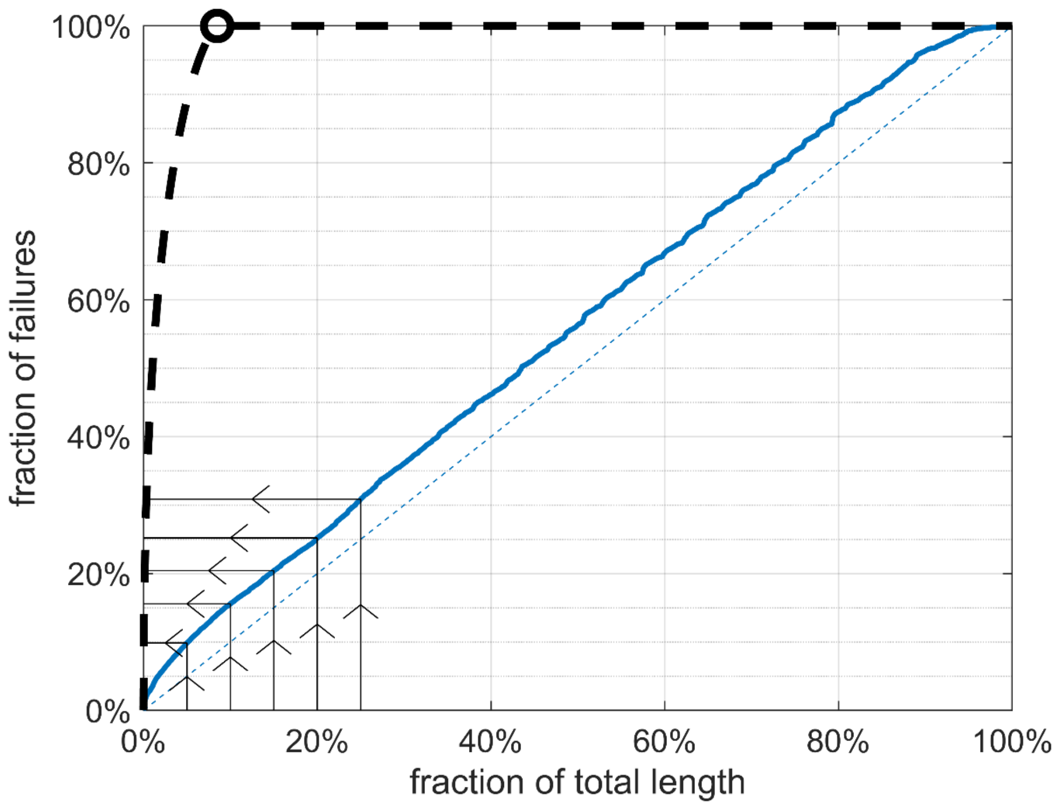

Figure 18 Use of linear interpolation to give predictive ability of the MRPS score for failure events. The dashed black line indicates the performance of an ideal risk score model. The circle indicates that all failures occurred in just 8.5% of the total pipe length.

4.4 Results

The fraction of GiB events and the fraction of failures including non-GiB events are shown in Figure 19, grouped by year. Values of the fraction of events in the 5% and 20% of pipes with the highest risk scores are given in Table 6.

The fraction of GiB events in Tier 1 ductile iron pipes and Tier 1 cast iron/spun iron pipes are shown in Figure 20, grouped by year. Values of the fraction of events in the 5% and 20% of pipes with the highest risk scores are given in Table 6.

The fraction of GiB events in Tier 1, Tier 2 and Tier 3 cast iron/spun iron pipes are shown in Figure 21, grouped by year. Values of the fraction of events in the 5% and 20% of pipes with the highest risk scores are given in Table 6.

A further breakdown of results by GDN is given in the appendices in Section 13 in Tables 9 to 11.

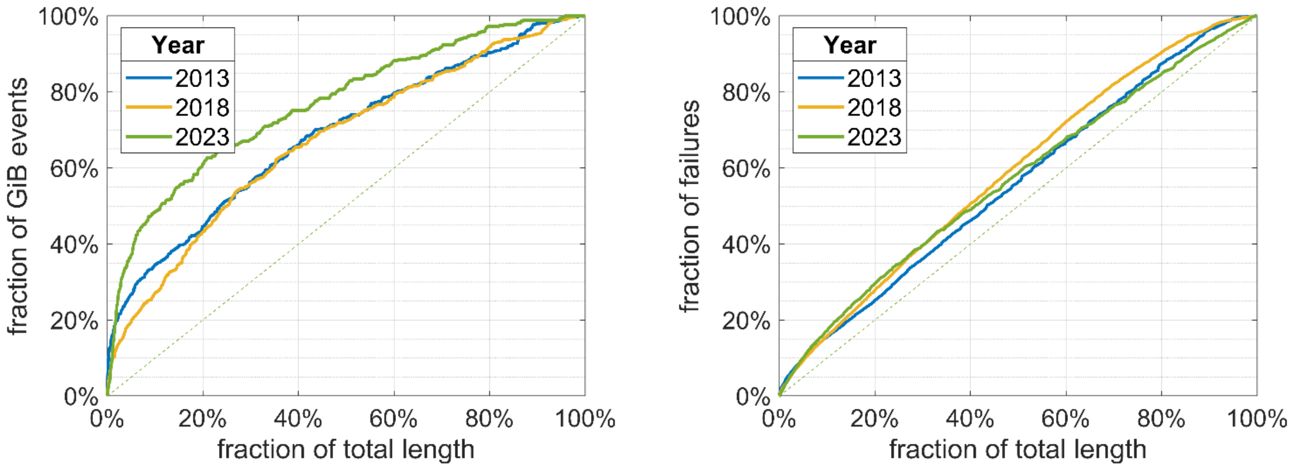

Figure 19 GiB events (left) and failure events (right) in Tier 1 pipes pooled over material, pressure and GDN.

Table 6 Fraction of events in the 5% and 20% of pipes with the highest risk scores per year.

Tier	Event	Material	2013 5% of length	2013 20% of length	2018 5% of length	2018 20% of length	2023 5% of length	2023 20% of length
1	GiB	Pooled	27%	45%	20%	43%	37%	61%
1	Failure	Pooled	10%	25%	9%	28%	10%	30%
1	GiB	DI	18%	29%	17%	50%	45%	73%
1	GiB	CI/SI	27%	45%	20%	41%	40%	61%
2	GiB	CI/SI	25%	39%	12%	34%	31%	64%
3	GiB	CI/SI	10%	25%	11%	24%	10%	16%

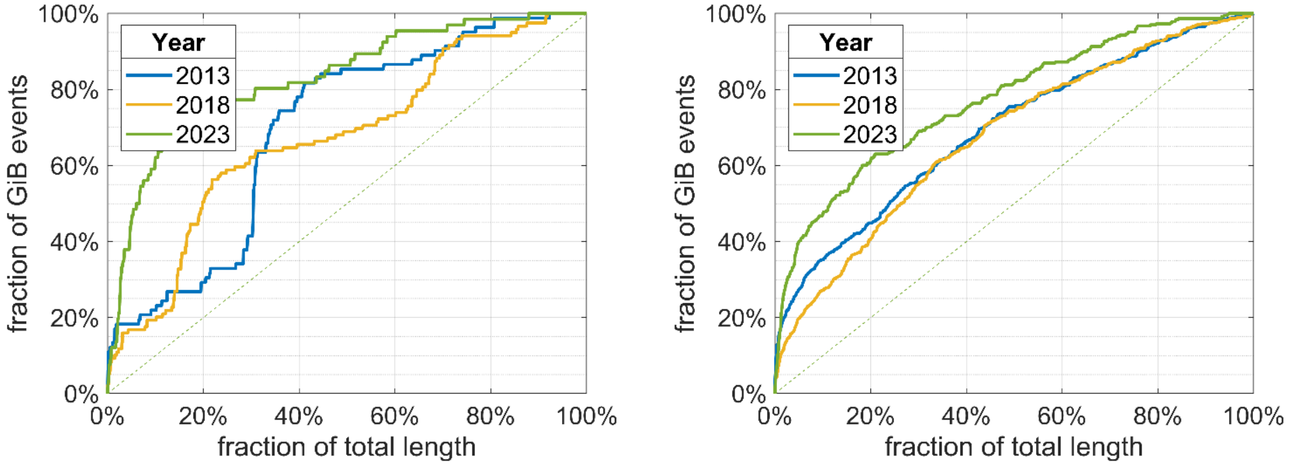

Figure 20 GiB events in ductile iron (left) and cast iron/spun iron (right) Tier 1 pipes, pooled over pressure and GDN.

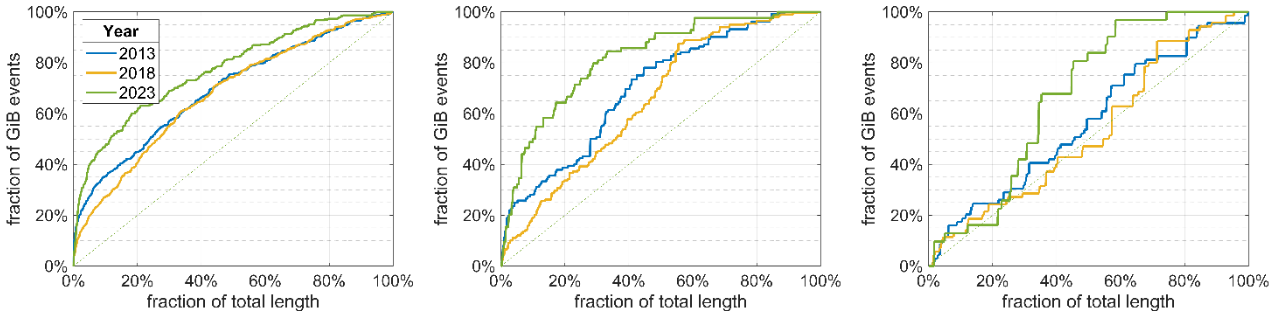

Figure 21 GiB events in Tier 1 (left), Tier 2 (centre) and Tier 3 (right) cast iron/spun iron pipes, pooled over pressure and GDN.

4.5 Discussion

Based on records from three years, 1745 pipe objects were found to have inconsistent values of one or more property: material, tier, or pressure. If we had data for more than three years, we would expect the number of inconsistent records to be higher, and further, we cannot determine how many of the pipes for which we had data for only one of the three years have one or more incorrectly assigned property value.

The set of 1745 pipe objects with inconsistent data corresponds to 0.2% of pipe objects in total, but 0.5% of pipe objects associated with failures and 1.5% of pipe objects associated with GiB events. The increased level of inconsistency with failure and GiB events may be due to those pipes being resurveyed following the corresponding events and thereby having previously incorrectly recorded properties rectified. Pipes with incorrectly recorded properties that did not suffer a failure may not be resurveyed, and hence the incorrect data will not be rectified in the data sets of subsequent years. This suggests that the true number of pipe objects with one or more field of data recorded incorrectly is about 1% or more, i.e., closer to the value for pipes that have suffered GiB events. Including more years of pipe object records in the analysis would likely increase this estimate.

While there is no way for our estimates of the predictive ability of the MRPS model to allow for the number of events that may have occurred in pipes which were, in reality, removed, the metrics given in this report indicate the maximum the number of *additional* events that could have been prevented if the highest risk scoring pipes had been removed *in addition to* those that were removed. (This maximum number would only be achieved if the additional pipes were removed at the start of the year). The results suggest that the MRPS risk score is still an effective predictor of GiB events for many subsets of pipe object, especially following the 2020 recalibration of the model, which now allows joint failures to be weighted separately to corrosion failures and may allow better modelling of risk as the ratio of joint failures to corrosion failures changes.

The model was a better predictor of GiB events in Tier 1 cast iron/spun iron pipes than in Tier 1 ductile iron pipes in 2012/2013, but in 2022/2023 the performance was better for ductile iron, with 73% of GiB events occurring in the 20% of pipe length with the highest risk scores. The results indicate that the predictive capability of the MRPS model is consistently lower for Tier 2 and Tier 3 cast iron/spun iron pipes than for Tier 1 cast iron/spun iron pipes, although performance was good for Tier 2 pipes in 2022/2023. Tier 3 performance is little above chance, although this may be largely due to the small number of GiB events associated with Tier 3 pipes.

For failures that do not result in a GiB event, the predictive capability of the model as measured by the fraction of the of failures predicted in the 5% or 20% highest risk pipes (by length) is significantly lower than the predictive capability for GiB events, although the absolute number of failures predicted may be higher than the absolute number of GiB events. Non-GiB events are much more frequent and distributed over a much larger fraction of the network: the use of GiB history in the model may make the subset of pipes that have subsequent GiB events easier to predict.

5 Workshop on risk factors

An internal HSE workshop was held on 5 February 2024 with the following aims:

- To review the risk factors currently considered in the IMRRP (both qualitatively and in the MRPS risk model) and identify any further risk factors that should be considered.
- To discuss the suitability of the MRPS risk model for assessing the risks posed by larger diameter pipes.
- To discuss alternative approaches for assessing the risks posed by iron mains.

This workshop was attended by HSE Regulatory Inspectors, Pipeline Specialists and scientific staff with expertise in mechanical engineering, materials, statistics and risk assessment.

Prior to the workshop, we provided participants with background information on the MRPS model and a list of the questions to be discussed in the workshop.

The workshop was facilitated by the project team and Microsoft Whiteboard was used to share ideas. Participants were split into two groups (each with a range of expertise) to discuss the workshop themes in breakout rooms. During the workshop, there were opportunities for the two groups to feed back to all participants.

5.1 Workshop theme 1: Risk factors considered in the IMRRP

We asked the workshop participants to consider the following questions:

1. What are the most important factors to consider when assessing the risks posed by iron mains?
2. Are there any additional risk factors that should be considered either qualitatively or in the MRPS risk model?
3. The mains risk reduction programme has been running for more than 20 years and many of the pipes with the highest risk scores have already been decommissioned. The range of risk scores output by the MRPS is now much smaller that it was at the start of the programme. When all the risk scores are similar, how should pipes be prioritised for decommissioning? Which additional factors could be considered when trying to distinguish between pipes with similar risk scores?

In response to the first question, a wide range of factors were identified, but a large proportion of the discussion centred on the themes of data quality and soil corrosivity.

5.1.1 Data quality

The workshop participants observed that decisions about pipe prioritisation should be based on accurate and up-to-date asset data (including pipe material, size and installation date), but many participants felt that the data held by the GDNs are not of high enough quality. The participants also noted that there is a lack of accurate condition data, as data on pipe condition have not been routinely recorded during the iron mains risk reduction programme.

The MRPS risk model is heavily reliant on accurate record keeping of leak history and repairs, but there is poor retention of historic data and knowledge.

Concerns were raised about the accuracy of the surveys on which the MRPS coefficients are based, and the competence of staff carrying out the MRPS surveys. One participant had reviewed MRPS survey data provided by the networks and reported that the distances were inaccurate and estimates of open ground were poor. Another participant had seen MRPS survey data in which the number of properties on a road halved from one survey to the next. Participants also had anecdotal evidence that trainee surveyors have been told (by their instructors) not to err on the side of caution when carrying out MRPS surveys.

5.1.2 Soil corrosivity

Corrosion is not considered for cast iron pipes in the MRPS [3], but participants felt that most pipe failures have a corrosion element. It was further noted that soil type and corrosivity are likely to be key factors in determining whether a Tier 2 pipe will fail.

Participants remarked that soil corrosivity could be measured using bar hole resistivity tests. It was proposed that soil samples or readings could be taken when excavating for another reason. This could be used to inform likely corrosion rates and build up a map of soil corrosivity which could overlay risk scores and other factors.

The workshop participants observed that corrosion is time dependent and that older pipes have had more time to degrade. However, age is only considered in the MRPS for ductile iron and only in cases where there have been no previous failures due to corrosion [3]. It was suggested that the rate of deterioration across the network could be estimated by sampling. However, it was recognised that this would be made difficult by the fact that soil backfill properties can vary significantly over short distances.

DNV has since informed us that corrosion will be modelled for all pipe types in the next release of the MRPS (DNV communication, June 28, 2024).

5.1.3 Additional risk factors

The workshop participants identified a range of additional risk factors that could be considered in the MRPS or qualitatively. Many participants felt that the risk modelling should take greater account of factors that could favour corrosion. These include:

- Soil type.

- Soil corrosivity.
- Any other causal factors that would give rise to corrosion.

Soil moisture and pH are not explicitly included in the MRPS but may influence the value of the Background Corrosion Zone coefficient [3].

A number of other risk factors associated with the ground conditions were identified:

- Subsidence / ground movement history. (Local ground subsidence is not included as a separate factor in the MRPS but may influence the value of the Background Breakage Zone coefficient [3].)
- Backfill, for example from World War II.
- Third party excavations in recent years. Is there a history of other invasive work, such as other utilities excavating in close proximity or ground disturbance from building works?
- Flooding and other natural hazards.

The workshop participants identified other factors that may affect the likelihood of a pipe failure occurring, which are not currently considered in the risk modelling:

- Potential for future external interference or third party damage.
- Ambient temperature profiles.
- Traffic density. Is a pipe failure more likely to occur on a busy main road than in a quiet cul-de-sac? (Although not explicitly included in the MRPS, traffic loading may influence the value of the Background Breakage Zone coefficient [3].)
- Any factors that would give rise to fractures (such as wall thinning or the pipe being under stress).

The following factors may affect the likelihood of ignition:

- Natural ventilation rate of properties in the vicinity of the iron main. This may depend on the property age.
- Presence of ignition sources within properties.

The workshop participants identified the following factors that may affect the consequences of an incident:

- The population density in the vicinity of the iron main.
- The type of housing in the local area and the presence of any transport networks.

- The presence of larger diameter / higher pressure mains running through the area to feed other locations.

The workshop participants also proposed that there should be the option to increase the priority of a given main based on local operational knowledge.

5.1.4 Distinguishing between pipes with similar risk scores

To distinguish between pipes with similar risk scores, the workshop participants suggested that the prioritisation scheme should take account of the severity of the consequences of an explosion. Larger diameter or higher pressure pipes (for which a failure could result in a high volume gas escape) should be prioritised for decommissioning. The MRPS already takes some account of this for cast and spun iron via the Gas Ingress Factor [4]. The Gas Ingress Factor for cast and spun iron is dependent on the diameter of the main because a fracture on a larger diameter main has the potential to release a larger quantity of gas that a fracture on a smaller diameter main. There is therefore a greater likelihood that a release from the larger diameter main will enter a building.

The workshop participants suggested that pipes located in areas of high population density or near vulnerable populations should also be prioritised, as should pipes in the vicinity of buildings more susceptible to explosion damage.

It was also proposed that decommissioning could be done at a regional level, by identifying larger areas within which pipes are likely to be more susceptible to failure. This could potentially be linked to data on soil type or corrosivity.

The age of the pipe could also be used to distinguish between pipes with similar risk scores. Currently age is only considered in the MRPS for ductile iron and steel and only in cases where there have been no previous failures due to corrosion or no previous joint failures [3].

5.2 Workshop theme 2: The suitability of the MRPS for larger diameter pipes

The MRPS is used to calculate risk scores for all diameters of pipe. The three tiers of pipe diameter are:

- Tier 1: 8 inches and below (approximately 80% of all 'at risk' iron pipes, where ‘at risk’ pipes are defined as those within 30 metres of a property).
- Tier 2: above 8 inches and below 18 inches (approximately 15% of all 'at risk' iron pipes).
- Tier 3: 18 inches and above (approximately 5% of all 'at risk' iron pipes).

The Iron Mains Risk Reduction Programme [1] requires all Tier 1 pipes within 30 metres of buildings to be decommissioned by 2032. However, only Tier 2 pipes that have a risk score above a Risk Action Threshold set by the GDN operator will be selected to receive appropriate attention (either decommissioned or, where a suitable and sufficient technique exists, assessed for continued use if found to be in good condition or remediated to allow for lifetime extension). No action is required for Tier 2 pipes that have risk scores below the threshold. We are therefore particularly interested in how well the MRPS risk model is performing for larger diameter pipes.

We asked the workshop participants to consider the following questions:

1. Are there any changes that would make the MRPS more useful for Tier 2 pipes?
2. Looking forward to the future, how should we be looking at the risks associated with larger diameter pipes?

5.2.1 Improving the MRPS for Tier 2 pipes

The workshop participants noted that for Tier 2 pipes, joint leakage and corrosion are the main failure mechanisms. Soil type and corrosivity are likely to play a significant role in determining whether a Tier 2 pipe will fail. Data on local soil conditions could be used to target Tier 2 pipes for decommissioning or other appropriate attention.

Corroded or failed bolts could be indicative of corrosion being an issue for the pipe body. Participants therefore thought that historical data on bolt failures on Tier 2 and Tier 3 pipes should be included in the analysis.

Joint leakage is common for larger cast iron pipes and could be used as a proxy for other failures. For example, an increase in joint leaks might indicate that there has been ground movement, which would place greater stress on the pipe.

The consequences of a pipe failure could be more severe for higher tiers than for Tier 1, as there is potential for a larger quantity of gas to be released. The MRPS accounts for the fact that there is a greater likelihood that a release from a larger diameter main will enter a building through the dependence of the Gas Ingress Factor for cast and spun iron on the pipe diameter. However, the methodology used to prioritise pipes for appropriate attention based on MRPS risk scores does not consider how the severity of an explosion might depend on the quantity of gas released, and the assumed fatality factor does not depend on the pipe diameter.

5.2.2 Other approaches for assessing the risks associated with larger diameter pipes

The workshop participants proposed that larger diameter pipes in densely populated areas should be targeted for decommissioning. One participant suggested subdividing Tier 3 pipes into three grades based on the local population density and using these gradings to prioritise the pipes for decommissioning.

It was also suggested that consideration should be given to adopting some of the approaches used in the management of offshore pipelines, such as the concept of design life. The design life of a pipeline is the length of time for which its designers expect it to operate within specified parameters without needing major repair.

5.3 Workshop theme 3: Alternative approaches to assessing risks from iron mains

We asked the workshop participants to consider the following questions:

1. Is there a completely different way of using risk-based calculations to prioritise iron mains for decommissioning?
2. Could condition monitoring data be used instead (particularly for higher risk parts of the network)?

5.3.1 Alternative approaches

The workshop participants felt that the risk modelling should place more emphasis on societal risk. This is particularly important for high density urban areas.

They also emphasised that the cumulative risk from multiple pipes in a street should be calculated and used to inform the decommissioning programmes. This approach could be further extended to consider the regional risk impact.

It was suggested that the GDNs should consider using Artificial Intelligence predictive systems to inform their analysis.

Greater use could be made of the hot spot analysis that is utilised by the networks to identify higher-risk service pipes [10]. As the service pipe and mains replacement are linked there may be scope to use this analysis to drive iron mains decommissioning and replacement with PE (polyethylene) mains. Alternatively, the hot spot tools could be used to identify areas of higher corrosion risk and the data could feed into the risk modelling for the iron mains.

One of the pipeline specialists attending the workshop had seen fifteen recent instances of service pipe corrosion and proposed that this might be indicative of the condition of the nearby main. I.e. if conditions are conducive to corrosion of service pipes, they might also be conducive to corrosion of the main.

5.3.2 Condition monitoring

The workshop participants felt that condition monitoring could be used in conjunction with risk calculations to prioritise pipes for decommissioning, if the technology is available. However, it was noted that the networks will not have historic condition data on which to base assumptions. Concerns were also raised about the levels of resource that would be required and the potential lack of suitably qualified staff.

If this approach is adopted, the GDNs would need to put procedures in place to start collecting network-wide data on pipe condition. The workshop participants recommended that data collection should be standardised over all networks and should include (but not be limited to) photographs, soil resistivity and coupon data. The collection of consistent data across the networks would allow statistical analysis to be undertaken.

The risk score could be down-rated if an inspection or other measurement has been carried out and indicates that the pipe is in good condition. Credit could also be given for interventions, such as liner systems or joint-sealing techniques.

6 Workshop on condition monitoring

The GDN operators are required to establish suitable condition monitoring regimes as part of their Approved Programmes [2]. Condition monitoring is used to help identify high-risk pipes in Tiers 2 and 3. In the approved programmes for GD2, all Tier 3 pipes, and Tier 2 pipes that have a risk score above the Risk Action threshold set by the GDN operator are subject to condition monitoring.

The condition monitoring regimes that the GDN operators currently have in place consist of walking or vehicle surveys using standard gas detection equipment to identify leaks [6,7], although more sensitive monitoring devices are being trialled [8].

Annual surveys are conducted in winter, at the time of year when failures are most likely to occur on the network. Additional surveys are triggered by extreme weather conditions or significant ground movement [6,7].

An internal HSE workshop was held on 2 February 2024 to discuss current condition monitoring techniques and possible alternative approaches.

This workshop was attended by HSE Regulatory Inspectors, Pipeline Specialists and scientists with expertise in mechanical engineering and materials science.

6.1 Workshop overview

The two main aims of the workshop were:

- To discuss whether current condition monitoring techniques are an appropriate way of identifying high-risk pipes in Tiers 2 and 3.
- To identify more robust techniques for condition monitoring.

The workshop was facilitated by the project team and Microsoft Whiteboard was used to share ideas.

Prior to the workshop, we provided participants with background information on current condition monitoring techniques and a list of the questions to be discussed in the workshop. The questions were divided into two themes: leakage surveys and methods for assessing pipe integrity.

6.2 Workshop theme 1: Leakage surveys

The current condition monitoring regimes rely on the outputs of leakage surveys. We asked the workshop participants to consider the following questions:

1. How effective are leakage surveys likely to be at identifying high-risk mains?

2. How could the effectiveness or sensitivity of leakage surveys be improved? Could any improvements be made in the following areas?

   - Technology
   - Techniques
   - Logistics

3. What criteria should be used to trigger leakage surveys?

4. What advantages and disadvantages would more sensitive monitoring devices (such as Picarro [8], currently being trialled by Cadent and SGN) offer?

6.2.1 Use of leakage surveys for condition monitoring

The workshop participants raised a number of concerns about the use of leakage surveys for condition monitoring. Of primary concern was the fact that leakage surveys are a lagging indicator. They only provide information about pipes whose condition has deteriorated to such an extent that gas has already leaked out.

Participants raised concerns about staff competency and the ability to follow processes accurately and consistently. The workforce is aging, and newer employees are inexperienced. As discussed in Section 5.1.1, there are known inaccuracies in the data recorded for MRPS surveys. Participants had similar concerns about the reliability of data recorded for leakage surveys. Staff competence was mentioned, but there may be other factors that impact on the reliability of the surveys.

The participants were also aware of record-keeping issues. The records of mains location and material contain errors, meaning that the GDNs do not know the locations of all iron mains.

Gas may track from the source asset to other asset locations (high-pressure and low-pressure mains are sometimes co-located) and it may be difficult to identify which main is leaking. Back fill or third party alteration (such as telecommunications or water) may provide tracking routes.

Participants questioned whether the gas detectors that are currently in use are sensitive enough to detect leaks that come up through grass, rather than through the road on which the survey vehicle is travelling. They also queried how leaks are detected from pipes that do not run close to roads. The participants raised concerns that leaks on mains under closed surfaces are being missed, meaning that no information is being gathered on the condition of these pipes.

The workshop participants queried how much of a main is assessed when a leakage survey identifies a leak at one point on the main. It was felt that confirmed leaks should lead to a further study along a reasonable length of the same main and that known defects should result in the rest of the main being prioritised for decommissioning.

As far as participants were aware, GPS data are not recorded during leakage surveys. This will make it harder to subsequently locate leaks and to maintain accurate records of which parts of the network have been surveyed.

6.2.2 Leakage survey timing

Annual surveys are carried out in winter, at the time of year when failures are most likely to occur on the network [6,7]. The trigger criteria used by the GDNs to initiate additional surveys are listed in their management procedures for leakage surveys [6,7] and include:

- Air temperatures below – 4°C for a continuous period of 12 hours.
- A rapid rise in air temperature following a sustained period of temperatures below – 4°C (the required temperature rise and time duration are specified by the individual GDNs).
- An abnormal increase in mains breakages identified through review of data.
- Prolonged dry spells where severe ground cracking is evident.
- Subsidence.
- Earth tremors.

Participants questioned whether it is reasonably practicable to survey all pipes that would need to be surveyed following a ‘trigger’ event. It was also noted that changes can occur between surveys that may accelerate pipe deterioration but will not trigger a further survey. For example, corrosion may worsen or there may be movement underground.

Participants queried whether the survey frequency has changed in recent years. The iron mains population is now significantly smaller than at the start of the risk reduction programme, but 20 years older, and it was suggested that leakage surveys should become more frequent to reflect the aging pipe population.

6.2.3 Alternative approaches

The workshop participants suggested some modifications that could be made to the existing condition monitoring regimes:

- Consideration should be given to using prioritisation rather than trigger criteria to determine which pipes should be surveyed. In urban areas there are large numbers of iron mains and it may not be practicable to survey them should a ‘trigger’ event occur. Participants suggested prioritising higher-pressure pipes as the potential consequences of a leak are more severe.
- Associating the leakage survey outputs with GPS data would allow leaks to be more easily located and rectified. Greater accuracy could be achieved by using, for example, real time kinematic positioning (RTK).

- Gas leaking from medium-pressure (MP) or high-pressure (HP) pipes may cool as it expands. It is possible that the escaping gas could be detected by infra-red (IR) cameras, which can detect surface temperature changes. Mounting the cameras on drones could enable wide areas to be covered.

- Local leakage surveys could be carried out by community support volunteers. Local volunteers would have an incentive to record thorough and accurate information as the safety of their own neighbourhood might rely on it.

6.2.4 Developments in gas detection

Cadent and SGN are trialling Picarro, a more sensitive gas detection system [8] that can be operated from an instrumented vehicle. Picarro can detect gas leaks at ppb sensitivity, whereas the sensitivity threshold for current vehicle surveys is set at 500 ppm [8].

The use of Picarro would address some of the concerns that workshop participants raised about standard leakage surveys. In Picarro surveys, data are collected automatically. This process is less reliant on the competency of the individual than standard leakage surveys, which require the operator to manually input information. The Picarro data correlate with high-precision GPS references, making leaks easy to follow up and enabling leakage data to be mapped across the entire network. Mapping of the data would allow gaps in network coverage to be identified and would enable the leakage data to be correlated with other geographical information such as soil corrosivity maps.

The same threshold for triggering a PRE (public reported escape) procedure would be used for Picarro surveys as is used currently. The data for smaller leaks would be used to build up a picture of the overall network condition (and could lead to remedial action). The workshop participants noted that this would allow small leaks to be used as leading indicators of a pipe’s condition. However, they also raised concerns that the detection of lower level leaks could shift resource from higher-risk areas.

The workshop participants queried how achievable it would be to roll out Picarro or another advanced leakage detection system across the entire network and whether sufficient competent operators and equipment are available.

6.3 Workshop theme 2: Methods for assessing pipe integrity

SGN recently commissioned DNV to carry out a review of survey methods that can be used to assess the integrity of cast iron mains and detect deterioration before a leak occurs [21]. The methods considered included radiography, ultrasonic examination, Magnetic Flux Leakage (MFL) and Pulsed Eddy Current (PEC). We asked the workshop participants to consider the DNV review and discuss the following questions:

1. Are the disadvantages / problems described for each of the techniques realistic, or are they being overplayed? Are there ways in which these techniques could be modified or improved to make them more suitable for the gas network?

2. Are any of the techniques suitable for local application in high-risk locations, such as town centre locations, locations close to high rise buildings etc.?
3. Could any of the techniques be used when undertaking other remediation work on the main, to reduce disruption? For example, could robotic inspection techniques such as CIRRIS be used when an excavation / launcher tube etc. is installed for CISBOT joint repairs? (CISBOT carries out robotic internal cast iron joint sealing in live mains.)
4. Are there any other techniques that could practicably be used?

6.3.1 Review of the DNV report

The DNV report [21] concluded that none of the methods were suitable for application on the network. The workshop participants agreed that the constraints of each technique had been fairly represented, but it was felt that more information was needed on the techniques that were listed in the report but not discussed further, such as acoustic emission detection.

The report concludes that data obtained from sampling one section of a pipe may not be applicable to other sections of the same pipe, because corrosion issues are often localised. HSE’s materials specialists agreed with this statement.

The report further states that the graphite flakes present in cast iron attenuate ultrasonic signals and generate noise, limiting the applicability and reliability of ultrasound techniques for cast iron mains. HSE’s materials specialists agreed with this conclusion but believed that graphite flakes would be less of an issue for Magnetic Flux Leakage techniques.

The workshop participants felt that the possibility of using crawlers should have been explored further in the report (but noted that pigging would not be an option for low-, intermediate- and medium-pressure pipes because pipes have not been pigged below 7 bar). They stated that it is difficult to obtain reliable information on the condition of a pipe from outside and that the only way of properly inspecting a pipe is from the inside.

One participant had carried out research on crawlers and noted that they are practicable for larger pipes. However, it is not clear whether the technology could be shrunk to produce crawlers for smaller pipes. Space would be required on the crawlers for detectors and cleaners.

6.3.2 Application of the techniques in high-risk locations

The workshop participants were asked to consider whether any of the techniques would be suitable for local application in high-risk locations. It was felt that consideration should be given to utilising crawler systems or acoustic sensors in high-risk areas.

The participants proposed that locations should be defined as ‘high-risk’ based on pipe diameter and leak history, rather than the nature of the surrounding population or buildings, as was suggested in the workshop brief.

6.3.3 Use of the techniques during remediation work

Whilst these techniques may not be appropriate for widespread roll out, they may be appropriate for use when access to a large diameter main is required for other purposes. The workshop participants felt that more consideration should be given to using internal inspection techniques when there is an excavation on a large diameter, high-risk pipe. For example, if internal access to a main is required in order to use CISBOT to seal joints, then a similar robotic system with appropriate sensors could be used to internally inspect the main at the same time.

6.3.4 Alternative options for assessing pipe integrity

The workshop participants identified a range of options that could be considered for assessing pipe integrity:

- Saturated low-frequency eddy current testing.
- Potential drop: crack lengths are routinely measured in this way.
- Magnetic Flux Leakage in conjunction with crawlers.
- Sonar: the graphite flakes in cast iron may have different effects on different frequencies of sound, so some frequencies might transmit better than others through cast iron.
- Acoustic emission testing: this technique is mentioned in the DNV review but not discussed in detail.
- Acoustic sensors on the pipe to pick up sudden large noisy events such as a crack forming. This has been applied in the petrochemical industry for undersea pipes and would require a network of sensors. The frequency that is detected would need to be carefully chosen, to allow failures to be distinguished from general noise.
- Use of a crawler to generate an impact pulse on the pipe wall and measure its response. This technique could be used to identify regions of significant corrosion or fractures (analogous to a wheeltapper on railways).
- CISBOT (robotic cast iron joint sealing): if a joint with movement is found during CISBOT joint maintenance, this may indicate that the pipe is under stress.
- Small cameras to examine joints.
- Coupon monitoring: coupons could be tested for graphitic corrosion.

The workshop participants noted that several of these techniques could be implemented using crawlers. However, they cautioned that valves, bends, T-junctions and siphons are an issue for crawlers. A crawler access point would be required: this would require cost and effort but is in theory achievable. A purging exercise would be required beforehand to ensure that there is not a flammable atmosphere present.

The participants stressed that whatever technique is chosen, it would need to be capable of detecting small anomalies, such as a small hole in a higher pressure pipe, which could result in the release of a large volume of gas.

It was suggested that a map of soil corrosivity could be developed by taking samples when excavating around a main. This could be used to identify hot spots of high soil corrosivity. Pipes within hot spots could be targeted for assessment with other condition monitoring techniques. There is a geological soil map (British Geology Soil Map) that could provide relevant information, although it does not take into account local deviations such as third-party backfill.

7 Review of report on alternative replacement scenarios for mains and services

On behalf of all networks, SGN commissioned a report by DNV on alternative replacement scenarios for mains and services in the GD3 price-control period (April 2026 to March 2031) and beyond, taking into account deterioration of the network. To investigate alternative scenarios, DNV developed a statistical model of network deterioration and estimated the number of GiB events up to 2055 under five scenarios: the findings are reported in [9].

7.1 Scenarios

The DNV report [9] considered five scenarios:

A. No future replacement (reactive maintenance only).

B. Continuation and completion of the IMRRP: decommissioning of Tier 1 iron mains within 30 m of a building by 2032.

C. As for scenario B, but also replacing steel services on PE mains by 2046.

D. As for scenario C, but also decommissioning Tier 1 iron mains more than 30 m from buildings and all Tier 2 and Tier 3 iron mains by 2046.

E. As for scenario D, but also decommissioning unprotected steel mains by 2046.

Scenarios C to E were chosen partly based on Net Zero considerations, making parts of the network suitable for hydrogen distribution (SGN communication, June 4, 2024). The year 2046 was chosen to comply with the stricter Net Zero target in Scotland than in the rest of the UK, which aims to reach Net Zero by 2050. Scenarios A and B give, respectively, a worst-case counterfactual scenario in which deterioration but not replacement is modelled, and a baseline scenario modelling deterioration and current planned replacement, against which the benefits of scenarios C to E can be measured in terms of the reduction in the number of GiB events.

The DNV report refers to ‘replacement’ scenarios, as it is assumed that decommissioned iron mains will be replaced by PE mains. For consistency with the DNV report, we adopt the same terminology here.

7.2 Deterioration and replacement modelling

GiB events resulting from failures in mains pipes and steel service pipes were modelled separately in the DNV analysis. The models estimate the fraction of pipes that will fail and that will result in GiB events in each year of the prediction period, 2023 to 2055, and combine the estimate with the length of the network to predict the number of GiB events in each year.

7.2.1 Steel service pipe model

As there were few data for steel service pipe failures, a simple model assuming a constant rate of failure and a constant fraction of GiBs per failure was used. Both factors were estimated using data for the period 2014 to 2021 provided by Cadent (the only robust data set available for the specified period). The calculation of the failure rate also used failure rates from other networks over a shorter period to scale the rate estimated from the Cadent data over the full range from 2014 to 2021.

7.2.2 Mains pipes model

For mains pipes, a statistical model was developed that allows the fraction of pipes that fail in each year and the fraction of failures that result in GiB events to vary over the prediction period.

Model outputs. The statistical model was used to make forward predictions of the number of failures (not reported) and GiB events in each year of the forecast period 2023 to 2055. Forecasts were made for each of nine asset types: three tiers for each of cast/spun iron, ductile iron, and steel mains. For each asset type two or three modes of failure were modelled: fracture (only for the three cast/spun iron asset types), corrosion (for all nine asset types), and joint failure (for all nine asset types), resulting in 21 failure groups. For each failure group, the model predicts the number of GiB events in each year of the forecast period.

Model predictors. While the model does not make pipe-level predictions, for each asset type stochastic simulations of individual pipe failures in 1,000,000 simulated pipes were used to estimate the fraction of pipes that fail via each failure mode in each year. For ease of computation, pipe lengths of 1 m were assumed so simulation of repeat failures of pipes was not needed (DNV communication, June 4, 2024). Tests of convergence demonstrated that the failure fractions estimated from the simulations were stable, and hence the model forecasts are unlikely to change significantly if different sequences of random numbers were to be used in the stochastic simulations.

The failure fractions were combined with the network length to give the predicted number of failures in each failure group. Simulated pipes do not have a failure history, so within each asset group and failure group, the probability of a simulated pipe failing depends on the age of the simulated pipe. Failure history of each cohort is used to estimate parameter values.

Model parameter estimates. The stochastic simulation of pipe failure uses probability distributions to generate the probability of failure for each failure mode for each year from 2023 to 2055 and to model in service pipe age. Standard distribution types (Weibull and log-normal) were used, each of which has two or three parameters. Parameter values for the pipe age and failure distributions were estimated for each asset type and each failure mode, respectively, by fitting the distributions to asset and historic failure data provided by all four GDNs. The installation date and hence current age of many pipes is unknown and so default values were combined with known values.

GiBs per failure have been increasing over the last two decades, so the factor to convert failures to GiB events for each failure group was estimated by a linear fit to a historical time series of annual GiBs per failure data, averaged with the constant mean value taken over ten years prior to the prediction period (as the model authors judge prediction of GiBs per failure in 2055 from the linear fit alone to be implausibly high). For Tier 1 cast/spun iron the factor increases from about 0.1 to 0.14 GiBs/failure over the prediction period.

Replacement scenario modelling. To estimate the number of failures and GiBs per year under each scenario, the length of pipe replaced under the scenario's replacement strategy was calculated and the predicted number of failures or GiB events (assuming no replacement) was reduced accordingly.

7.3 Model predictions

Under scenario A the modelled deterioration of the network (with no replacement) predicts that:

- The number of GiB events, relative to current values, increases significantly faster than the relative number of failures in mains pipes, due to the linearly increasing model of GiBs per failure.
- The number of GiB events in Tier 1 mains is an order of magnitude higher than in Tier 2 and Tier 3 mains over much of the prediction period for all mains asset types.
- Joint failures account for more GiB events than fracture and corrosion in cast/spun iron and increase at a faster rate, especially in Tiers 2 and 3.
- The number of GiB events in ductile iron and steel are each an order of magnitude lower than the number in cast/spun iron.
- The number of GiB events due to failures of steel services is constant at over 5,000 per annum.
- The total number of GiB events pooled across all asset types is dominated by those resulting from steel service failures over the prediction period.

These core predictions of the deterioration model are modified in the replacement scenarios B to E by reducing the predicted GiB events in the relevant asset categories. Each of these scenarios replaces a superset of the pipes replaced under the previous scenario: the greatest reduction in the number of GiB events comes from B (the current IMRRP) as it replaces all Tier 1 cast/spun iron within 30 m of a building and failed steel services, the two largest failure groups. Scenarios C and D both reduce the number of GiB events by similar amounts to each other.

The largest predicted reduction in the number of GiB events in 2055, per km of mains asset replaced, is for Tier 3 cast/spun iron (0.123 GiBs per km replaced), followed by Tier 1 and Tier 2 cast/spun iron, then Tier 3 ductile iron followed by Tier 1 steel mains and ductile iron. GiB events due to service failures in 2055 are predicted to be reduced by 0.003 per service replaced.

7.4 Discussion

Forward predictions from the model of network deterioration used in the replacement scenario analysis suggest that joint failures are the dominant mode of failure in iron mains pipes, as expected following the replacement of pipes with high risk of fracture as estimated by the MRPS risk score. Accordingly, the change of weights in the MRPS model for joint failures (compared with corrosion failures) in ductile iron pipes for the GD2 price control period may allow the MRPS risk model to reflect a change in the ratio of failure modes. However, the report authors note that explosions have historically been predominantly due to mains fractures, which typically release larger volumes of gas than other failure modes, including joint failure. This suggests that a post-processing step to the analysis could allow subjective weighting factors, less than one, to multiply the GiB events from non-fracture failures, giving an ‘effective’ number of GiB events for each failure mode. This may affect which asset categories give the greatest reduction in (effective) GiBs per km removed.

A notable difference from the MRPS risk model is the use of pipe age as a predictor of failure for all asset types: the MRPS risk model only uses age for corrosion and joint failures in ductile iron and steel mains that have no previous failures. If age is a valid predictor of failure probability, it could possibly be usefully incorporated into the MRPS model across all asset types to improve its predictive capability. However, if pipe age is (perhaps weakly) correlated with failure history, it may already be implicitly incorporated in the MRPS model and provide little benefit. The results we presented in Section 4.4 comparing risk scores to historic pipe-level GiB data suggest that the MRPS model, which does not use pipe age (except for corrosion and joint failure), generates valid risk scores. While the current model of network deterioration does not make pipe-level predictions, validating the model by, say, fitting it to asset and failure data before 2013, and predicting the number of failures at the network level from 2014 to 2023, would provide reassurance in the model predictions, or may indicate the level of bias and/or variability in the predictions.

Further reassurance could be provided by sensitivity studies. The current model does not incorporate parameter uncertainty, even though the parameters of the probability distributions fitted to historic data may have high levels of uncertainty due to the relatively low historic failure frequencies, and because the installation dates of many pipes are unknown. Distributions giving, say, older simulated pipes on average could increase the number of failures predicted. This may be asset-type dependent, so may affect conclusions about which asset types give the greatest benefit when replaced. A Bayesian analysis incorporating uncertainty in parameters fitted to historic data could give upper percentiles on the number of predicted failures, which would add value to the analysis from a risk assessment perspective. However, this would add considerable complexity to the analysis and there may be data considerations that make a Bayesian analysis unfeasible. Alternatively, sensitivity studies may provide value, using feasible upper and lower values of parameter values (suggested by the standard error of the values provided by the fitting routine). Likewise, sensitivity to the GiBs per failure parameterisation would be helpful to understand if/how the predictions change if the GiBs per failure does not continue increasing linearly, but, say, flattens over time.

The authors note that the use of a risk model to simulate targeted replacement of high-risk pipes would be beneficial, although this would only be the case if risk scores were used to simulate failure. In the simulation of pipe failure used in the current model, older pipes are predicted to fail on average before newer pipes, suggesting that targeting by age might be possible in the model. However, simulating the targeted replacement of specific pipes may require modelling the whole network at the pipe level (rather than using simulations to estimate the mean fraction of failed 1 m pipe lengths at the network level) and thus simulating the effect of targeting may not be possible using the current network deterioration model. Lack of targeted replacement in the model suggests that the current model may be conservative, and realistic replacement strategies may be more effective in reducing the number of GiB events than the model suggests.

8 Analysis of steel service pipe failures

Steel service pipes are not within scope of the Iron Mains Enforcement Policy, but the risk they present is in part being managed through the iron mains programme because steel services are replaced by PE (polyethylene) when a new PE main is installed.

To assess whether the rate of steel service pipe replacement needs to be increased in order to prevent the service pipe risk profile deteriorating, we have analysed incident data relating to steel service pipes provided under GSMR (Gas Safety (Management) Regulations 1996) and data on GiB events from services provided by the GDNs.

8.1 Steel services population

To inform our analysis, we asked the GDNs to provide an estimate of the number of steel services remaining on their networks. The responses that we received are summarised in Table 7. Cadent and SGN also provided estimates of the number of mixed PE / steel services remaining.

The SGN populations were estimated from historical rates of replacement activity, site survey data and current lengths of iron and steel distribution mains. The Cadent estimates are based on a survey of service pipes that was undertaken in 2002/03 as part of the national leakage test programme, with numbers adjusted in each subsequent year by the number of completed service pipe replacements.

NGN reported that fully steel services make up 12% of the total services commissioned (2,549,937). For Cadent, fully steel services make up 8.6% of the total services (11,000,806).

Table 7 Estimates of the number of steel and mixed PE / steel services remaining.

Service material	Cadent	NGN	SGN (Scotland)	SGN (Southern)
Steel	945,145	310,245	97,224	441,669
Mixed PE / Steel	78,383	No data	134,752	439,766

The networks are required to report the annual number of domestic metallic service replacements as part of their annual SPI returns. Figure 22 shows the number of domestic metallic service replacements that were carried out each year between 2015/2016 and 2022/2023. 2015/2016 is the first year for which we have data from Cadent, so it is not clear whether the large number of replacements carried out by Cadent that year was typical of the previous years. The number of replacements per year has remained fairly constant since 2016 for all networks. We assume that the dip in the number of replacements in 2020/2021 was caused by the restrictions imposed during the initial stages of the Covid-19 pandemic.

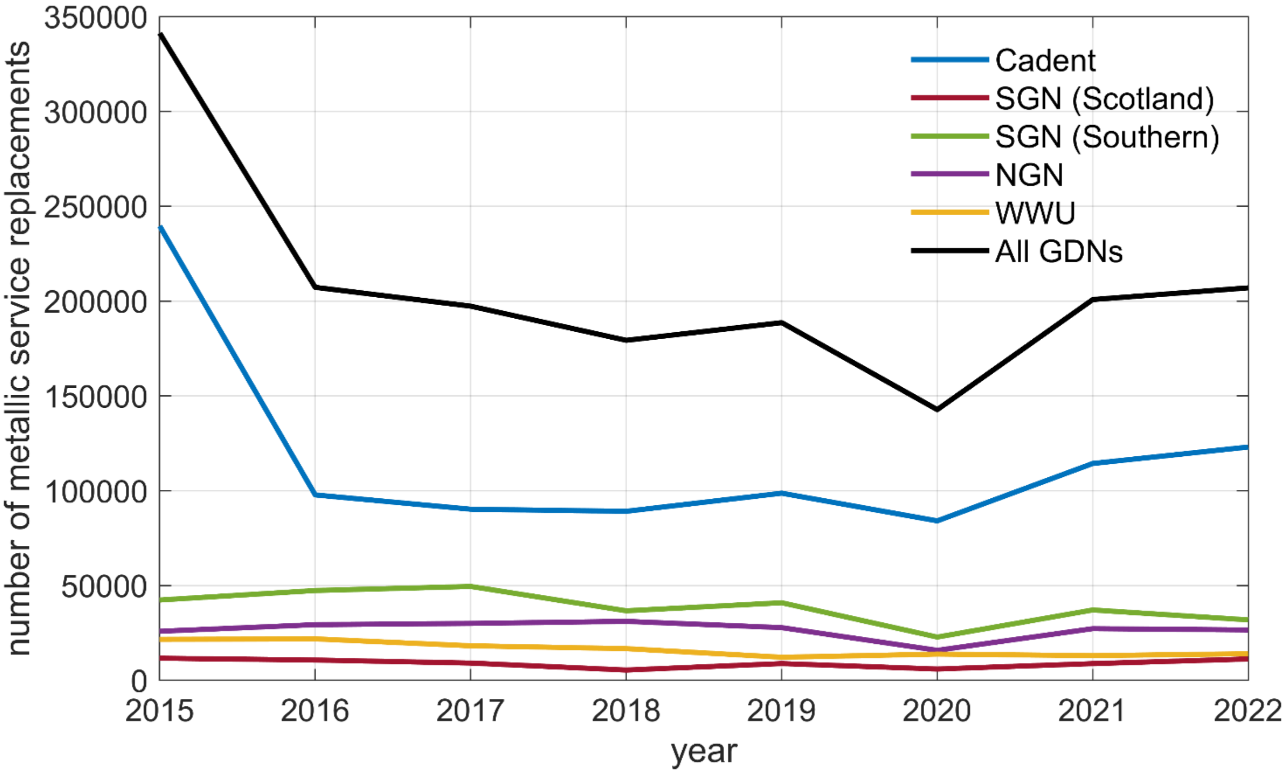

Figure 22 The annual number of metallic service replacements, as reported in the GDNs' annual SPI returns.

For the purposes of this analysis, we have assumed that the number of metallic service replacements include replacements of both steel and mixed PE / steel services. Therefore, for the networks for which we have a current estimate of the total population of metallic services (the sum of the steel and mixed PE / steel services), we can estimate the population in previous years. We have assumed that the population at the end of 2021/2022 is the sum of the population at the end of 2022/2023 and the number of metallic service replacements that were carried out during 2022/2023. This methodology has been used to estimate the total population of metallic services back to March 2012 for SGN (Southern) and SGN (Scotland) and March 2015 for Cadent. The estimated populations are shown in Figure 23.

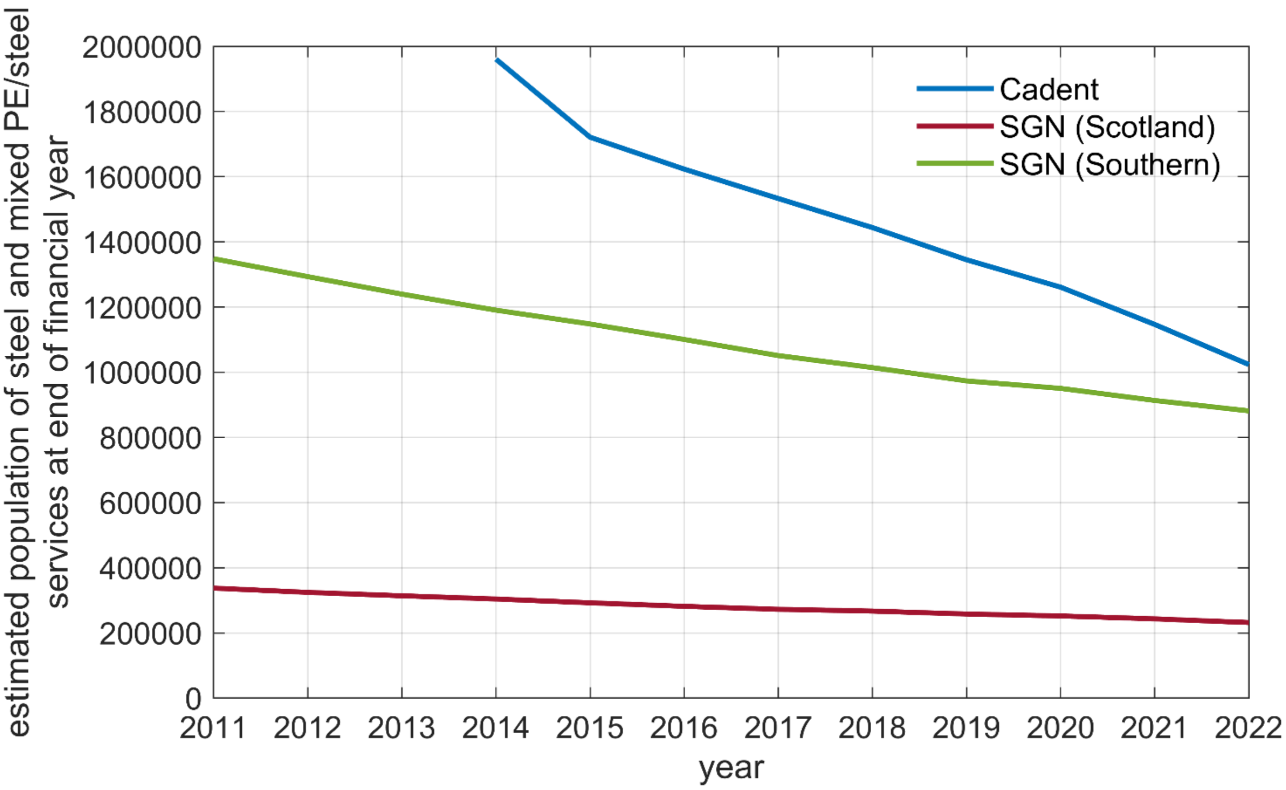

Figure 23 Estimated total population of steel and mixed PE / steel services for selected GDNs.

Regression analysis of the data shows that the total population of metallic services (summed over the Cadent, SGN (Southern) and SGN (Scotland) networks) decreased by an average of 7% a year between 2015 and 2023. This is not too dissimilar from the rate of decrease in iron mains population over the same time period, which accords with the fact that steel service pipes are replaced when the iron main to which they are connected is replaced. As discussed in Section 2.4.1, the overall population of iron mains (summed over all networks and all tiers) decreased by an average of 5.7% each year between 2013 and 2023.

8.2 Steel service failures

To comply with GSMR, the GDNs are required to notify HSE of incidents which have or could have resulted in a fire or explosion event, and to investigate them. The reports of these investigations have to be submitted to HSE. Notifiable incidents are usually interpreted as incidents which result in an injury, an evacuation or a GiB event where the quantity of gas exceeds 10 kg or the concentration of gas is greater than 20% of the Lower Explosive Limit of natural gas.

We extracted the number of GSMR notifiable steel service failures from a summary of GSMR investigation reports for the years from 2013/2014 to 2021/2022 (the last year for which a full year of data were available to us). Table 8 shows the total number of steel service failures notifiable under GSMR for each year, together with the number of those failures that resulted in a GiB event. These data are plotted on Figure 24.

Table 8 Steel service failures notifiable under GSMR (total number of failures and number of failures that resulted in a GiB event).

Year	Steel service failures notifiable under GSMR	Steel service failures notifiable under GSMR resulting in a GiB event (>20% LEL or 10 kg)
2013/2014	61	37
2014/2015	27	18
2015/2016	39	22
2016/2017	46	28
2017/2018	30	13
2018/2019	38	17
2019/2020	39	10
2020/2021	20	10
2021/2022	15	7

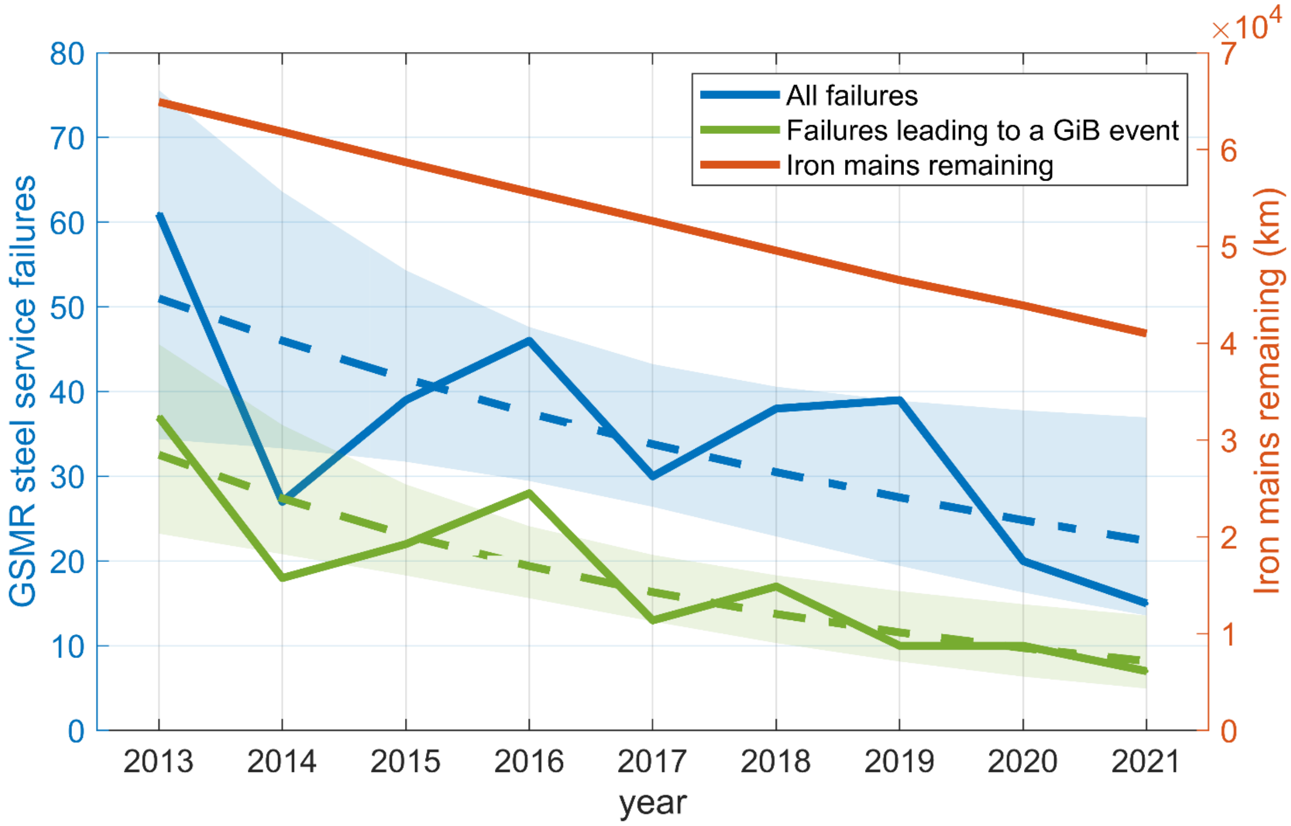

Figure 24 The variation in the number of steel service failures notifiable under GSMR between the years 2013/2014 and 2021/2022. The dashed lines represent the predictions based on Quasi-Poisson regression. The shaded areas represent the 95% confidence interval of the predictions of the regression model.

A Quasi-Poisson regression analysis was carried out on the GSMR data, which indicated that there was a statistically significant decrease in the number of GSMR steel service failures over this time period. The number of GSMR steel service failures decreased by an average of 9.8% each year, and the number of failures that resulted in a GiB event decreased by an average of 15.8% each year. These values exceed the rate of decrease in the iron mains population (5.7%, also shown on Figure 24) and the estimated rate of decrease in the total population of metallic services (7%). This may indicate that the rate of replacement of steel service pipes is sufficiently high that the service pipe risk profile is not deteriorating. However, care should be taken when interpreting these data as it is known that GSMR reporting rates vary from year to year.

No other data specific to failures of metallic services were available to us. However, GDNs are required to report the number of Gas in Building events where any percentage gas level is recorded, resulting from services, in their annual SPI returns. These data are plotted in Figure 25 and include GiB events arising from all services, including PE (polyethylene) services. The annual number of GiB events resulting from services did not decrease over the period from 2013/2014 to 2021/2022. However, this does not necessarily indicate that the risk profile of the steel service pipes is deteriorating, since some of the GiB events will result from PE services. Although PE services are less prone to failure than steel services, in recent years, approximately 20% of GSMR notifiable service pipe failures have been associated with PE services. Many of the PE service failures had an external cause, such as the service pipe being melted by a faulty electrical cable.

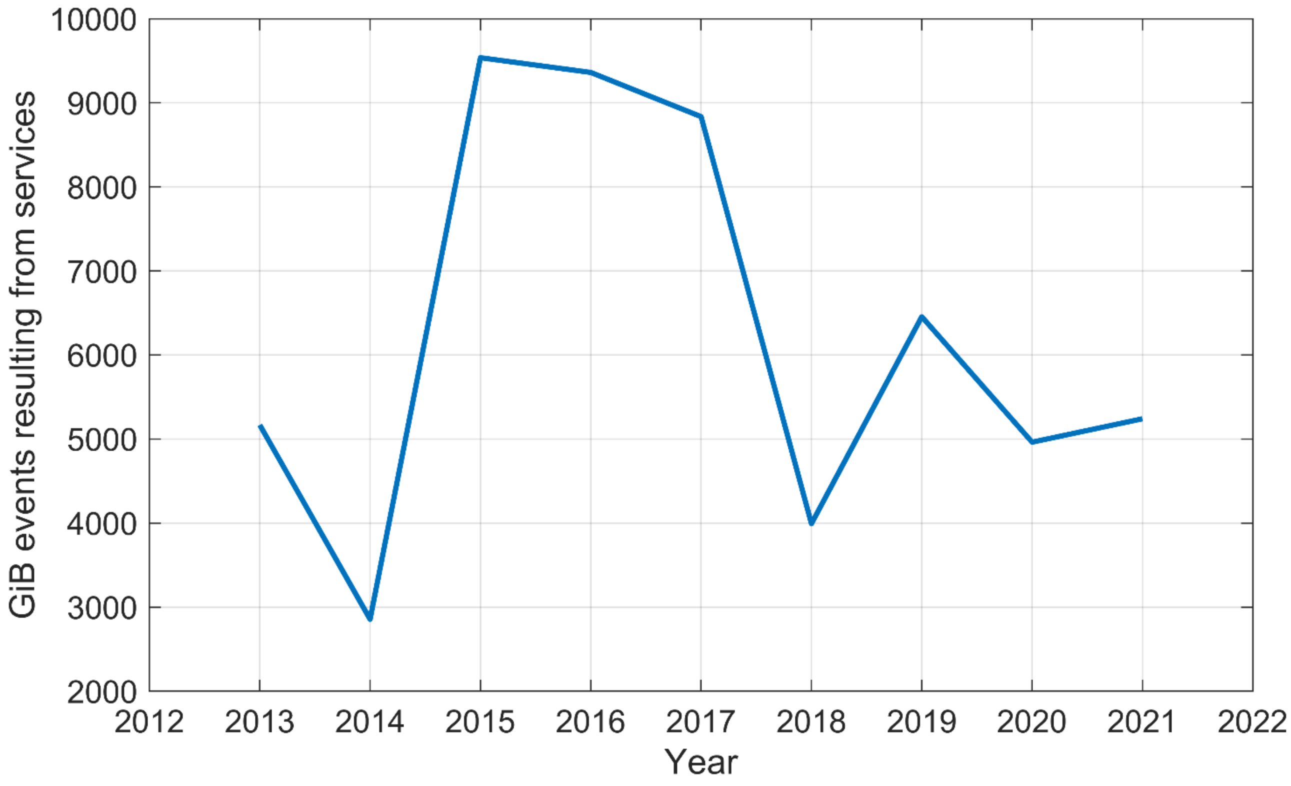

Figure 25 GiB events where any percentage gas level is recorded, resulting from services, summed over all GDNs.

8.3 Discussion

The population of steel and mixed PE / steel services is decreasing at a similar rate to the population of iron mains. The number of GSMR notifiable GiB events from steel services is decreasing at a faster rate, which may indicate that the risk profile of the steel service pipes is not deteriorating. It is possible, however, that deterioration is still occurring, but that it is not resulting in leaks large enough to cause a GiB event that is notifiable under GSMR. If data were available on the number of GiB events arising from steel services, where any percentage gas is recorded, a more thorough analysis could be carried out.

There has been no decrease in the number of GiB events from services where any percentage gas is recorded over the time period of interest, but these data are not limited to failures of metallic services, so it is difficult to draw conclusions about the condition of the remaining steel services from these data.

9 Wider considerations

The Iron Mains Risk Reduction Programme cannot be considered in isolation from the wider strategic needs of the network, such as the need to meet Net Zero targets [22]. In this review, we have considered whether there is scope for additional flexibility to be added to the prioritisation programme, to facilitate the transition from natural gas to alternatives such as hydrogen in the distribution network.

HM Government is delivering a programme of work considering the feasibility of hydrogen in the distribution network, including safety. However, current standards and guidance associated with hydrogen systems [23,24], recognised by HSE as ‘Relevant Good Practice’, indicate that cast iron should not be used in hydrogen service. Consequently, for a particular region to transition to hydrogen, all iron mains in the region would need to be decommissioned, regardless of size or proximity to buildings. As it stands, it is unlikely that this would be achieved by the end of the IMRRP, because the programme does not require the decommissioning of all Tier 2 and Tier 3 pipes, nor the decommissioning of pipes greater than 30 m from a building [2].

The networks have commissioned research to investigate this topic further, with a view to providing evidence that iron pipes can be used to transport hydrogen, subject to certain controls.

9.1 Geographical decommissioning of iron mains

We have considered whether any flexibility can be added to the prioritisation programme, to support the decommissioning of iron mains by geographical area and facilitate the transition to natural gas alternatives in a given region.

Under the current HSE Enforcement Policy [2], networks are no longer required to assign the 20% of Tier 1 pipes with the highest risk scores as mandatory, although some networks still adopt this approach [11,13]. Cadent has adopted a different approach, using a risk-based threshold to determine the mandatory Tier 1 pipes [10]. The length of Tier 1 pipe in the Cadent network with a risk score exceeding this Risk Action Threshold is much less than 20% (possibly less than 1%), giving Cadent greater flexibility in its decommissioning programme. Cadent adopted this approach in 2021, at the start of the GD2 period. As yet, there is no evidence that this approach is performing less well than that of the other GDNs, in terms of reducing the number of GiB events and fracture and corrosion events. This indicates that an approach that is less targeted by risk score may still be appropriate.

Tier 1 risk reduction programmes in which only the pipes with the very highest risk scores exceed the Risk Action Threshold (such as the programme used by Cadent) would give networks the flexibility to decommission all the pipes in a geographical area and may therefore facilitate the transition to natural gas alternatives such as hydrogen in a given region.

10 Conclusions

The aim of this review was to assess whether HSE's Iron Mains Enforcement Policy for the IMRRP has secured the decommissioning of the highest risk iron mains (leading to a significant reduction in the risk of gas escapes from the network) over the period 2013 to 2023. The findings of our review are summarised in the following sections.

10.1 Data analysis

10.1.1 Iron mains

The performance of the IMRRP was assessed by reviewing data on fracture and corrosion events and Gas in Building events on the iron mains network. Our analysis is presented in Section 2 and shows that the number of pipe failures per year is decreasing as the length of iron mains decreases. However, the number of pipe failures per km per year and the number of GiB events per km per year on the remaining cast iron network are constant or increasing slightly.

This could be a result of either incorrect prioritisation of pipes for decommissioning (i.e. a failure to remove the highest-risk iron mains) or network deterioration.

The analysis of pipe-specific data provided by the GDNs, presented in Section 4, shows a good correlation between the risk score calculated by the MRPS for a specific pipe and the number of GiB events that are observed on that pipe. This suggests that the MRPS risk scores are an appropriate measure on which to prioritise pipes for decommissioning. It should be noted, however, that the ability of the MRPS risk model to predict the likelihood of a fracture or corrosion failure is much lower.

The good performance of the MRPS may indicate that the trends in the number of pipe failures and GiB events per km per year at a network level are influenced by network deterioration. Alternatively, the trends may be a manifestation of issues with the way in which the MRPS risk scores are used to prioritise pipes for decommissioning.

10.1.2 Steel service pipes

Our analysis in Section 8 shows that the population of steel and mixed PE / steel services is decreasing at a similar rate to the population of iron mains. The number of GSMR notifiable GiB events from steel services is decreasing at a faster rate, which may indicate that the risk profile of the steel service pipes is not deteriorating. It is possible, however, that deterioration is still occurring, but that it is not resulting in leaks large enough to cause a GiB event that is notifiable under GSMR.

10.2 Review of risk factors considered in the IMRRP

HSE's Iron Mains Enforcement Policy requires the GDNs to use a risk-based approach to prioritise iron pipes for decommissioning and consequently for replacement if required. An internal HSE workshop was held to review the risk factors currently included in these calculations, both in the MRPS model and qualitatively. The workshop findings are discussed in Section 5.

The workshop participants raised concerns about the quality of the historical and survey data that are input to the MRPS.

Corrosion is not currently considered for cast iron pipes in the MRPS [3], but the workshop participants felt that most pipe failures have a corrosion element, so corrosion should be included for all pipes. It was further noted that soil type and corrosivity are likely to be key factors in determining whether a Tier 2 pipe will fail. DNV has informed us that corrosion will be modelled for all pipe types in the next release of the MRPS (DNV communication, June 28, 2024).

For distinguishing between pipes with similar risk scores, the participants suggested that more weight should be placed on the severity of the consequences of an explosion. They also suggested that pipes in areas with high population density, or near vulnerable populations or vulnerable buildings, could be prioritised.

The workshop participants felt that the risk modelling should place more emphasis on societal risk. This is particularly important for high density urban areas. They also emphasised that the cumulative risk from multiple pipes in a street should be calculated and used to inform the decommissioning programmes.

It was suggested that the GDNs should consider using Artificial Intelligence predictive systems to inform their analysis. The workshop participants also proposed that greater use could be made of the hot spot analysis that is utilised by the networks to identify higher-risk service pipes [10].

10.3 Review of pipe-prioritisation methodologies

In Section 3, we review the methodologies used by the GDNs to prioritise pipes for decommissioning, based on the outputs of the MRPS. Our review has identified multiple issues with the methodology used for Tier 2 pipes. In this methodology, the individual risk of fatality is calculated from the MRPS score and compared to a Risk Action Threshold, to determine what action is required. The following points are of particular concern:

- The MRPS outputs are being used as a measure of absolute risk, rather than a measure of relative risk. The 10-year review of the IMRP [1] raised concerns about using the MRPS risk scores in this way.

- Individual risk is being shared across multiple people in multiple buildings. This is not consistent with the definition of individual risk used by HSE [16]. This smearing of individual risk means that it is not appropriate to compare the individual risk calculated in this way with the tolerability limits for individual risk given in HSE guidance [16].

- Cumulative risk from multiple pipes is not considered. The individual risk of fatality posed by a specific pipe may be below threshold, but when combined with the risk posed by other pipes in the vicinity, the cumulative risk may exceed the threshold.

- No action is required for Tier 2 pipes with risk scores below the Risk Action Threshold.

- Some networks have no Tier 2 pipes with risk scores above the Risk Action Threshold.

- For most networks, the Tier 1 Risk Action Threshold is significantly lower than the Tier 2 Risk Action Threshold.

- The MRPS does not currently include corrosion events for cast iron, which could be significant for larger pipes. DNV has informed us that corrosion will be considered for all pipe types in the next release of the MRPS (DNV communication, June 28, 2024).

10.4 Review of condition monitoring regimes

Condition monitoring is used to help identify high-risk pipes in Tiers 2 and 3. The GDNs' current condition monitoring regimes are based on leakage surveys. An internal HSE workshop was held to discuss current condition monitoring techniques and possible alternative approaches. The workshop findings are summarised in Section 6.

The workshop participants identified a number of concerns about the use of leakage surveys for condition monitoring, including:

- Leakage surveys are a lagging indicator.

- Issues with staff competency and the ability to follow processes accurately may limit the quality of the data obtained from leakage surveys.

- It is unclear whether GPS data are recorded during leakage surveys.

The use of advanced leakage detection systems, such as Picarro [8] (currently being trialled by two GDNs) would address many of the concerns raised.

Workshop participants felt it would be better to base condition monitoring on pipe integrity measurements (a leading indicator) rather than leakage surveys (a lagging indicator).

However, it was noted that this approach may be hampered by a lack of historic condition data.

10.5 Review of report on alternative replacement scenarios

DNV has carried out a study of alternative replacement scenarios for mains and services in the GD3 price-control period and beyond [9]. To evaluate the impact of each scenario, DNV developed a statistical model of network deterioration. Our review of the DNV study is described in Section 7.

The model of network deterioration includes pipe age as a predictor of failure for all asset types: the MRPS risk model only uses age for corrosion failures in ductile iron and steel mains that have no previous failures. If age is a valid predictor of failure probability, it could possibly be usefully incorporated into the MRPS model across all asset types to improve its predictive capability.

Our review noted that incorporating parameter uncertainty into the model of network deterioration, and carrying out sensitivity studies, could provide further confidence in the model outputs.

The current model of network deterioration does not make pipe-level predictions, so cannot be used to model targeted replacement of specific pipes. Lack of targeted replacement in the current model of network deterioration suggests that the model may be conservative, and realistic replacement strategies may be more effective in reducing the number of GiB events than this model suggests.

10.6 Options for revising the Iron Mains Enforcement Policy

Based on the findings of our review, we present the following options for revising HSE’s Iron Mains Enforcement Policy as it enters the final six years of the 30-year programme (2026-2032), to ensure that it remains fit for purpose.

10.6.1 Tier 1

The current Enforcement Policy requires all Tier 1 pipe within 30 m of a building to be decommissioned by 2032. It may not be practicable to accelerate the Tier 1 decommissioning programme beyond what is already planned.

The current Enforcement Policy gives the GDNs flexibility about how Tier 1 pipes are prioritised for decommissioning. Tier 1 decommissioning programmes in which only the pipes with the very highest risk scores are mandatory (rather than the 20% of pipes with the highest risk scores as currently practised by two of the GDNs) would give networks more flexibility to decommission all the pipes in a given geographical area and may facilitate the transition to natural gas alternatives such as hydrogen in a given region.

A revised Enforcement Policy could more strongly encourage GDNs to take advantage of this flexibility and carry out more decommissioning on a geographical basis.

10.6.2 Tier 2

This review raised multiple concerns about the methodology currently used to prioritise Tier 2 pipes for decommissioning or other appropriate attention. One particular concern was the fact that no action is required for Tier 2 pipes with risk scores below the Risk Action Threshold. This could be addressed in a revised Enforcement Policy.

Another concern was the large difference between the Tier 1 and Tier 2 Risk Action Thresholds used within some LDZs. One option would be to require consistent Risk Action Thresholds to be used for Tier 1 and Tier 2 (however, this approach may not be feasible if the GDNs choose to use a more flexible approach for Tier 1 decommissioning that is less targeted by risk score).

The data analysis carried out for this review showed that there is a good correlation between the risk scores for Tier 2 pipes and the observed number of GiB events. It may therefore be appropriate to introduce a programme for addressing high-scoring Tier 2 mains.

10.6.3 Condition monitoring

Many of the concerns raised about the use of leakage surveys for condition monitoring would be addressed by the use of advanced leakage detection systems. A revised Enforcement Policy could encourage a move to such systems and the use of data for smaller leaks as leading indicators of a pipe’s condition.

11 References

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12 Appendix 1: Tier 3 data for network level analysis

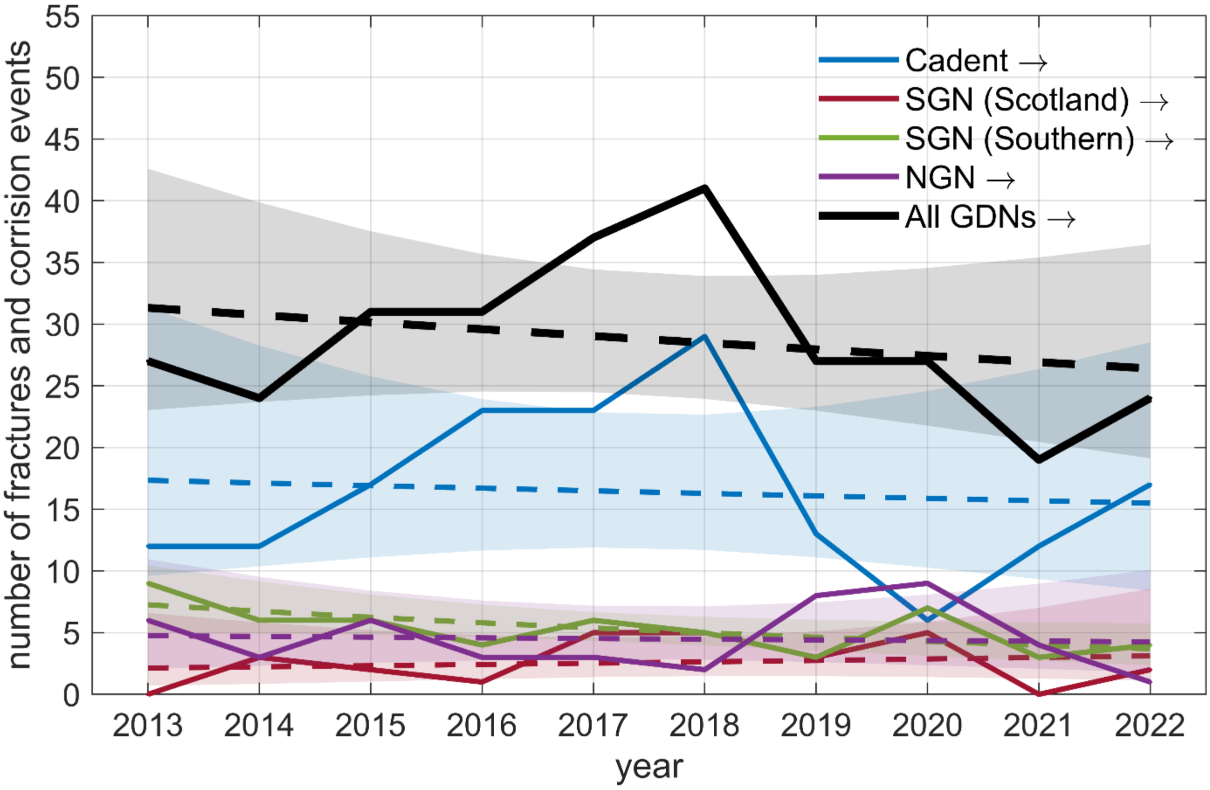

Figure 26 The number of fracture and corrosion events associated with Tier 3 pipes, showing the Quasi-Poisson regression analysis.

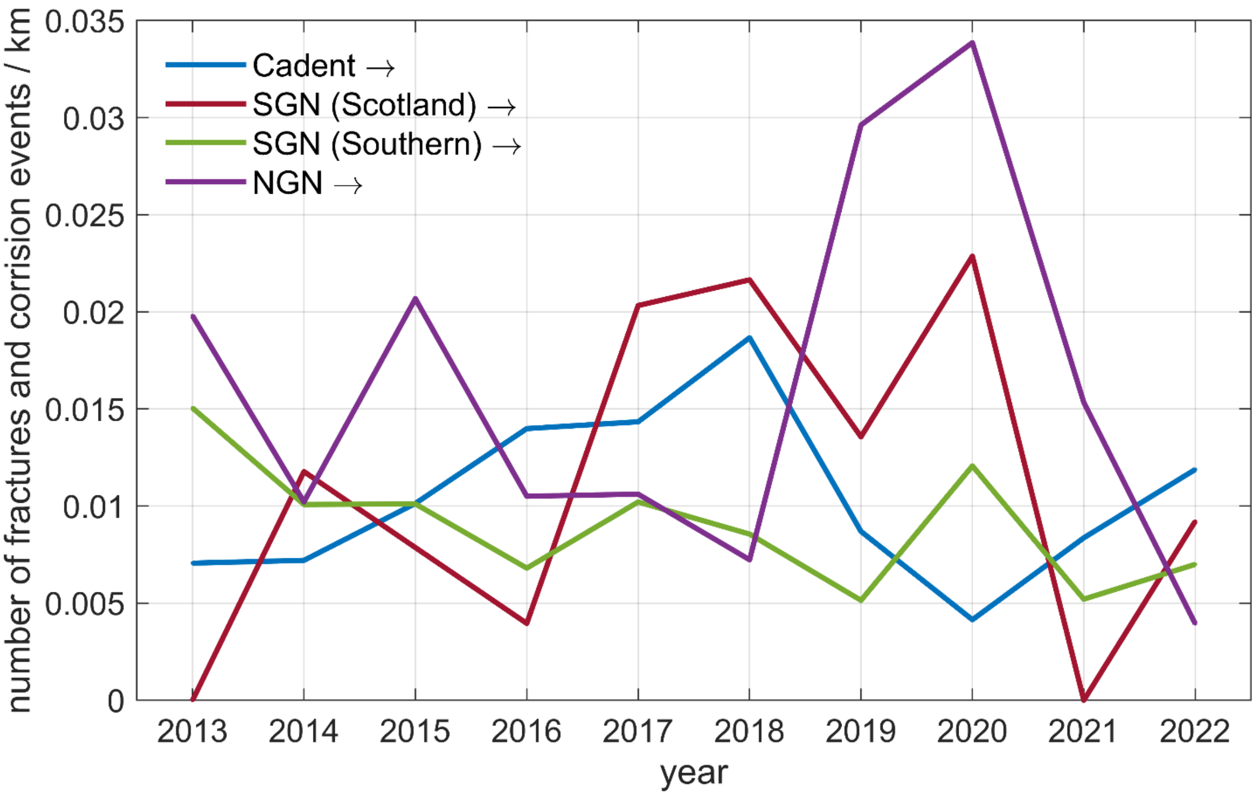

Figure 27 The number of fracture and corrosion events per km associated with Tier 3 pipes.

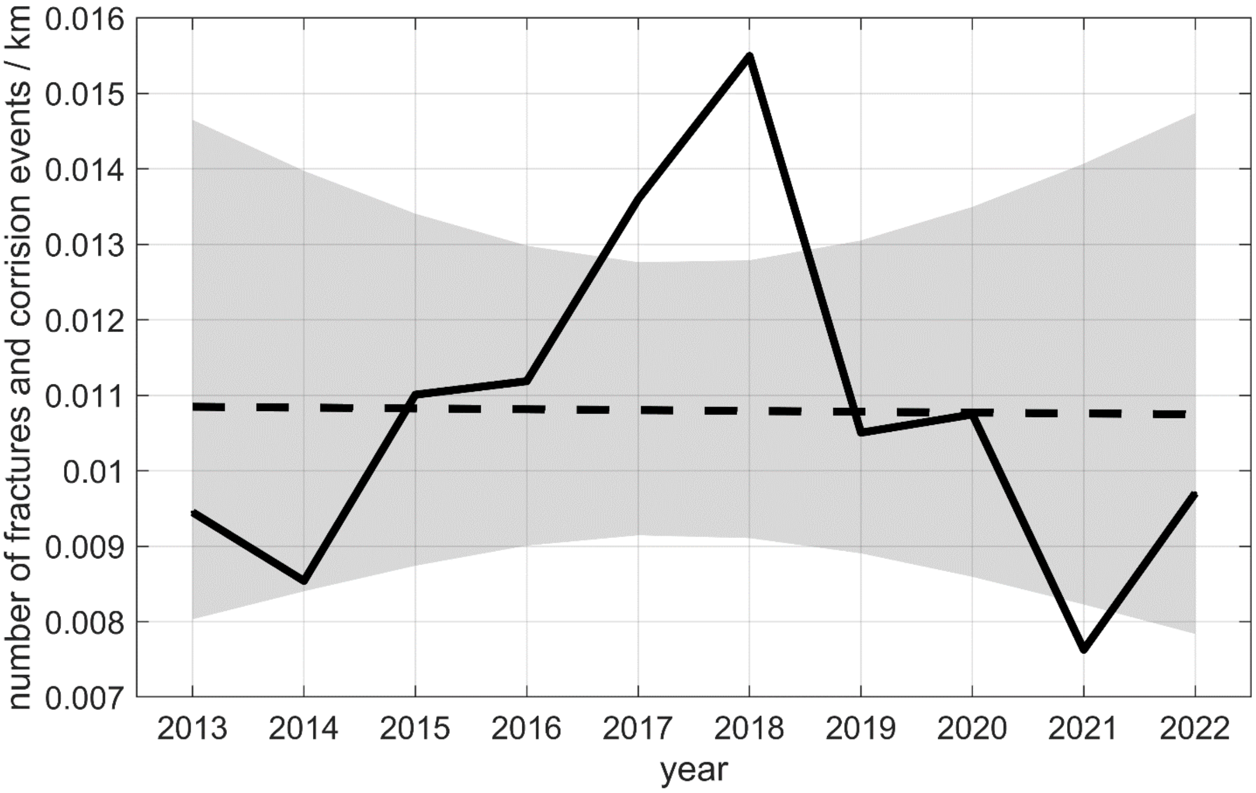

Figure 28 Quasi-Poisson regression of the number of fracture and corrosion events per km associated with Tier 3 pipes, summed over all GDNs. The data do not show a statistically significant trend.

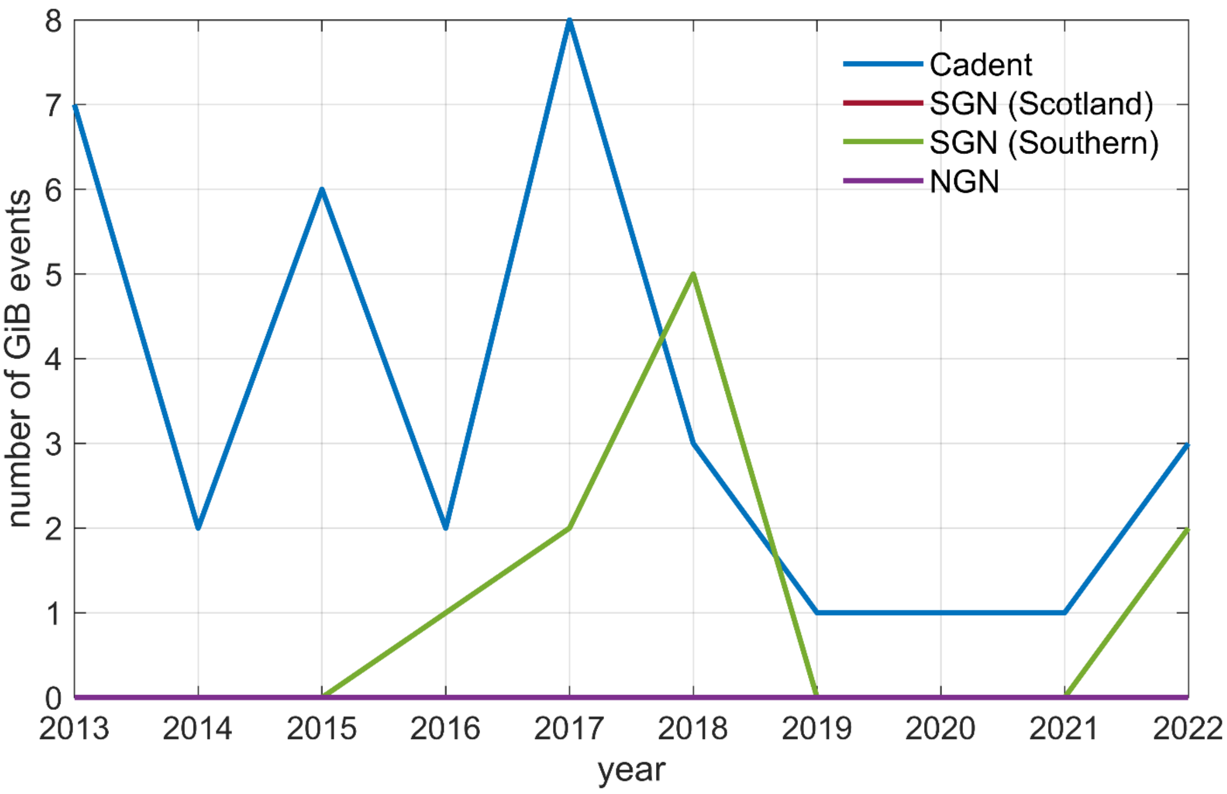

Figure 29 The number of Gas in Building events associated with Tier 3 pipes. No GiB events associated with Tier 3 pipes were recorded by SGN (Scotland) or NGN in this time period.

13 Appendix 2: Breakdown of pipe object risk scores by GDN

Table 9 Fraction of GiB events and failure events in the 5% and 20% of Tier 1 pipes (pooled over materials) with the highest risk scores per year.

GDN	Event	2013 5% of length	2013 20% of length	2018 5% of length	2018 20% of length	2023 5% of length	2023 20% of length
Pooled	GiB	27%	45%	20%	43%	37%	61%
Cadent	GiB	8%	37%	8%	34%	12%	33%
NGN	GiB	36%	53%	27%	45%	20%†	40%†
SGN	GiB	26%	45%	25%	42%	70%	84%
WWU	GiB	46%	68%	38%	73%	77%	100%
Pooled	Failure	10%	25%	9%	28%	10%	30%
Cadent	Failure	10%	27%	8%	25%	8%	27%
NGN	Failure	14%	32%	12%	29%	10%	28%
SGN	Failure	9%	26%	10%	26%	14%	35%
WWU	Failure	31%	53%	20%	43%	32%	60%

† The number of events corresponding to this entry is below 10.

Table 10 Fraction of GiB events in the 5% and 20% of Tier 1 Cast Iron/Spun Iron pipes and Tier 1 Ductile Iron pipes with the highest risk scores per year.

GDN	Material	2013 5% of length	2013 20% of length	2018 5% of length	2018 20% of length	2023 5% of length	2023 20% of length
Pooled	CI/SI	27%	45%	20%	41%	40%	61%
Cadent	CI/SI	9%	37%	7%	30%	11%	35%
NGN	CI/SI	35%	58%	29%	44%	0%†	33%†
SGN	CI/SI	26%	47%	25%	41%	68%	83%
WWU	CI/SI	44%	66%	42%	71%	90%	100%
Pooled	DI	18%	29%	17%	50%	45%	73%
Cadent	DI	0%†	29%†	3%	23%	16%	53%
NGN	DI	20%	84%	22%	68%	50%†	50%†
SGN	DI	17%	61%	25%	50%	73%	92%
WWU	DI	29%†	29%†	13%†	25%†	83%†	100%†

† The number of events corresponding to this entry is below 10.

Table 11 Fraction of GiB events in the 5% and 20% of Cast Iron/Spun Iron Tier 1, Tier 2 and Tier 3 pipes with the highest risk scores per year.

GDN	Tier	2013 5% of length	2013 20% of length	2018 5% of length	2018 20% of length	2023 5% of length	2023 20% of length
Pooled	1	27%	45%	20%	41%	40%	61%
Cadent	1	9%	37%	7%	30%	11%	35%
NGN	1	35%	58%	29%	44%	0%†	33%†
SGN	1	26%	47%	25%	41%	68%	83%
WWU	1	44%	66%	42%	71%	90%	100%
Pooled	2	25%	39%	12%	34%	31%	64%
Cadent	2	13%†	50%†	0%	24%	16%	29%
NGN	2	18%	26%	14%	31%	0%†	0%†
SGN	2	31%	46%	15%	43%	58%	88%
WWU	2	20%†	60%†	17%†	67%†	100%†	100%†
Pooled	3	10%	25%	11%	24%	10%	16%
Cadent	3	0%†	0%†	0%†	33%†	0%†	0%†
NGN	3	0%	17%	3%	8%	0%†	0%†
SGN	3	5%	33%	23%	45%	14%	18%
WWU	3	0%†	0%†	0%†	0%†	0%†	0%†

† The number of events corresponding to this entry is below 10.

The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains with the risk of injuries, fatalities, and property damage. A review of the IMRP was carried out in 2011 and published as HSE Research Report 888. Following the review, the IMRP was renamed the Iron Mains Risk Reduction Programme (IMRRP) and the HSE Iron Mains Enforcement Policy governing the IMRRP was revised taking into account the review findings.

This report describes research commissioned in 2023 to review the progress of the IMRRP since 2013 to:

- **determine whether over the period 2013-2023 the Iron Mains Enforcement Policy has secured the decommissioning of the highest risk iron mains; and**
- **consider if there should be changes to how the programme is structured as it enters the final six years of the 30-year programme (2026-2032).**

The review found that the number of pipe failures recorded each year per kilometre of remaining iron mains is increasing slightly and identified concerns with the methodology used to prioritise larger diameter pipes for decommissioning. The review also suggests an alternative approach to address weaknesses in the Condition (integrity) Monitoring practices currently used by the Gas Distribution Networks. Based on the findings of our review, we present a number of options for revising HSE’s Iron Mains Enforcement Policy as it enters the final six years of the 30-year programme (2026-2032), to ensure that it remains fit for purpose.

DOI: https://doi.org/10.69730/hse.24rr1216

Published by the Health and Safety Executive 10/24