Attachment 8.17

Response to Draft Decision:
HSE/Ofgem: 10 Year Review of the Iron Mains Replacement Program

A report by CEPA

2016/17 to 2020/21 Access Arrangement Information Response to Draft Decision

Australian Gas Networks

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Health and Safety Executive

HSE/Ofgem: 10 year review of the Iron Mains Replacement Programme

Prepared by **Cambridge Economic Policy Associates Ltd** for the Health and Safety Executive and Office of Gas and Electricity Markets 2011

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Research Report

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Health and Safety Executive

HSE/Ofgem: 10 year review of the Iron Mains Replacement Programme

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The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains and the consequent risk of injuries, fatalities and damage to buildings (defined as incidents). The objective of the IMRP was to decommission all cast iron mains within 30 metres of property in 30 years - the IMRP is often referred to as the '30/30' programme. The IMRP accelerated the replacement of cast iron mains to a level that was estimated to be as fast as practicable at that time, given the potential risks faced by society and the resources required. The IMRP excluded steel mains and services from the replacement programme as potential risks from steel, at that time, were considered to be at a lower level than risks from cast iron mains.

The Health & Safety Executive (HSE) and Office of Gas and Electricity Markets (Ofgem) have commissioned jointly an independent review to assess the progress of the IMRP to date, and evaluate potential options for the remaining 20 years of the original programme. Cambridge Economic Policy Associates (CEPA), working in partnership with Advanced Engineering Solutions Ltd (AESL), has been contracted by the HSE and Ofgem to conduct this review.

Advanced Engineering Solutions Ltd has considered the overall performance of the IMRP since 2002, as evident from assessment of operational data provided by all Gas Distribution Networks (GDNs). This technical report records the apparent performance of the IMRP, as evident from the data study, and any perceived characteristics or other observations arising from the study. The AESL analysis is intended to inform and advise CEPA of technical issues relevant to this report "HSE/OFGEM: 10 Year Review of the Iron Mains Replacement Programme".

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IMPORTANT NOTICE

This report has been commissioned jointly by the Health and Safety Executive and Ofgem to complete an independent review of the Iron Mains Replacement Programme. However, the views expressed are those of the authors alone.

CEPA accepts no liability in relation to use by any third party of the analysis or recommendations contained in this report.

CONTENTS

GLOSSARY

This section defines the key terms used throughout the report.

- 30:30 programme – The Iron Mains Replacement Programme
- ALARP - As Low as Reasonably Practicable
- CBA - Cost Benefit Analysis
- Deterioration rate – defined in report as % change in the rate of incidence of failure per Kilometre per annum
- GDN Gas Distribution Network
- GIB – A reportable Gas in Building event
- IMRP – Iron Mains Replacement Programme
- Km – Kilometres
- Large diameter mains > 12 inch mains
- LP – Low pressure (≤ 75 millibar)
- MRPS - Mains Risk Prioritisation System
- MP – Medium pressure (> 75 millibar & ≤ 2 bar)
- NPV - Net Present Value
- NGG – National Grid Gas
- NGN – Northern Gas Networks
- PSR - Pipeline Safety Regulation
- PE – Polyethylene main
- SGN – Scotia Gas Networks
- Small diameter mains ≤ 12 inch mains
- WWU – Wales and the West Utilities

EXECUTIVE SUMMARY

ES.1 Introduction

Cambridge Economic Policy Associates (CEPA), working in partnership with Advanced Engineering Solutions Ltd (AESL), has been contracted by the Health & Safety Executive (HSE) and Office of Gas and Electricity Markets (Ofgem) to conduct a comprehensive review of the Iron Mains Replacement Programme (IMRP).

Based on the Terms of Reference (ToRs) (presented in Annex A) the objectives of the review were as follows:

- Review and assess evidence of the effectiveness of the programme to date in particular related to its delivery and the robustness of the risk modelling.
- Review the initial assumptions and objectives behind the replacement expenditure programme and confirming if these are still appropriate.
- Complete a full cost-benefit-analysis (CBA) and impact assessment to assess whether the IMRP is proportionate to the level of risk involved and to evaluate the potential impact of changes to the design of the programme for instance changes in the rate of iron mains replacement.
- Consider potential options to deliver risk reduction on the distribution network more effectively.

To meet these objectives we have managed the completion of the review over two stages.

The first stage involved the collection of data and information from the HSE, Ofgem, the GDNs, which we obtained by issuing a questionnaire. The objective of this was to establish, as far as possible, the pertinent facts, in terms of technical and financial data, necessary to undertake the review. The main output from the first phase of analysis was an Interim report which set out the results arising from the investigation into the available to data.

Following the receipt of comments on the Interim report from the HSE, Ofgem and the GDNs we moved onto the second stage of the analysis, which involved interpreting the data and information available to produce the ex post assessment of the IMRP and to develop the CBA and forward looking assessment.

This report brings together the analysis presented in the Interim report together with the ex-post review and forward looking analysis of the IMRP to provide a comprehensive response to the requirements set out in the ToRs.

Throughout both stages of the review both CEPA and AESL have met the HSE, Ofgem and the GDNs on a number of occasions to keep them informed of progress.

The remainder of the Executive Summary draws out the key findings and issues that we encountered while completing the review that may be of particular importance when determining the future development of the programme.

ES.2 Data availability, quality and usage

A significant issue that has arisen during the study has been the availability of the data required to address many of the questions asked in the Terms of Reference (ToRs), particularly those questions relating to network assets outside of the Iron Mains Replacement Programme (IMRP). Even with the IMRP related data, whilst the GDNs have been responsive to us within a relatively short space of time, the information received was sometimes incomplete or incorrect and often in inconsistent formats. In particular it was difficult to establish data consistency across the different sources of information available. For instance, we would expect that the data on the 'at risk' mains population from the Mains Risk Prioritisation System (MRPS) would be broadly consistent with the data presented in the Business Plan Questionnaires (BPQs) – however, this was not always the case. The problems with the quality and consistency of the data that we received limited the inferences that we could draw while completing the analysis.

The impression that we have formed while completing the review is that data capture over the life of the IMRP has not been a priority by the GDNs. In part, however, this may be a result of the programme failing to stipulate these monitoring requirements, as well as an absence of more general regulatory requirements for such data to be kept.

A recommendation going forward is therefore that much greater effort is made to capture and interrogate the types of data necessary to optimising the programme on a year to year basis and to be used in any future appraisal / review of the programme.

ES.3 Evidence of the effectiveness of the programme to date and robustness of the risk modelling

ES.3.1 Evidence of effectiveness of the programme to date

Determining the effectiveness of the programme to date has several aspects. At the highest level this might be taken as to whether the programme has reduced unfavourable outcomes and impacts arising from the remaining "at risk" iron mains network. At another, it involves whether it has been undertaken in the most effective manner, particularly from a cost perspective.

The extent to which the programme has been effective at removing the risk of an incident arising from the network is difficult to observe directly. The two main approaches are to try to observe the direct outcomes in terms of fracture rates, GIBs and incidents and impacts, after controlling for other influences; and the second, is to try and model the level of risk removed. As we discuss – the latter in the next sub-section – these are very difficult to do.

Outcomes and impacts

Whilst the ultimate objective of the IMRP may have been to avoid undesired impacts of network failure, such as damage to property and other infrastructure, personal injury and death, because of other contributing factors, these may not necessarily be the best measures of the success of the programme per se. Indeed, even favourable outcomes in reducing GIBs and incidents are downstream benefits from the direct outcome of the IMRP which is to reduce the chances of mains fracture or other means of failure. In other words, the direct influence of the IMRP is on reducing the number of fractures from what might otherwise have been the case, if the mains in question had not been removed and the probabilities of GIBs and potentially incidents that this would then give rise to.

However, even when attempting to calculate the influence of the IMRP on reducing the number of fractures, isolating the influence of other factors is far from trivial. Such factors would include the impact of weather and other factors involved in deterioration, which remains a highly controversial point. Indeed, there are many views on the extent of and rate of deterioration of the remaining network. As set out, it is also important to consider the variance in the deterioration rate by area, which could range significantly. Obviously, though, the greater the extent of deterioration in a given area and overall, the more difficult it is for replacement activity to keep pace, as illustrated in the CBA that we have carried out.

Although subject to varying finite “engineering” lives, not all mains have been subject to failure and some have been much more problematic than others. Therefore, another aspect of effectiveness is whether those most problematic mains have been removed, at least within the parameters placed on them. Whether this has occurred is linked to the accuracy of the model which is discussed below.

A further method of assessing the success of the programme would be for a more systematic checking of the conditions of mains that have been decommissioned either by inserts or full replacement. Although this analysis may be partial, it may give some idea of the condition of the mains being replaced. However, the medium pressure ductile iron mains which were linked to a number of incidents were removed early on in the programme.

Therefore, the evidence for the effectiveness of the programme to date remains mixed; although it is difficult to be completely definitive without being able to control for other factors, particularly deterioration.

ES.4 Risk modelling

The role of the risk model is central to IMRP, particularly as it used by the GDNs to help prioritise their replacement activity. At present the MRPS outputs are used to calculate the risk of an incident, and to provide an indication of the risk removed by replacement activity.

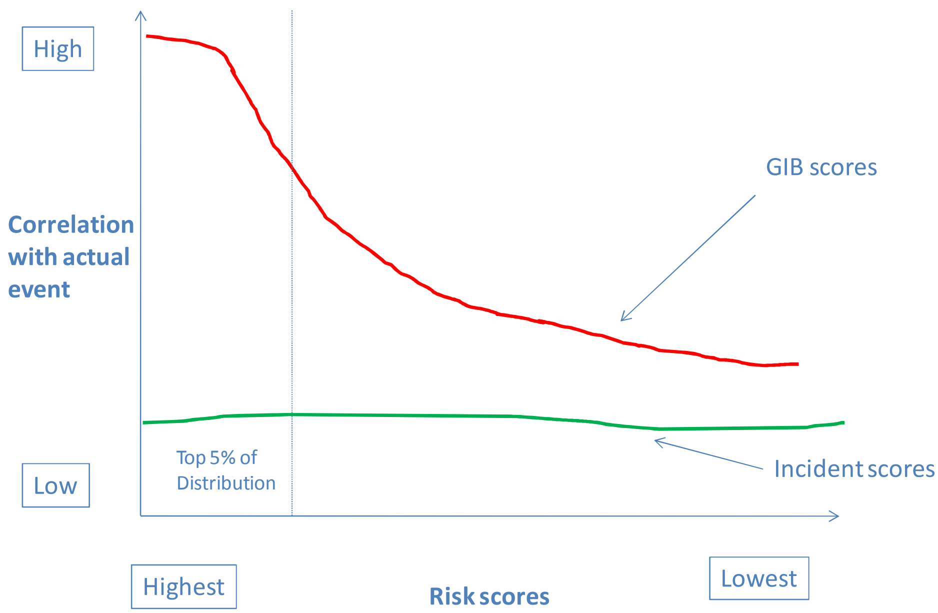
However, our review suggests that the MRPS and its outputs are not necessarily being used in the most appropriate way, and that the data contained in the model could potentially be used more effectively to address many of the issues raised in the terms of reference.

ES.4.1 Calculating the risk of an incident

The direct output from the MPRS is a measure or score, for each mains remaining in the ground, of the risk of an incident occurring per Km. As explained in the main report, this score is a function of the fracture, GIB and consequence factors.

The analysis carried out while completing the review would seem to suggest the risk scores show a good correlation with GIB events (and by inference fractures) but less so with incidents, as illustrated in Figure ES.1 below.

Figure ES.1: Correlation between the risk score and both GIBs and incidents



The extent to which the consequence factor changes the risk ranking of mains is not entirely clear, but it does suggest that there is limited mileage in basing the prioritisation of replacement activity on the risk of incident, when the model has much more power in predicting GIBs and fractures.

ES.4.2 Risk removed

The model has also been used as a means by which to estimate how much risk of incident has been removed from the network. However, a reliance on this measure seems to be even more problematic, both in terms of estimating the risk removed by replacement activity and in using such measures to construct equivalent (in terms of risk removal) repex programmes across different network assets.

Overall, we would argue, that using the scores in such a way bestows a level of accuracy on the model outputs which cannot be justified, particularly given the extreme difficulties in calculating a risk of an incident on which the scores are based. We would consider that using these scores for purposes of trading equivalent amounts of risk; for instance, substituting a higher risk mains for a similar equivalent sum of lower risk scored mains; is highly spurious (especially as higher risk scores would still appear to have a higher correlation with actual GIBs).

ES.4.3 Potential of the model

The risk model does, however, include substantial amounts of potentially highly useful data, although it is not clear that optimum use is currently being made of this. Because risk ranking is based on risk of incidents – which to a degree is understandable because of the existing health and safety framework, there is a chance that disproportionate amount of time is focused on trying to increase the model's ability to predict incidents, rather than in interrogating the other information it holds. Although there are some bespoke projects being looked at there are several things that might be examined, not least attempting to identify national, regional and local evidence of deterioration.[1][2]

Focusing on fractures and GIBs is likely to be much more fruitful given the substantial data that exists. This could be used to provide historical and distributional trends in fractures and GIBs which could help to fine tune replacement expenditure based, for instance, on clusters of fractures and or GIBs, a theme we return to in options going forward. This could help in the development of understanding of deterioration and where it is worst, thus potentially helping to make the replacement more targeted and /or cost effective.

In addition, it might also make sense to expand the remit of information capture to include services and other potential at risk network assets. The case for a central repository would be that it would then be easier to run more comprehensive analyses.

In going forward, ideally governance structures should be constructed that provide for the data contained within the model to be exploited to the full.

ES.5 Future development of the programme

ES.5.1 Cost benefit analysis

The CBA and options appraisal that is presented in the report is subject to uncertainty and should be interpreted as such. However, it does provide an illustration of the magnitude of costs and benefits that might arise from reforming the structure and or surrounding legal and regulatory framework of the IMRP.

One of the main findings from the CBA is that the main benefits arising from the IMRP relate to network efficiency (reduced repair costs and reductions in the level of private shrinkage) and environmental benefits (lower emissions). Health and safety benefits, although clearly important, are not material when set against the costs of the programme. However despite what the analysis shows, care must be taken in equating the same monetary amount of the different benefits identified.

As part of the CBA we compared the IMRP in its current form to a number of potential options for reforming the programme going forward. Potentially the most interesting result from the options appraisal is that in simple cost-benefit terms the analysis shows that there may be a significant benefit arising from restricting replacement activity to focus on smaller diameter mains. Importantly these benefits are robust to the different deterioration rate assumptions.

ES.6 Options for delivering risk removal more effectively

Taking the network as a whole, the issue of risk removal is effectively part of how to manage overall network risk in terms of avoiding incidents, irrespective of from where they arise. The IMRP as regards replacing the iron mains and repex more broadly, is a major tool in this risk management framework, although they are not the only ones available. For instance, it is

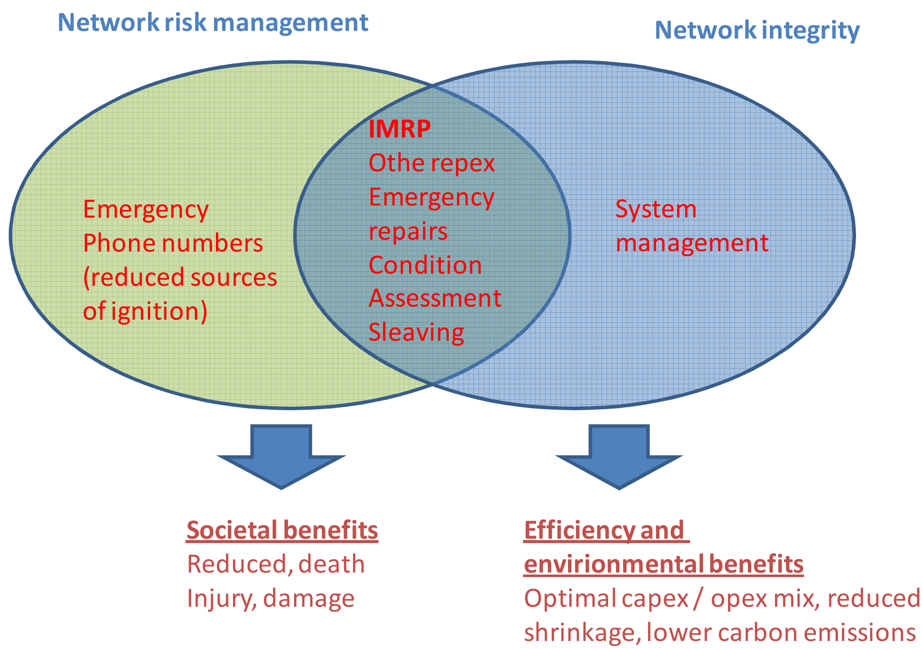
[1] Such as the Advantica (2004) report into large diameter cast iron mains. Advantica (2004), Large diameter cast iron mains failure investigations.

[2] For the purposes of the review the deterioration rate is defined in the change in the rate of failure per Km per annum.

possible that fewer ignitions of gas have occurred in recent years due to prompter reporting of gas leaks (through the availability of emergency phone numbers) and possibly reduced sources of ignition (for instance, plugs being sold with appliances rather than fitted by home-owners, reduced numbers of pilot lights).

These risk management policies also overlap to a high degree with other policies undertaken by the GDNs to maintain network integrity; for instance, to reduce shrinkage, including overall system management, pressure control etc.) as illustrated in Figure ES.2.

Figure ES.2 Approach to risk management



These two different strategies contribute to the societal benefits arising from risk management and efficiency and environmental benefits that arise through maintaining overall network integrity.

To date, the IMRP is supposed to be focused very much on risk management, whereas as shown in the CBA most of its future likely benefits relate to efficiency and particularly environmental benefits. Indeed, as it has been deemed that all cast iron is not fit for purpose, all IMRP repex is based on a de facto safety grounds, when the real case is likely to be more nuanced.

In consideration of these observations, in addition to maintaining the IMRP as it is, we put forward two main alternative options for the taking forward the IMRP, which try to unpick and reconstitute safety and efficiency / environmental objectives, albeit in different ways. One is based on revisions to the existing approach, the other involves a more radical rethink of how repex is treated in general. Elements of either, however, could be incorporated into the other.

ES.6.1 Revising the existing IMRP

This option is based on the recommendations made by AESL, see Section 7 Annex F. This would involve limiting the IMRP primarily to mains below 8" in diameter, where deterioration and failure are most observed. In other words, larger diameter mains would be dealt with separately outside of the programme, as are currently other elements of repex, as they are not considered to represent the same degree of problem as smaller diameter mains.

Within this, however, replacement schemes would be undertaken on zonal basis in which a greater proportion of high risk mains would be incorporated, on the basis of either probability of fracture or GIB, rather than incident. This would make such schemes much more safety targeted, whilst trying to ensure that they remain as economical as possible.

The scale of the programme would continue as current, although may be accelerated if there is evidence of increasing deterioration, such that the replacement programme cannot keep pace.

ES.6.2 An investment case approach to repex

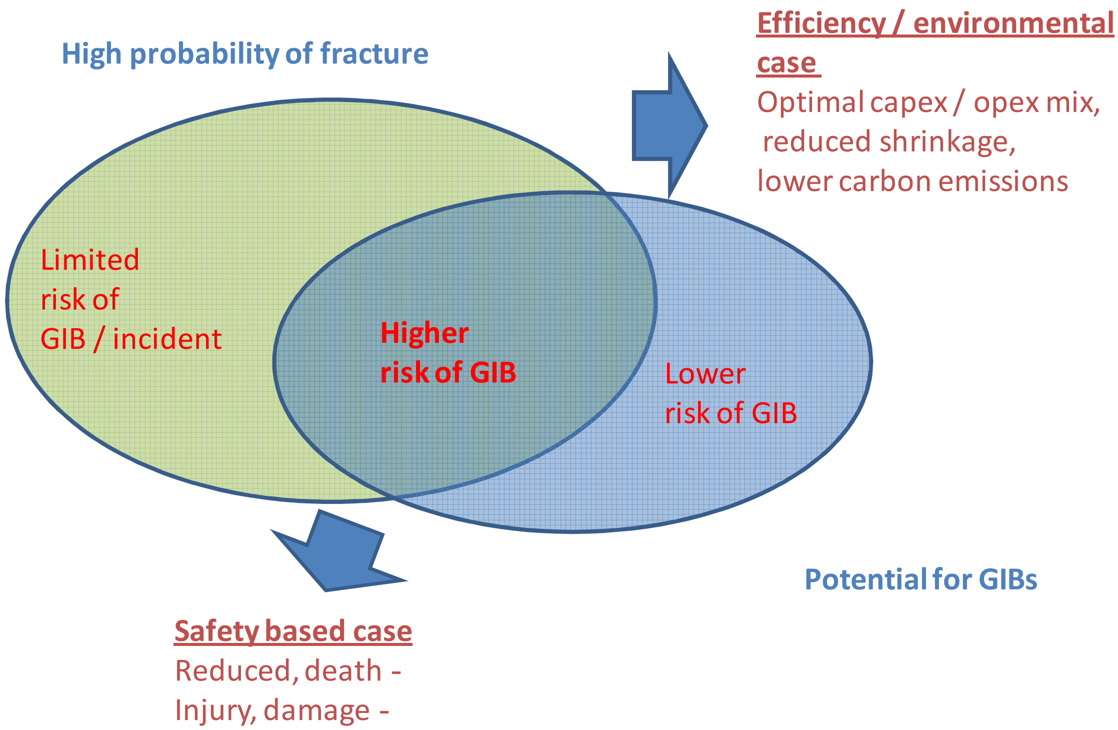
In the second option, rather than having a single monolithic IMRP which focuses exclusively on iron mains replacement, it may be desirable to have a more broad-based approach to repex, which covers all network assets, but which prioritises such expenditure on one of two bases; either safety or efficiency, rather than wrapping both up together as is arguably the case with the existing IMRP.

This might involve an overall estimate of expenditure, but would be subject to change depending upon the evidence provided. However, within this, significant amounts of repex, of whatever kind, would need to be justified on the basis of either an explicit efficiency or safety based investment case, which would have to be agreed by either HSE or Ofgem as appropriate. Therefore, one off fractures might be dealt with by repair. But more systematic failures and significant risk of GIBs should be prioritised for replacement. Where there is a significant risk of GIB, this might be addressed by a safety-based case. This might also be based around potential impacts as well as risk.

Efficiency-based cases should demonstrate the favourable economics and wider cost benefits of doing so. For instance, it is possible that a group of mains could be problematic in terms of repeated failure (by whatever means), but they might not necessarily pose such a risk in terms of the potential for a GIB, because say, the gas might be likely to be released slowly in an area with few cellars. None-the-less there would be a case for prioritising a zonal replacement programme on basis of cost effectiveness of repex as opposed to just repair. This might contrast with a situation in which repeated fracture was less of a problem but where there was still a relatively high possibility of a GIB occurring.

Both situations would have a strong case for prioritisation, but the criteria for assessing them might be different, the former being more cost based, whereas the latter would emphasise risk management / risk removal, with a commensurately higher tolerance of cost. This is illustrated in Figure 7.3.

Figure 7.3: Efficiency versus safety based investment cases



Joint targets, on the part of Ofgem, HSE and the GDNs might provide a framework for approaching these issues. Regulatory performance targets might be applied to support these objectives, although the impact of external factors – such as weather or differing deterioration rates, would ideally need to be factored in.

ES.7 Summary conclusions

The analysis has shown that to date the IMRP has been extremely expensive, given the number of lives potentially saved from it, but this was already known to be the likely outcome when the programme was originally designed. The evidence provided by AESL combined with the CBA suggests that there are a number of options available to restructure the programme that have the potential to deliver significant cost savings in the future.

It is critical that any structural changes that may occur to the IMRP in the future be accompanied with a significant improvement in the way in which data is captured and interrogated to inform the implementation of the programme. This will play an important role in optimising the delivery of the IMRP on a year on year basis going forward and would also support any future appraisal / review of the programme.

1. INTRODUCTION

The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains and the consequent risk of injuries, fatalities and damage to buildings (defined as incidents). The objective of the IMRP was to decommission all cast iron mains within 30 metres of property in 30 years - the IMRP is often referred to as the '30/30' programme. The IMRP accelerated the replacement of cast iron mains to a level that was estimated to be as fast as practicable at that time, given the potential risks faced by society and the resources required. The IMRP excluded steel mains and services from the replacement programme as potential risks from steel, at that time, were considered to be at a lower level than risks from cast iron mains.

The Health & Safety Executive (HSE) and Office of Gas and Electricity Markets (Ofgem) have commissioned jointly an independent review to assess the progress of the IMRP to date, and evaluate potential options for the remaining 20 years of the original programme. Cambridge Economic Policy Associates (CEPA), working in partnership with Advanced Engineering Solutions Ltd (AESL), has been contracted by the HSE and Ofgem to conduct this review.

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1.1. Objectives of the review

This report has been completed to develop the evidence base necessary to respond to the Terms of Reference (ToRs) for the review (included in Annex A). The development of the ToRs involved input from the HSE, Ofgem and the Gas Distribution Network Operators (GDNs).

Based on the ToRs the high-level objectives for the review are set out in Box 1.1 below.

Box 1.1: Objectives for the review
Review and assess evidence of the effectiveness of the programme to date in particular related to its delivery and the robustness of the risk modelling.
Review the initial assumptions and objectives behind the replacement expenditure programme and confirming if these are still appropriate.
Complete a full cost-benefit-analysis (CBA) and impact assessment to assess whether the IMRP is proportionate to the level of risk involved and to evaluate the potential impact of changes to the design of the programme for instance changes in the rate of iron mains replacement.
Consider potential options to deliver risk reduction on the distribution network more effectively.

1.1.1. Our interpretation of the objectives

In the sub-sections below, we set out our interpretation of these objectives and the key issues in addressing them.

The two main objectives of project are to establish (i) how the IMRP has performed to date; and (ii) how it should be implemented in future. It is therefore based around two forms of assessment: from a backward looking perspective – an *ex-post* assessment – and from a forward-looking perspective, *ex-ante* appraisal of future options.

Ex post assessment

We would interpret a core objective of the ex post assessment as being to establish how successful the IMRP has been at reducing the risks to public safety arising from the cast and ductile iron pipes population, given the costs involved. Arguably, however, the IMRP – that is, the decommissioning and replacement of iron mains is just one aspect of the required risk management of an aging network. First, the residual part of the iron mains piping that has not been replaced as part of the IMRP is likely to continue to pose a risk for many years to come. Even under the most ambitious plans it will take decades before all iron mains within the programme are replaced. Second, there are other network assets – such as services – which were not explicitly part of the IMRP, which evidence suggests have also failed.

More widely, the review provides an opportunity to extract learning from the experience of the programme to date, which might be used in refining the IMRP going forward. Part of this involves looking at the context at the time when the IMRP was introduced to see if this remains the same today.

Ex-ante appraisal

From a forward-looking perspective, it is an opportunity to consider alternative options, potentially taking into account considerations that are more recent – such as potential environmental benefits – as well as the experiences of the programme to date, which might also be taking into account looking forward. A specific issue to consider in this respect is whether the remaining risk on the iron mains network is proportionate to the level of expenditure required to deliver the programme. Again, as well as the IMRP, it is important to consider how risk relating to the residual cast iron pipes, which may represent a growing risk that cannot be addressed through the IMRP, is managed. This may involve the development and roll out of new solutions which extends the life of some of the pipes, without necessarily decommissioning them and / or a greater focus on monitoring the condition of mains. A further issue is to establish whether a broader approach to manage risk on a wider range of assets is required.

Irrespective of the direction of the future programme it is essential that all options, are as evidenced based as possible, pre-supposing that such evidence is readily available.

1.1.2. Key facts to establish

In order to establish both the success of the programme and what the future options might be, it is important to determine a number of facts, which form the building blocks for the assessment. We discuss a few of the most important below.

Residual network risk

Whilst in a perfect world, all iron mains within the IMRP would be replaced at once, this has been deemed understandably not to be practicable. Indeed, the IMRP has involved an increase in the rate of implementation relative to historical averages[3]. Moreover, whilst all iron mains have been deemed no longer fit for purpose, some were assumed to be at greater risk than others. An aspect of the IMRP was therefore to rank the mains population by level of risk, with the programme focused proportionately more on decommissioning the highest risk pipes. That said, it should be remembered that the risks of being killed in an incident was relatively low at the introduction of the IMRP; according to the analysis presented in the Lord Gill Inquiry, approximately 1 in 10,000,000, roughly double those of being killed by a lightning strike.[4]

In order to help identify an optimal replacement rate and focus, a key challenge of the project is to ascertain whether the risk of incidents on the cast iron pipe network is increasing, decreasing or staying the same, both in aggregate and by type of pipe (size, ductile versus cast iron etc) and whether that risk is proportionate to the level of expenditure. This is important, for instance, because an increasing rate of mains failures might indicate that risk was increasing despite the introduction of the IMRP and would suggest that the programme needed to change, whether by increasing the speed of its implementation or by doing it differently, depending upon the underlying cause for the increase. The opposite observation; that is, a falling number of failures, would not only be an endorsement of the programme's success to date, but could also help create a *prima facie* case for considering reducing the speed of implementation.

It is first important to consider what is meant by risk in terms of the programme. In the first instance, this is (i) the probability of a mains *failing*. This then gives rise to (ii) the potential for a Gas In Buildings (GIB) event which may then lead to (iii) the likelihood of an ignition causing an incident; that is, death and serious injury through a gas explosion. Whilst the IMRP is aimed ultimately at minimising the latter, in itself it only actually has any direct or controllable impact on the risk of pipe failure. The risk of an incident arising from a GIB and is determined by a whole range of other factors and, to an extent, might be expected to be more random, with a reduced degree of predictability.

The probability of a mains failing would appear to be determined by the underlying state of the network combined with other external shocks leading to fracture; in particular, adverse (cold) weather conditions, or poorly managed construction activities, which can lead to pipe movement and possibly to fracture. The state of the network – which might be seen as a background risk – would appear to be a function of the condition of the remaining mains network, which in turn is determined by a combination of the rate of network deterioration (arising from corrosion from

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[3] From a methodological perspective, the assessment is therefore against a counterfactual of what might have happened if the IMRP had not been introduced.

[4] The ICL Inquiry Report. Explosion at Grovepark Mills, Maryhill, Glasgow, 11 May 2004, page 123.

soils and other factors) and how successful the IMRP has been at replacing pipes with the greatest predicted probability of failure. A declining number of fractures, for instance, after controlling for weather and other factors, would suggest that a combination of the overall rate of replacement and the accuracy of this replacement is greater than the rate of decline.

Thus, ideally in order to help determine an appropriate future strategy, an evidence based approach to determining this, would start by considering the number of mains failures (which is directly observed), but then the full range of the factors driving failure including the weather, location of proximate construction etc. Establishing these different drivers would arguably help define a more optimal risk management strategy. Such a strategy would involve a more targeted risk management programme in which it would be possible to better manage the decline of remaining risk in the cast iron pipe population, allowing greater flexibility in the implementation in the programme. But this is difficult to do, without the above information and ideally a better understanding of the condition of the remaining network assets. Moreover, a key issue in analysing deterioration is that whilst it may be possible to establish an average rate this could perhaps mask considerable geographical differences in rates.

Modelling reliability and usefulness

The Mains Risk Prioritisation System (MRPS) is a model which has been developed to help provide insight into these issues. Establishing the extent to which it can be relied on, and if it cannot be fully, whether it is possible to increase its ability to predict, are also crucial to determine in establishing the future options. Strong predictive powers would increase confidence in the ability to predict the level and locational distribution of pipe failures would assist a more flexible implementation, whereas the opposite would tend to support a policy of maximum practicable implementation (essentially a continuation of the status quo) – although notwithstanding the need to finding other ways of managing risks of incidents arising from the residual cast iron mains. All the incident probabilities derived by the model are very small numbers. Whether the differences between these small numbers are reliably predictive and informative, to the extent that they can be used to drive the replacement programme, needs to be assessed.

The importance of the MRPS model, however, is not just limited to its role in prioritising mains replacement, but what this implies within the regulatory and legal framework. In particular, the extent to which it is used by all stakeholders and the GDNs as part of the process to ensure compliance with Pipeline Safety Regulation (PSR) 13 A.

1.1.3. Risk management versus cost-benefit analysis

The terms of reference would seem to suggest that there are two ways to evaluate the IMRP. First, in terms of its effectiveness as a means by which to manage risk on the network and second as a cost benefit analysis of the overall repex programme, in which wider costs and benefits might be considered.

Historical risk management assessment

There are perhaps two aspects to this – as set out, whether the IMRP has focused on the right things; that is, the greatest risks with the greatest potential consequences. In addition to identification of risk, an aspect of this will be to see the extent to which mains adjacent to high "impact / consequence" buildings such as schools and hospitals were prioritised within the programme.

A further key issue is whether network risks which were not included in the IMRP should have been, including services and gas holders. The terms of reference suggest a potential concern that the IMRP has militated against a more comprehensive, risk management programme. Arguably, this risk-based assessment should form the basis for an ex-post assessment, of the IMRP

Forward looking CBA

As part of a future wider repex programme, wider costs and benefits can be taken into account, such as an increasing ability to increase network pressure (reducing the need for gas holders) and the wider, particularly environmental benefits which go beyond the safety / risk management aspects of the programme, which capture the economic and environmental externalities of the programme's implementation. Arguably these aspects might be best confined to the forward looking assessment, given that they were never a factor in the initial implementation of the programme.

A further issue to assess is whether or not new cost effective technologies have been discovered over the period of the IMRP, which mean that the life of the mains might be extended rather than replaced, even though this approach would not be recognised as compliant to the PSR.

Whilst it is recognised that a CBA was not used to provide the justification for the rationale or design of the IMRP, we note that note within the HSE's economic policy framework CBA can be used to help make judgements about whether future risk reduction measures are reasonably practicable.[5] The CBA presented in this report is developed according to HM Treasury Green Book guidance in response to the ToRs. Clearly, it is the responsibility of the stakeholders of the review to determine how to apply the results of this analysis when considering any potential reform to the IMRP.

1.1.4. Availability of information

The extent to which it is possible to obtain the information from stakeholders in order to conduct the relevant analyses, is informative in itself, both in terms of the appropriateness of the regulatory, legal and monitoring and evaluation frameworks, established at the IMRP's inception and the incentives and constraints that this has given rise to. Indeed, in evaluating it, the IMRP, should not just be seen as an expenditure programme, but arguably as part of a legal and regulatory regime as regards the rules and incentives that govern and incentivise behaviour.

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[5] The HSE do include a high-level assessment of the costs and benefits associated with the IMRP in HSE (2001), The Health and Safety Executive's Enforcement Policy for the Replacement of Iron Gas Mains, Appendix 2.

1.2. Process for undertaking the review

The first stage of completing the review involved the collection of data and information from the HSE, Ofgem, the GDNs based on a questionnaire and information request. The objective of this was to establish, as far as possible, the pertinent facts, in terms of technical and financial data, necessary to undertake the review.

This involved the following activities:

- Kick-off meeting (December 7th 2010). A kick-off meeting was held between CEPA, AESL, the HSE, Ofgem, and representatives from each of the GDNs to initiate the review. During the kick-off meet the deliverables and timetable for the review was agreed between the parties. CEPA agreed to send the GDNs:
    - an updated approach and workplan for completing the review; and
    - a Questionnaire to provide the GDNs an opportunity to supply the information and evidence necessary for CEPA to complete the review. - The Questionnaire was sent out to the HSE, Ofgem and the GDNs on 21st December 2011 Subsequently a copy of the Questionnaire was also sent to the GMB union.
- A meeting with HSE was held on January 11th between CEPA, AESL and Ofgem to discuss the HSE's approach to conducting CBA and discuss some of the background to the review.
- A meeting between CEPA, AESL, Ofgem, the HSE and the GDNs to discuss the information provided by the GDNs in response to the Questionnaire was held February 2, subsequent to this meeting a series of clarification questions were sent by both CEPA and AESL.

The main output from the initial phase of analysis was an Interim report which set out the results arising from the investigation into the available to data. Following the receipt of comments on the Interim report from the HSE, Ofgem and the GDNs we have moved onto the next stage of the analysis, which involved interpreting the data and information available to produce the ex post assessment of the IMRP and to develop the CBA and forward looking assessment. As part of the process of completing this analysis we held the following additional meetings with stakeholders:

- A meeting was held between CEPA, AESL, Ofgem, the HSE, WWU and National Grid on February 21st to discuss the results emerging from the WWU and National Grid analysis of the costs and benefits associated with the IMRP.
- A meeting was held between CEPA, AESL, the HSE and Ofgem to discuss the emerging results from the CBA of the review was held on March 7th.
- WWU organised a meeting between CEPA, Ofgem, the other GDNs and GL to discuss the workings of the risk model and the application of the model outputs as part of the GDNs replacement strategy.

This report brings together the analysis presented in the Interim report together with the ex-post review and forward looking analysis of the IMRP to provide a comprehensive response to the requirements set out in the ToRs.

1.3. Structure of this report

This report is set out as follows:

- Section 2 presents a more detailed discussion of the background, rationale and objectives of the IMRP, set against the context of the HSE's risk assessment framework.
- Section 3 sets out the context for the 2011 review of the IMRP.
- Section 4 provides a summary response on the ToR questions on the ex post assessment of the IMRP, including a value for money analysis. Section 4 in particular should be read in conjunction with AESL's analysis presented in Annex F, which provides a more detailed discussion of the achievements of the IMRP to date.
- Section 5 brings together the analysis carried out in the ex post review with the cost data to carry out a value for money assessment of the IMRP.
- Section 6 sets out the results of our economic modelling of the costs and benefits associated with the IMRP and the potential options for reforming the programme.
- Section 7 presents the overall conclusions of the review, it draws on the main findings of the ex post assessment and the illustrative analysis presented in the CBA to discuss the overall conclusions of the review.

The report is also supported by a number of annexes:

- Annex A provides the ToRs for this assignment.
- Annex B includes a summary of the responses received from the GDNs to the Questionnaire.
- Annex C sets out the timeline of programmes and policies that preceded the introduction of the IMRP.
- Annex D includes draft case studies that discuss other health and safety related programmes both in the UK and internationally.
- Annex E provides a detailed description of our approach to modelling the costs and benefits associated with the IMRP, including a discussion of the key assumptions.
- Annex F presents the technical analysis carried out by AESL to support CEPA's analysis.[6]

[6] AESL (2011), HSE: 10 year review of the iron mains replacement programme.

2. BACKGROUND AND RATIONALE FOR THE IMRP

This section sets out the background to the IMRP; we detail the rationale behind the introduction of the programme and describe the surrounding legal, regulatory and the policy context provided by the HSE's approach to managing risks and hazards.

2.1. IMRP Background

When the UK gas distribution network was originally developed it was considered that cast iron mains were an appropriate material for distributing gas safely, as a result by the late 1960s around 80% of the network was constructed of cast iron. Over time it became evident that cast iron mains were more susceptible to fracture and thus posed an increased risk of gas related 'incidents' (iron gas mains failures that lead to injuries, fatalities and damage to buildings explosions) – failures are defined as fracture and corrosion events.

The need to replace cast iron mains was acknowledged in the early 1970s. It was determined that polyethylene (PE) and protected steel pipelines were more appropriate for distributing gas safely and efficiently and thus since then these materials were used to replace cast iron mains.

The first national replacement programme was introduced in 1974, at the time it was determined that 1% of the network should be replaced each year (1,920Km) for ten years based on a qualitative assessment of the evidence. Following a number of severe gas explosions in the winter of 1976/77 the King Enquiry was held, the findings of the enquiry led to the introduction of the King Replacement Programme. From then on there have been a series of replacement programmes introduced with the aim of reducing the risk posed by cast iron mains. Box 2.1 lists the national replacement programmes that preceded the introduction of the IMRP, Annex C provides a more detailed summary of the timeline of events preceding the IMRP.

Box 2.1: Timeline for the introduction of the IMRP

- **1977 - 1984: King Replacement Programme** – was the first national replacement programme, introduced following the King Enquiry. The programme led to an increase in the replacement rate of the highest risk priority mains. The mains selected for replacement were small diameter cast iron mains and unprotected steel mains in the most hazardous locations.[7] The objective was to remove all of the priority mains by 1984.
- **1984 – 1989 Post King Replacement Programme:** A study was carried out in 1980 to identify secondary risk mains for replacement, based on this study it was determined that it was necessary to decommission 2,600Km per annum of mains to keep the forecast level of incidents constant at the 1984 level.
- **1990 – 1996 Replacement Policy:** Was based on an analysis of the trends of incidents and fractures to assess the appropriate level of abandonment to maintain a given level of safety. In addition the model used to prioritise mains that had been introduced in the 1980s was updated.
- **1996 – 2000 Replacement Strategy for Distribution Mains:** The replacement strategy for 1996 – 2000 set the replacement rate at 2,500Km per annum for the next 10 years.

Source: Ofgem, Transco, HSE (2000), Tripartite Review of Transco's Mains Replacement Methodology

[7] Hazardous locations were defined as: places of public assembly; buildings with basements or cellars; places where the ground surface is completely sealed; and for a given set of conditions buildings very close to mains.

Perhaps the most important point to note from this background section is that the introduction of the IMRP in 2002 was not a new development. It marked the continuation of a replacement policy that had been implemented in some form or another for around thirty years. Over time the design of the programme has been reformed continually; the replacement rate has both increased and decreased and the process for prioritising mains updated, based on the evidence available to the responsible institutions.

2.2. Introduction of the IMRP

In the twelve years preceding the introduction of the IMRP there were a total of 56 incidents on the gas distribution network that led to 14 fatalities. Table 2.1 below sets out both the source and primary cause of the pipe failure, suspected to have caused the incidents. The table shows that the majority of incidents (80%) were caused by the fracture of cast iron mains – primarily on iron mains with a diameter smaller than 12 inches.

Table 2.1: Source and causes of incidents on the gas network 1990 - 2001

Source of incident	Number of incidents	Cause of failure
Cast iron<12"	41	Fracture all cases
Cast iron>12"	4	Fracture all cases
Ductile iron	3	Corrosion all cases
Steel mains	0	n/a
Steel services	8	Corrosion all cases

Source: National Grid (2011), Response to CEPA Questionnaire

As a result of the number of incidents and fatalities experienced related to iron mains - in particular the multiple fatalities at Larkhall, Linfield and Batley - policy makers at the time determined that the cast iron mains posed a 'societal risk' (defined below in Section 2.5). The IMPRP was therefore introduced in 2002 to address societal concerns around the risk posed by iron mains (both cast and ductile iron).

In addition to a focus on iron mains, it was determined that under normal conditions it was unlikely that failure in a pipe located more than 30m away from a building posed a risk of causing an incident. Thus it was only the iron pipes situated within 30m of buildings that were classified as being 'at risk' of causing incidents. Based on the information received from the GDNs in response to the Questionnaire over 90% of the mains population was located within 30m of buildings; over time the 'at risk' population might grow through encroachment as new buildings are constructed.

In 2002 it was estimated that there was approximately 91,000Km of these 'at risk' mains remaining on the network, which were scheduled for replacement or decommissioning over time. In introducing the IMRP the HSE took the decision that given the uncertainty around the risks posed by the remaining iron mains pipes it was necessary to replace them ***as fast as practicable*** to address societal concerns.

2.2.1. Programme rationale

As stated above, the justification for the implementation of the IMRP centred around the uncertainty that existed in 2002 about whether large parts of the iron mains network had reached, or were approaching (over the next 20-30 years) the end of their reliable mechanical life. The concern was that this would increase the probability of an accelerating rate of failure in the future, which could then lead to an increased number of incidents. If this were to occur it would lead to a loss of public confidence and create significant pressure for the operators to replace large parts of the network in a very short period of time; this was in itself deemed to be inherently risky, highly disruptive and costly.

As a result of these concerns a precautionary decision was taken by the HSE – to increase the replacement rate in 2002, in order to avoid the risk of having to replace significant parts of the network in a short time period, following wide-spread failure of the network and an increase in the number of incidents. The HSE decision (HSE (2001)) at the time stated that:[8]

'This precautionary approach is in line with the principles of risk aversion under conditions of uncertainty and the duty to avoid unacceptable harm unless the costs of doing so can be shown to be grossly disproportionate.'

2.2.2. Accelerating the rate of mains replacement

Central to the implementation of the IMRP was the decision about the rate of replacement that would be considered as fast as practicable. Prior to 2002 the historic (1977 – 2002) rate of replacement of the iron mains was around 2,650Km per annum, at this rate the remaining at risk mains would have been removed in 35 years. However in the five years before 2002 the rate of replacement had fallen to around 1,840km per annum, which implied replacing the at risk mains in 51 years.

At the time of implementing the IMRP three options were considered for accelerating the rate of replacement: Table 2.2 below summarises the options considered.

Table 2.2: Policy options considered in 2002 to accelerate the rate of mains replacement

Time to remove at risk mains	Max replacement rate required (Km per annum)	Average replacement rate required (Km per annum)	Net present value of total cost (2001 prices)
25 years	4,300	3,640	£7.3bn
30 years	3,580	3,033	£6.5bn
35 years	2,650	2,600	£5.8bn

Source: HSE (2001)

It was determined that the 35 year option was the minimum rate of replacement that would enable Transco to comply with its legal requirements, however it was not the fastest rate practicable. The 25 year option was discounted on the grounds that a replacement rate of 4,300Km per annum had never been achieved, and had the potential to lead to a level of disruption too high for the public to tolerate. The 30 year option would require a maximum replacement rate of 3,580Km per annum; this was judged to represent an achievable level of

[8] HSE (2001), The HSE's enforcement policy for the replacement of iron gas mains.

replacement that would not cause excessive disruption for the public. The 30 year replacement option was determined to be consistent with As Low as Reasonably Practicable (ALARP) principles.

Thus the objective of the IMRP in 2002 was for the **GDNs to increase the rate of replacement to be in a position to replace the 'at risk' pipes within a total of 30 years**.

Cost-benefit assessment

At the time of making the decision to set a 30 year target for the removal of 'at risk' pipes, we understand that a full comprehensive CBA was not undertaken. However the HSE 2001 decision document did include a high-level assessment of the potential costs and benefits of the programme.[9] The analysis estimated that accelerating the rate of replacement to remove 'at risk' mains in 30 years would cost **£650m net** (in NPV terms, compared to the option of replacement in 35 years), and would prevent around **four incidents**. When the IMRP was initially introduced it was therefore estimated that it would cost around £160m for every incident averted. It should be noted that the analysis did not seek to quantify the wider costs and benefits associated with the IMRP.

2.3. IMRP risk model

In addition to accelerating the rate of replacement for iron mains, one of the key developments associated with the IMRP was the use of a more quantified approach to assess the level of risk posed by iron mains. In 1999 the risk model used to assess the level of risk posed by different parts of the network was updated following a comprehensive Tripartite Review (HSE, Ofgem and Transco) of Transco's mains replacement methodology. As a result of the review the MRPS was introduced.

The MRPS is used to estimate the probability that each unit of mains will cause an incident, per Km of mains, per annum. There are separate MRPS models used to assess the level of risk posed by:

- cast iron mains with a diameter lower than 12";
- cast iron mains with a diameter greater than 12";
- ductile iron mains; and
- steel mains. (this is understood not to be used)

It should be noted that the results of the four models are directly comparable, and thus can be - used to assess the level of resource allocation to address risk on the mains network. -

The estimate of risk posed by the different iron mains is based on three factors: -

- The mains "fracture" factor, which estimated by combining data on the diameter of the main, its individual breakage history, and the breakage history of other mains within a 400m zone of the main being considered.

[9] HSE (2001), The Health and safety executive's enforcement policy for the replacement of iron gas mains.

- The gas "ingress" factor (the likelihood that the gas will enter a building), which is based on factors such as the diameter of the main, the distance between the main and the nearest property, the amount of open ground within that distance, and whether the property has a cellar or a basement.
- The "consequence" factor, which takes account of the pressure at which the gas main is operating and the presence of cellars.

2.3.1. MRPS application

The output of the model is primarily used as a prioritisation tool to help inform the replacement strategy of the GDNs over the coming years. It enables the GDNs to make an economic assessment of whether to include all the most risky pipes in a single programme or to balance a top-down replacement of the most risky mains with the costs involved. In addition the MRPS can be used to compare the level of risk posed by the different pipe diameters and materials, and whether different geographic locations have an above average exposure to risk.

Effectively the MRPS can be used to enable the GDNs to develop an optimal approach to removing risk on the network.

2.4. Legal and regulatory context

The key legislation underpinning the IMRP is the 1996 Pipeline Safety Regulations (PSR):

- PSR 8 requires the pipelines to be composed of a material that is suitable.
- PSR 9 requires pipelines to have been constructed so as to be sound and fit for purpose.
- PSR 13 requires pipeline to be maintained in an efficient state, in working order and in good repair. PSR 13, A (enacted in 2003) is particularly important as it effectively provides the GDNs with an agreed (with the HSE) scope of replacement work, which effectively provides them with some legal protection should an incident occur.

The PSR regulations and other health and safety regulations are relevant across the various risks posed by the pipeline across the network, and not focussed solely on iron mains. The focus of the replacement programme on iron mains was because in 2002 the risks posed by steel mains and services were not estimated to be as significant as the risks posed by iron mains.

2.4.1. Regulating the costs of the IMRP

Given the significant replacement expenditure (repex) required to implement the IMRP Ofgem needed to make a determination as to how the expenditure would be funded. Ofgem decided to finance repex on the following basis:

- 50% of repex to be expensed and recovered in the year in which it is incurred; and
- 50% of repex to be added to the Regulatory Asset Value and depreciated over a 45 year horizon.

The principle underlying the decision to partially expense repex was that while repex is an enhancement to the long term asset base, the renewal programme is primarily concerned with present safety requirements rather than increasing the networks' capacity or significantly for the benefit of future customers. As such it was deemed appropriate for present consumers to fund a proportion of the repex programme, while the remainder is funded over the life of the assets.

An important part of the replacement programme is the inclusion of an incentive mechanism, which was introduced to provide the GDNs with greater incentives to deliver the programme. As part of the 2002 TransCo price control, Ofgem set a mains replacement baseline allowance with a supplementary incentive mechanism which adjusted GDN revenue depending on the volume and diameter mix of mains replacement. This was in response to the HSE requirement to accelerate the replacement of iron mains within 30 metres of premises over 30 years in response to safety concerns (the 30:30 programme) and the uncertainty over the mix of mains to be replaced each year.

The supplementary incentive mechanism provided the GDNs with flexibility to vary their annual spend in line with their need to replace a different diameter mix of pipes from that originally forecast at the time of the control review. The mechanism also protected consumers by capping the mains replacement allowance to the total of the five year forecast of spend.

In the current 2007 - 2013 GDN price control Ofgem has:

- included service costs related to mains replacement in the incentive;
- included unit costs for larger diameter pipes; and
- aligned the mains replacement incentive with the capex incentives.

Under the refined incentive, GDNs are subject to separate unit costs for re-laid services associated with iron mains replacement. There is a single allowance for mains and services costs. As the mains replacement incentive is aligned with GDNs capex incentive, each GDN group has a different mains replacement incentive rate as determined by the Information Quality Incentive (IQI). Ofgem has also included three additional diameter sizes to the mains incentive to take account of 13-18", 19-24" and greater than 24" diameter mains.

Under the incentive arrangements, GDNs are allowed to pass-through the costs of *changes in the volume of different diameters of mains abandoned and volumes of different types of services replaced at given unit costs*. This mechanism gives incentives for the GDNs to minimise the unit costs for each type of mains and services replacement work as they are subject to the IQI sharing factor. Adjustments are made through an annual adjustment to allowed revenue. The arrangements are subject to an expenditure cap over the 5 years of the price equal to the total expenditure allowance (post-IQI) for incentivised mains and services. Beyond this cap, the IQI sharing factor applies to changes in both volumes and unit cost.

2.5. Health & Safety policy context

The implementation of the IMRP has to be considered within the HSE's general health and safety policies designed to manage the risks associated with hazards in the UK. The HSE is responsible for managing both individual risks and societal risks.

- **Individual risks** relate to hazards that pose potential tangible harm to individuals.

- **Societal risks** are hazards that impact society at large and are considered to have the potential to harm the social fabric if realised. Any societal concern caused by the risk of multiple fatalities caused by a single event is a societal risk. Typical examples relate to railway travel and nuclear power generation.

Given the potential impact of societal risks the HSE applies a higher standard of regulatory control than if individual risks were the only consideration. The justification for this is that given the potential impact of societal risks, HSE applies a higher standard of regulatory control than if individual risks were the only consideration

Tolerability of Risk

The Tolerability of Risk framework effectively helps to classify the nature of the risk posed by any potential hazard. In simple terms the classification is based on an assessment of the probability of a hazard leading to fatalities and or injuries, however there are clearly difficulties involved in assessing these probabilities given the uncertainty involved in developing a suitable estimate. Overall the framework classifies risks as follows:

- **Intolerable risks**, these are classified as hazards that impose risks that are deemed to be intolerable save in extraordinary circumstances. As a general rule intolerable risks apply to any hazard that implies a risk of death for employees of greater than 1 in 1,000 per year (1 in 10,000 per year for risks imposed on individuals by third parties). We would expect that the HSE would ban / restrict any activity that posed an intolerable risk.

- **Broadly acceptable risks**, which are hazards that are deemed to represent an insignificant risk to individuals and society. Acceptable risks apply to any hazard that imposes an individual risk of fatality of less than 1 in 1,000,000 per annum. In this case we would expect that any regulations designed to reduce risks would be disproportionate to the potential risk reduction achieved.

- **Tolerable risks**. In between intolerable and broadly acceptable risks are hazards that are classified as tolerable risks. These are risks that pose a concern that can be tolerated provided that they *are reduced to a level 'as low as reasonably practicable' (ALARP).*[10] It is in the management of tolerable risks that the HSE's regulations and controls become effective – the HSE is responsible for providing the guidance and regulations to help ensure that duty holders achieve ALARP on tolerable risks.

It is important to note that the boundaries between the levels of risk mentioned above are only general guidelines. In practice the decision on the categorisation of different hazards is based on a more complicated process involving a wider range of considerations in particular reflecting any societal concerns related to a potential risk.

2.5.1. Determining that risks have been reduced to ALARP

To determine that if duty holder (responsible for managing the risk) has achieved ALARP the potential impact of the risk and the costs involved in trying to mitigate the risks needs to be

[10] The ALARP principle was derived from the Edwards vs. The National Coal Board Case, in which the Court of Appeal considered whether or not it was reasonably practicable to make the roof and sides of a road mine secure.

considered. Unless there is a gross disproportion between them the duty holder has to undertake the risk reduction measure. Thus, the process is not one of simply balancing the costs and benefits of measures but, rather, of ***adopting measures except where they are ruled out because they involve grossly disproportionate sacrifices.***[11]

CBA and ALARP

To establish if a programme / activity designed to reduce risk is ALARP it is necessary to compare the costs of risk reduction against the benefits to see if they are grossly disproportionate to the benefits. The use of CBA can be used as part of the analysis; however it should be noted that a CBA cannot be used:

- on its own to constitute an ALARP case;
- against the implementation of a relevant good practice, unless some alternative measure is demonstrated unequivocally to be at least as effective; or
- against statutory duties.

According to the HSE's guidance when carrying out a CBA of a programme, it will be classed as reasonably practicable unless its costs are grossly disproportionate to the benefits, or:

$$\frac{\boldsymbol{Costs}}{\boldsymbol{Benefit}} > 1 * \boldsymbol{Disproportionate\ factor}\ (\boldsymbol{DF})$$

There is no precise statement on the value that the DF should take, however guidance on the HSE's approach to CBA suggests that a disproportionate factor of greater than 10 is unlikely.[12]

2.6. Summary

The key points to note from the analysis presented in the background and rationale section are as follows.

Box 2.3: Key points to note from Section 2
• The IMRP was introduced to update existing replacement policies; national replacement programmes have been in place in one form or another since the 1970s.
• The decision to implement the IMRP was precautionary - given the uncertainty about the state of the network a decision was taken to increase the rate of replacement in 2002 to reduce the risks of a sudden deterioration of the network creating unacceptable costs in the future.
• The key decisions involved in the introduction of the IMRP are as follows: o All iron mains located within 30m of buildings were defined as posing a societal risk. o The rate of replacement for these mains was set to increases to a maximum of 3,580Km per annum to achieve replacement of all 'at risk' mains in 30 years, based on an assessment that this was consistent with ALARP (i.e. an achievable rate of replacement that would not cause undue disruption to the public).

[11] There is no authoritative guidance from the Courts as to what factors should be taken into account in determining whether cost is grossly disproportionate. HSE has not formulated an algorithm which can be used to determine, in any case, when the degree of disproportion can be considered 'gross'; the judgement must be made on a case by case basis.

[12] HSE, Cost Benefit Analysis Checklist (on HSE website)

- The MRPS model was introduced alongside the IMRP. The MRPS provides an estimate of the level of risk of an incident posed by each Km of mains per annum. The model provides an opportunity for the GDNs to weigh up the costs and benefits of their mains replacement strategy to implement an optimised risk reduction strategy.

3. Context for the 2011 Review of the IMRP

In this section we present a brief discussion of the context for the 2011 review of the IMRP, this is important because it, helps to establish what previous reviews or assessments have been undertaken on the IMRP. The section discusses how policy makers may intend to use the outputs of the review and concludes by describing the network under consideration for the review.

3.1. HSE 2005 Review of the IMRP

We understand that to date the only formal comprehensive review of the IMRP was carried out by the HSE in 2005.[13] The review touched on a number of issues related to the implementation of the programme that we discuss below.

3.1.1. Re-evaluation of number of 'at risk' pipes on the network

One of the key issues highlighted in the review was that the length of the 'at risk' pipes was significantly higher than estimated in 2001. Transco's 2004 survey found that in 2001 there had been 101,800Km of 'at risk' mains compared to the original estimate of 91,000Km.

3.1.2. Transco's 20:70:10 methodology

When the IMRP was initially introduced, it was assumed that replacement would take place on a top-down risk ranking order, based on the outputs of the risk model. However, when implanting the programme Transco determined that by adopting a 20:70:10 approach to replacement they would be in a position to more effectively balance risk reduction and the costs of the IMRP.

In the 20/70/10 programme, 20% of the total mains decommissioned each year were selected from the highest risk population of the 'at risk' mains (based on the risk scores generated by the MRPS), 70% from the secondary risk population and 10% from the remaining risk population. According to the analysis produced at the time, by utilising this approach Transco could benefit from efficiency gains, and reduce the need for disruption of gas supplies and traffic movements.

The HSE accepted Transco's proposals with the proviso that an equivalent amount of risk was removed (based on calculations of risk reduction using the MRPS) from the network as would be the case when using the top-down approach. ***As a result Transco had to increase the level of replacement by 10% against the targets original baseline targets***.[14] HSE had the approach reviewed independently and the review concluded that the 20/70/10 programme would remove an equivalent level of risk over 5-7 years as the top-down approach.

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[13] HSE (2005), Review of the Health and Safety Executive's 2002 – 2007 enforcement policy for the replacement of iron gas mains.

[14] The increase in the replacement rate also reflected the increase in the 'at risk' population that occurred as a result of encroachment and discovery of additional iron mains.

3.1.3. Large diameter mains replacement (>12")

When the IMRP was introduced it was determined that additional work was required to determine the appropriate policy for decommissioning the large diameter iron pipes. This was primarily because the low failure rate of the large diameter pipes made it difficult to adequately assess the level of risk posed, but also because of the high costs involved in replacing the large pipes. As a result the HSE set a slightly lower rate of replacement for the large pipes compared to the remaining 'at risk' population, while requiring Transco to consider alternative ways to manage the risk, such as condition monitoring.

The 2005 review stated the need for additional research into approach to addressing the risk posed by large diameter pipes, concluding that *'the policy towards large diameter cast iron mains is still developing'*.

The overall conclusions and recommendations presented in the 2005 review are shown in Box 3.1 below.

Box 3.1: Conclusions and recommendations of the 2005 Review
The 2005 review concluded that: • There remained uncertainty about the condition of the remaining iron mains, thus it was still conceivable that over the next 20 years large parts of the network might reach the end of their reliable mechanic life. • The IMRP had helped to keep the level of major incidents low and avoid significant deterioration in the network. • The replacement targets had been met and been shown to be practicable. • The risk model was deemed to be satisfactory, but in need of continual review. Overall, the main recommendation of the 2005 review was that the IMRP was fit for purpose and should continue for at least the next 6-years at a minimum rate of 3,500Km per annum.
Source: HSE (2005)

3.2. Ofgem RIIO Proposals

The key motivation for the review is the need for an independent assessment of the IMRP to be carried out following close to 10 years since introduction; however we understand that the commissioning of the review has also been designed to fit in with Ofgem's current process for the RIIO (Regulation = Incentives + Innovation + Outputs) proposals for the next price control review for the GDNs (2013 – 2021).

Ofgem's RIIO Consultation paper discusses the 2011 review and states that the outputs of the review will be used by the HSE, GDNs and Ofgem to consider the future design and development of the programme.[15]

In their RIIO Consultation documents Ofgem also set out a number of proposals directly related to the IMRP:

[15] Ofgem (2010), Consultation on strategy for the next gas distribution price control – RIIO – GD1 Overview paper, page 19.

- Reforming the revenue incentive mechanism to reward GDNs for the level of risk removed, instead of rewarding companies for the length and diameter of mains and services replaced.
- The inclusion of a re-opener depending on the implementation of any significant reforms to the IMRP.
- Ofgem are consulting on front end loading the depreciation profile to reflect the uncertainty over the economic life of gas distribution networks.
- Ofgem are proposing to increase the rate of mains replacement expenditure that is capitalised, to bring it in line with the rate used for other cost categories.

3.3. Elements of the network under consideration

In this section we provide a brief description of the network under consideration for the review.[16]

The analysis is focused on all iron mains located within 30 metres of buildings. These iron mains are composed primarily of cast and ductile iron. In addition the IMRP involves the replacement of steel services that are attached to iron mains located within 30 meters of buildings.

The different types of iron mains are prone to different types of failure, and some of these failure modes are known to be more likely to have serious consequences.

3.3.1. Failure modes for iron mains

Historically the fracture of smaller diameter cast and spun iron mains, has been the most frequent cause of incidents. This is because fractures may lead to a sudden release of a relatively large volume of gas into a building, which makes it less likely that the gas will be detected before it has reached a level of concentration that might cause an incident. Cast iron mains can fracture for a number of reasons, such as ground movement, traffic loading and weather related effects.

Cast iron mains have also been known to fail due to corrosion. Compared to fractures, corrosion failures on pit and spun cast gray iron have released smaller quantities of more slowly, and have therefore not historically caused incidents.

In contrast to cast iron, ductile iron (especially medium pressure), may suffer a form of corrosion failure that gives rise to a sudden release of gas into a building. Thus based on historic evidence ductile iron failure has also caused incidents. The causes of corrosion failure may be due to factors such as the age of the gas main and its surrounding soil conditions.

3.3.2. Consequences of iron mains failure

When an iron main fails there are essentially three broad consequences that can occur:

- a release of gas requiring repair;
- an escape that enters into a building (a GIB), but does not ignite; and

[16] This analysis draws on the accompanying AESL report.

- an escape that leads to an incident occurring.

The factors that lead to a GIB following a failure are relatively well known and include:

- The distance between the gas main and the property. The further the gas main is away from a building, the more chance that the gas has of venting out before entering the building. Related to this point, the presence of open ground is also an important issue.
- The diameter and pressure of the main, which affects the quantity of gas released.
- Weather conditions. The surrounding weather conditions can have a causal impact on the probability of a GIB. If a failure occurs and the ground is frozen there might be less opportunity for the gas to escape before entering a building.

There is less precise information / data available on the factors that lead to an incident occurring following a GIB. But it is understood that for a GIB to lead to an incident there needs to be some source of ignition, which might be caused by factors as diverse as someone smoking a cigarette or some faulty wiring.

In addition to considering the iron mains and steel services included in the IMRP, depending on the available data we have sought to provide some analysis of the other network assets including; steel mains, PE mains, gas holders and risers in multi-dwelling buildings.

3.4. Summary

The key points to note from the analysis presented in the background and rationale section are as follows.

Box 3.2: Key points to note from Section 3
• The HSE carried out a formal review of the IMRP in 2005. The review concluded that the IMRP was fit for purpose and recommended the continuation of the programme for an additional six years at a rate of 3,500Km per annum.
• The adoption of the 20/70/10 approach required Transco to increase the level of replacement to 10% above the originally agreed baseline.
• The decision to both accept the 20/70/10 approach to replacement and to delay further the ramping up of the replacement of large diameter mains both included an element of balancing risk reduction against economic cost.
• The 2011 review will feed into the RIIO proposals for the 2013 – 2021 gas distribution price control.
• The review is focused on the iron mains and services included within the 30:30 replacement programme. This includes both cast and ductile iron mains, which have different failure modes. Cast iron (in particular small diameter cast iron) is more prone to fail due to fracture, while ductile iron mains are more prone to fail due to corrosion. • Both the fracture of cast iron and the corrosion of ductile iron have in the past been known to cause incidents.

4. EX-POST REVIEW OF THE IMRP 2002 – 2009

In this section we present our response to the questions posed in the ToRs presented in Annex A relating to the ex-post review.

The ToRs set out a number of issues and questions that the ex-post review of the IMRP was intended to address. In this section we have provided summary responses on the questions for which adequate data is available, the responses draw on the analysis presented in Annex F, which presents AESL's analysis, as such the relevant sections of the AESL work should be read to gain a more detailed understanding of the issues covered. We would recommend that given the nature of the analysis and quality of data provided all of the responses should be treated with a degree of caution.

Given the data that has been made available to us when completing the review it is not possible to provide evidence based responses to some of the questions raised in the ToRs - this reflects some of the problems with data collection and consistency that we have encountered. We have sought to provide a broader response to these questions / issues in the Conclusions section.

In the following sub-sections we provide our findings on the different questions raised, as grouped in the ToRs. The ToRs as drafted have two separate lists of questions, which are in many places repetitive. In our responses below we have grouped the questions into a single list to set our understanding on the specific questions being raised.

We therefore cover the following:

- Performance of the IMRP in removing risk.
- Deterioration of the network.
- Risk modelling.
- Other network risks.

4.1. Performance of the IMRP in removing risk

The ToRs pose a number of questions on the performance of the IMRP in removing risk. Effectively these questions are attempting to develop understanding on the *quantity of risk removed* by the IMRP, and the extent to which the IMRP has achieved an *optimal level of risk removal*.

To answer these questions it is first necessary to *clarify exactly what is meant by risk*. For this review we initially considered risk to relate simply to the risk of an incident per Km of iron mains that falls out of the MRPS. However, as we have developed our analysis it has become clear that there are a number of exogenous factors that cause an incident following a GIB that are outside of the control of mains replacement. As such there is likely more information on the risk removed by mains replacement in the GIB statistics, rather than in the MRPS outputs on predicted incidents per Km or even the evidence on the actual number of incidents.

To understand what we are saying above it is useful to consider the following theoretical example. Over the last eight years it is possible that replacement activity had been highly successful in replacing the mains most at risk of failure and therefore in reducing the number of GIBs significantly. Theoretically, this would in itself be a good outcome for replacement activity.

However, at the same time as reducing the number of GIBs the network might have experienced a high level of incidents due to exogenous factors (such as an increase in potential ignition sources in households). In the above state of the world if we judged the success of mains replacement simply on the risk of incidents per Km we might conclude incorrectly that mains replacement activity had not been successful. It is equally important to consider that the opposite might be true – that replacement activity had failed to reduce GIBs, but that incidents had fallen due to an exogenous reduction in incidents.

Therefore, in our discussion of risk removal below, we discuss the outputs of the modelled risk removed and the actual occurrence of incidents. However we would argue that the most informative evidence on the performance of the IMRP in removing risk can be found in the GIB statistics. Though the analysis of the achievements of the IMRP in reducing GIBs, needs to be taken within the context that replacement activity in the first stage of the IMRP has been notionally targeted around the removal of the risk of incidents per Km.

4.1.1. Net impact of the IMRP on the quantity of risk removed

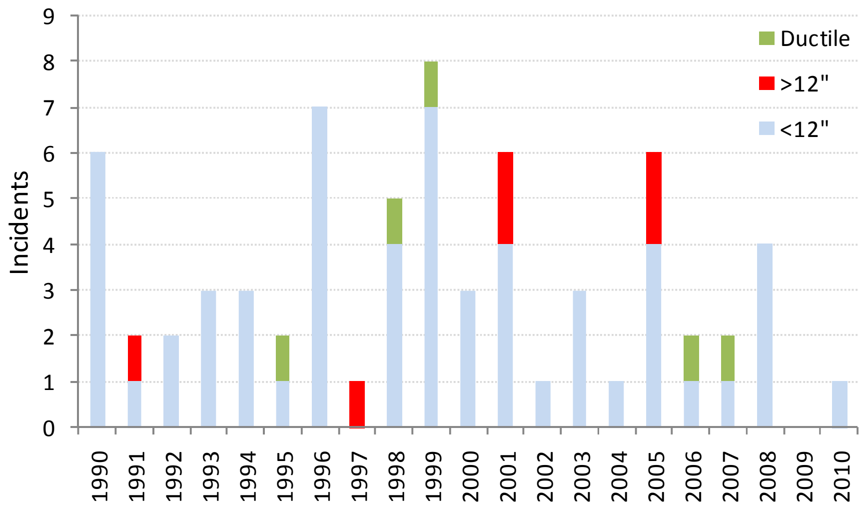
To gain an understanding of the quantity of risk removed by mains replacement we have considered the following:

- actual evidence on incidents;
- modelled risk removed; and
- performance of GIB indicators.

Historic evidence on incidents

As discussed in Section 2, the IMRP was introduced to achieve the outcome of reducing the number of incidents related to iron mains. Figure 4.1 shows how the number of incidents related to iron mains has varied each year and by source in the years 1990 to 2010. In the 12 years prior to the introduction of the IMRP there were 48 iron mains related incidents occurring at an average rate of 4 per annum; in the years since implementation there have been a total 20 iron mains related incidents occurring at an average rate of 2.2 per annum. Therefore, since the introduction of the IMRP the number of observed incidents has declined significantly. It is not really possible to determine how much of the reduction in the observed number of incidents was caused by mains replacement, and how much is due to exogenous factors such as changes in household ignition sources without having the data on the exogenous factors.

Figure 4.1: Iron Mains related incidents 1990 - 2010



Source: HSE (2010). Summary of UK gas distribution mains and services related incidents.

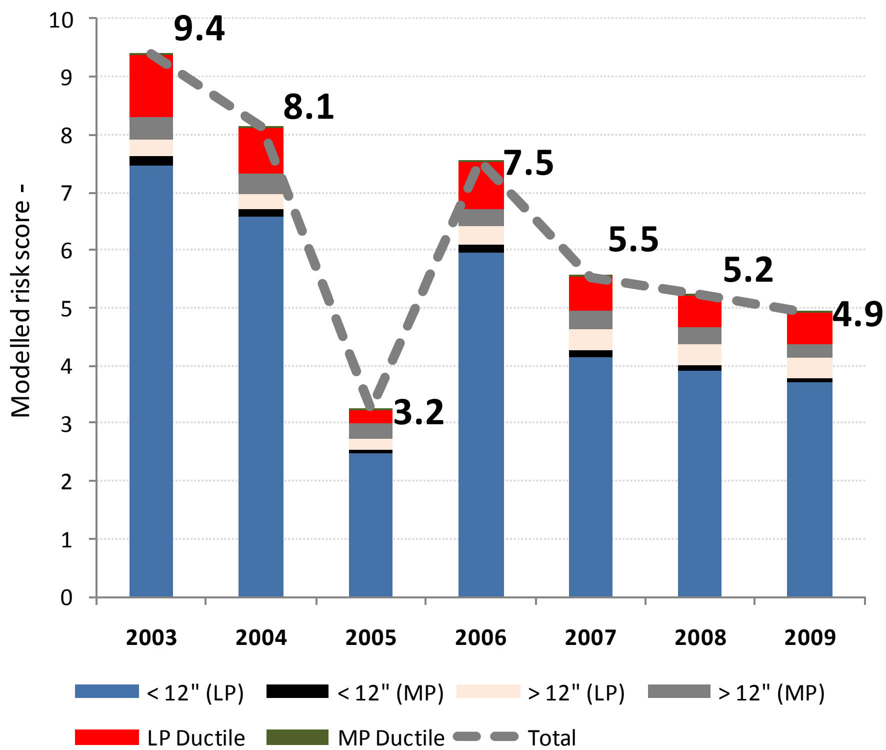
Modelled risk removed

We can provide perhaps only a high-level understanding of the level of risk removed by replacement activity by focusing on the outputs of the MRPS. According to the model, in 2003 the iron mains network presented a risk of 9.4 incidents per annum in total – as at end 2009 the model estimated that this had fallen to 4.9 incidents per annum, which implies an approximate 48% reduction in the modelled level of risk presented by the gas distribution network between 2003 and 2009.

Figure 4.2 below sets out the trends observed in the level of modelled risk removed from the network since 2003. It presents the modelled estimate of the incidents per Km for the six different categories of iron mains included in the risk model. It is worth noting that there seems to be a problem with the information provided for 2005.

It is important to note that the recalibration of the model adjusts output such that it corresponds to the recent observations. As such the model is not providing new information but merely expressing the recent incident events as a future prediction albeit with length and recent history adjustments.

Figure 4.2: Modelled level of risk in iron mains network (total modelled incidents per annum)



Source: GDN response to Annex D of Questionnaire

Table 4.1 helps to identify further the source of the modelled risk removed since 2003. Out of the modelled risk of 4.5 incidents removed from network, 83% is due to a decline in the modelled risk associated with low pressure small diameter mains. None of the other asset classes have contributed significantly to the modelled risk removal.

Table 4.1: Source of modelled risk removed (no. of incidents 2003 – 2009)

Asset	Modelled risk removed
< 12" (LP)	3.8
< 12" (MP)	0.1
> 12" (LP)	0.0
> 12" (MP)	0.2
LP Ductile	0.5
MP Ductile	0.0
Total	**4.5***

Source: GDN response to Annex D of Questionnaire

**Table does not sum due to rounding*

Overall, using the outputs of the MRPS it is possible to estimate that **mains replacement activity has prevented 22 'modelled' incidents** from occurring compared to a state of a world in which mains replacement activity stopped in 2002.

It is difficult to get an accurate estimate of the net impact of the IMRP on modelled risk removal. This is because it is not possible to determine how replacement activity would have been targeted if the IMRP had not been introduced. A high-level estimate can be developed if we consider that prior to the introduction of the IMRP around 1,840Km of mains were being replaced each year. Over the period 2003 – 2009 the average number of Km replaced has increased to around 3,200Km. If we simply assume that the level of modelled risk reduction is proportionate to the increased level of replacement it suggests that in net terms the IMRP has **prevented around 9.5 'modelled' incidents**.

We note that this may be an underestimate as we would expect the IMRP to have delivered additional benefits, in terms of modelled risk removal, through improved targeting of 'at risk' mains.

GIB indicators

The analysis that we have carried out while completing the review suggests that the best indication of the risk removed by mains replacement activity may be determined by analysing the observed trends on GIBs.

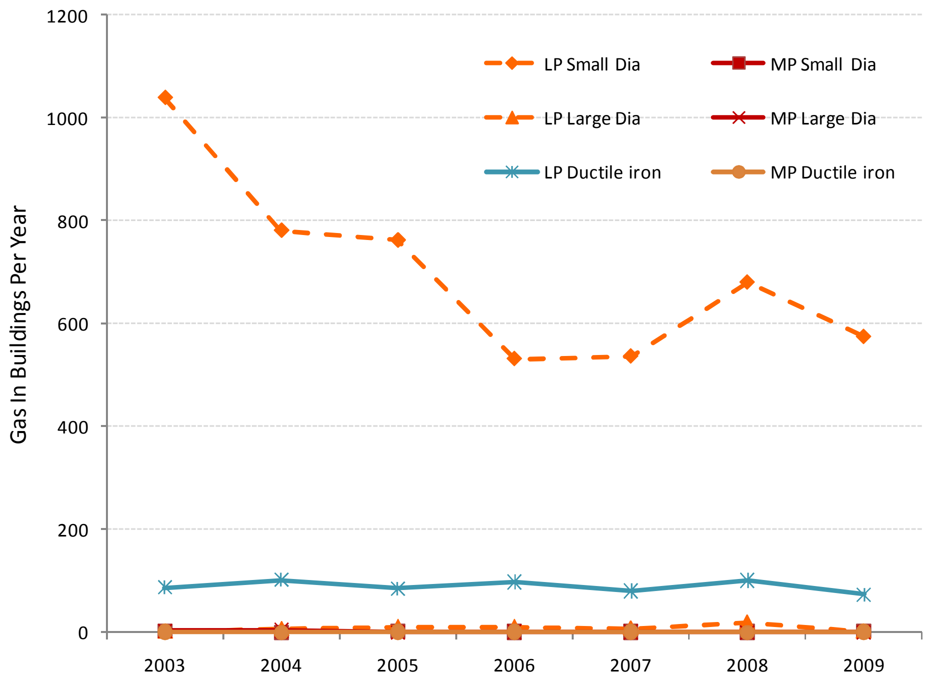
Table 4.2 below shows the total number of GIBs observed for the period 2003 – 2009, based on the information received from the GDNs in response to the Questionnaire. It shows that the total number of GIBs observed on the network from the iron mains in the 30:30 programme have declined by over 40% since the introduction of the IMRP.

Table 4.2: Observed GIBs 2003 - 2009

	2003	2004	2005	2006	2007	2008	2009
National Grid	514	438	465	392	371	469	341
NGN	161	161	130	92	131	130	128
WWU	103	71	75	68	125	129	151
SGN	358	224	191	91	0	74	32
Total	**1136**	**894**	**861**	**643**	**627**	**802**	**652**

Figure 4.3 below sets out the total number of GIBs recorded by mains category over the period 2003 – 2009. Over the period the number of GIBs associated with small diameter low pressure mains has declined by over 44%. The number of GIBs caused by Low pressure ductile iron mains, which are the only other significant source of GIBs, have remained broadly stable since 2003. Overall it is also worth noting that, based on the data available, most of the incidence of GIBs is due to the small diameter mains.

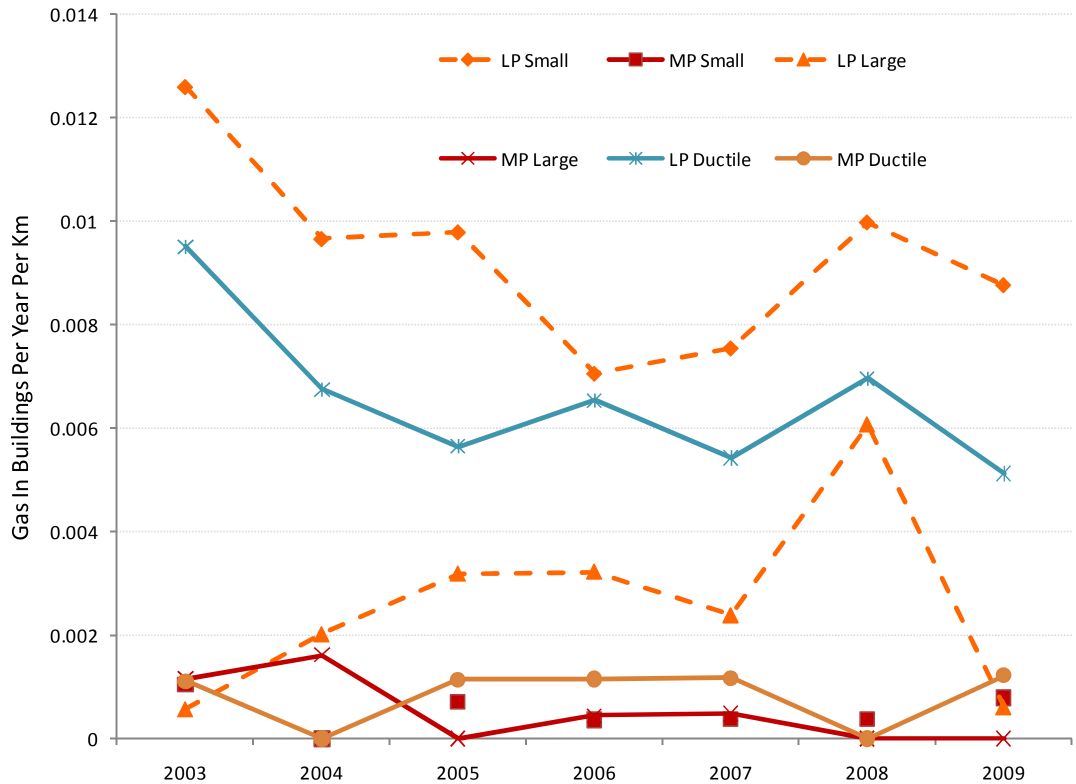
Figure 4.3: Total number of GIBs by mains category 2003 - 2009



Source: GDN response to Annex D of Questionnaire

It is also useful to consider the trends on GIBs per Km, which provides some indication of how effectively replacement activity has been targeted. This analysis is shown in Figure 4.4 below. Looking at the evidence for the period 2003 – 2009 the GIB per Km data is quite volatile over the period though there would seem to be an overall downward trend in the GIB per Km for low pressure small diameter cast iron mains. Overall there appears to be a higher incidence of GIBs per Km for both small diameter cast and ductile iron mains than for the large diameter mains. It is important to note that it also likely reflects inconsistencies, errors and omissions in the data received to complete the analysis.

Figure 4.4: Total number of GIBs per Km by mains category 2003 – 2009



Source: GDN response to Annex D of Questionnaire

The evidence may suggest that the IMRP has had some success in targeting the removal of mains prone to reducing GIBs, as all other things remaining equal we might expect GIBs per Km to remain broadly stable if replacement activity was not targeted. In the next section we consider if replacement activity has had an 'optimal' impact on achieving risk reduction.

4.1.2. Has the IMRP achieved an optimal level of risk removal?

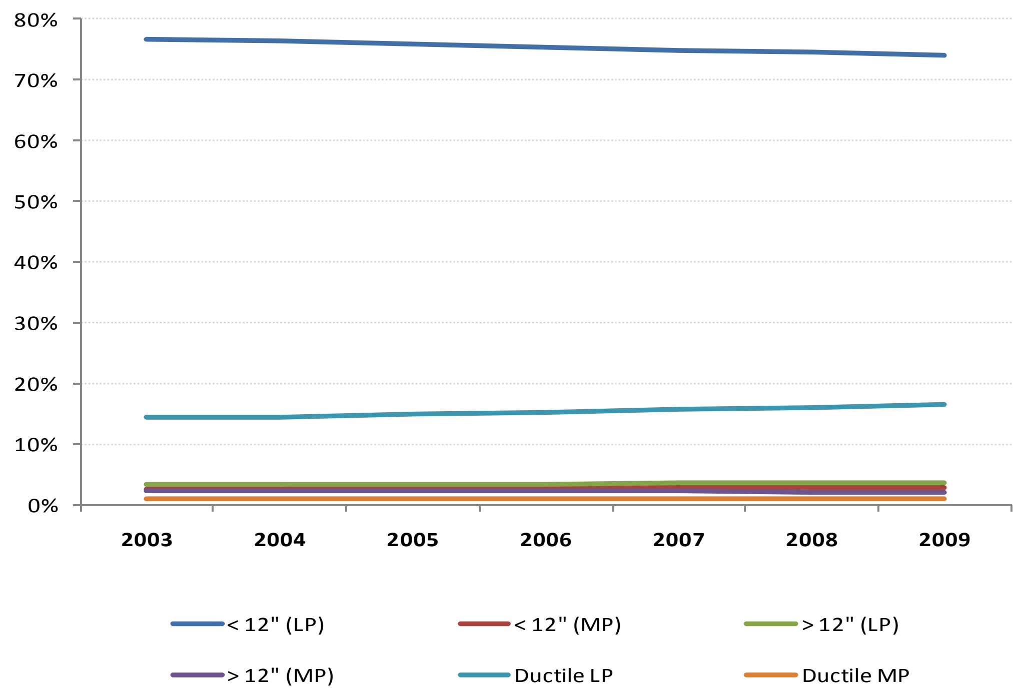
Our analysis of the extent to which the IMRP has achieved an optimal level of risk removal does not consider the costs involved. The value for money analysis in Section 5 brings costs considerations into the analysis.

To answer the question it is necessary to determine if replacement activity has been targeted proportionately on the highest risk mains. The analysis that we have presented indicates that low pressure small diameter mains and low pressure ductile iron mains are the high risk class of mains (in terms of observations on GIBs per Km). Therefore we need to assess the extent to which replacement activity has focused on these two classes of iron mains.

Overall replacement activity

To answer this question we look at the proportion of the different categories of mains accounted for by the different class of assets. Figure 4.5 below, shows the different categories share of the 'at risk' population since 2003. The figure shows that the low pressure small diameter mains accounted for 77% of the ‘at risk’ mains population in 2003, but that this has fallen to 74% in 2009 suggesting that the replacement activity has targeted specifically this category of mains. However, low pressure ductile iron mains (14% to 16%) have seen their share of the iron mains population increase, suggesting that replacement activity has not been focused on this category. The remaining categories have remained relatively constant as a proportion of the mains population since 2003.

Figure 4.5: Proportion of remaining ‘at risk’ mains population by category 2003 - 2009



Source: GDN response to Annex D of Questionnaire

Thus overall the analysis suggests that replacement activity has targeted the replacement of small diameter cast iron mains, but has not targeted low pressure ductile iron mains. It is important to note that towards the end of the period 2003 – 2009, replacement activity has focused less intensively on small diameter mains. In 2003 over 88% of replacement activity was on small diameter mains, but this fell to 83% in 2009.

Replacement activity for small diameter mains

Section 6 of Annex F provides a more detailed analysis of the potential impact targeting of replacement activity of small diameter mains more intensively on the higher risk scoring mains.

The AESL analysis shows that in 2007 only a small proportion of the of the total length of the top 2% of risk scoring remains were replaced through the IMRP. Their analysis suggests that if however, the top 2% of risk scoring mains in 2007 had been replaced completely, the number of fractures observed on the network in 2008 would have been reduced by 8% and the number of GIBs by around 14%.

Thus the analysis suggests that there might be significant benefits, in terms of reductions in observed fractures and GIBs if replacement activity were to be focused more intensively on the highest scoring risk mains.

4.2. Deterioration of the network

The ToRs present a number of questions on the deterioration of the network – defined for the purposes of the review as the change in the rate of failure per Km per annum. We note that there is an important gap in the research and evidence that has been carried out to establish network deterioration. In theory the underlying level of network deterioration should be a key variable to determine the appropriate level of mains replacement, therefore it is clearly an important variable to understand.

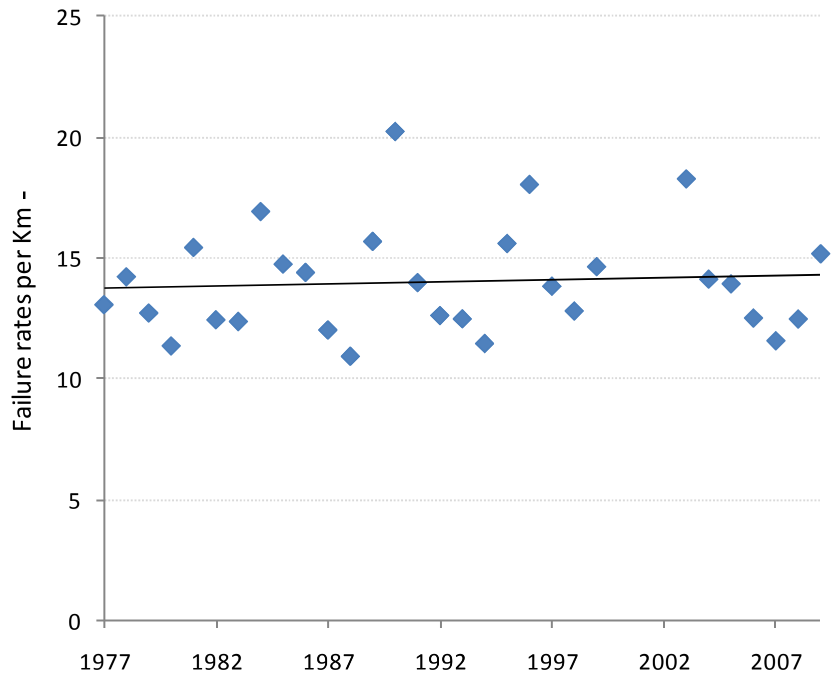
The questions posed in the ToRs on deterioration centre largely around the extent to which replacement activity has kept pace with the deterioration of the network. The lack of a consistent data set with enough historic observations together with the general lack of analysis on this issue prior to the review makes it difficult to provide any substantive answers on the issue. As set out in the introduction, it is important to consider mains deterioration from a spatial as well as an average perspective. We therefore suggest that additional comprehensive research and analysis needs to be undertaken on these issues to understand fully the nature, rate and distribution of mains deterioration.

4.2.1. Historic observations on failure rates

One way to understand the level of network deterioration is to analyse historic observations on failure rates per Km. All other things remaining equal if replacement activity were keeping pace with the deterioration rate we would expect the observed incidence of failure per Km of iron mains to remain broadly stable over time.

Figure 4.6 below presents information on the failure rate per 100Km of mains for the periods 1977 – 1999 and 2003 – 2009. The chart combines failure rate data for Transco for the period 1977 – 1999 and the information received from the GDNs in response to Annex D for 2003 – 2009. The source of information for the Transco data does not make it clear if the historical information includes large diameter and ductile iron failures, therefore it is not clear if the two sources are directly comparable. However, a high-level overview of the data does give an overview of how failure rates have varied significantly over a longer time horizon, which suggests that the replacement activity has enabled the failure rate to remain broadly stable over time.

Figure 4.6: Failure rates 1977 – 1999 and 2003 – 2009 (per 100km of iron mains)



Source: GDNs response to Annex D

4.2.2. Analysis on underlying failure trends

In addition to the concerns about the consistency of the data, the analysis above may not reflect adequately the impact of replacement activity on the underlying network failure rates. If for instance replacement activity has focused on the riskiest mains, and the failure rates per Km have remained broadly stable this might suggest that the deterioration rate is greater than the replacement rate.

AESL have carried out some analysis in an attempt to consider the level of network deterioration, see Section 5 of Annex F. Their analysis focuses on the observed number of fractures of the mains that have remained in the ground throughout the period 2003 – 2009, and therefore gets at the underlying deterioration of the network by removing the potential impact of replacement activity on observed failures. However, the trade off is that they have only been able to analyse information for a much shorter time period.

The AESL analysis concludes that the deterioration rate of cast iron mains might be between 3-4% per annum, and for ductile iron mains 8% per annum. Though the report notes that they had access to a small dataset, and that their result is influenced by the first and last data points, both of which may have been outliers caused by exogenous factors.

4.3. Risk modelling

The ToRs also set out a number of questions on the MRPS in particular focused on the success of the model in identifying the highest risk mains.

A detailed response to this set of questions is presented in AESL's analysis, see Section 4.2 of Annex F. The key findings in their analysis are as follows:

- By analysing the risk scores of a sample of twelve iron mains that have caused an incident in the period 2003 – 2009 their analysis suggests that the risk model does not provide a good prediction of the risk of an incident.
- AESL then carried out a similar analysis to compare the risk scores with the incidence of GIBs. They find that the risk scores produced by the model provide a more accurate prediction of the risk of a GIB.

Taking a step back from the analysis these are findings that we would intuitively expect to observe. First, incidents occur very rarely; furthermore, given a GIB, the likelihood of an incident is determined by a number of factors that are exogenous to the modelling process. The model currently seeks to estimate the probability of an incident given a GIB based on the pressure of the main and the presence of a cellar and does not take account of more important causal factors such as the potential existence of household ignition factors; plugs being sold with appliances rather than fitted by home-owners; and the change in the numbers of pilot lights in households. We understand that the model cannot include this type of information because of the difficulty and likely costs involved in seeking to collect the data.

To summarise given that the incidents are relatively rare, and are caused (given a GIB) by factors not included in the model we would not expect the model to be capable of predicting incidents with any accuracy. However, we would expect the model to have more success in estimating the likelihood of a GIB given a mains failure. This is simply because there are more observations on GIBs and therefore more information available to develop a more effective model.

4.4. Other network risks

The ToRs provide a number of questions on the other potential risks posed by the gas distribution network. These questions seek to establish, to the extent possible, the relative risk of the other network assets compared to the iron mains – this might help to shape thinking if going forward other risks need to be given the same status of the iron mains in any replacement activity.

There is a particular lack of information available on the level of risk posed by the other network assets, though we note that both Wales and West and National Grid provided helpful responses on this issue.

AESL's analysis, see Section 8 of Annex F, presents a more detailed discussion of the other network risks, the key conclusions to highlight are as follows:

- PE mains may pose a significantly lower risk than the metallic mains that they are replacing.
- The quality of information on steel services is incomplete; in particular the current population of steel services is uncertain.

AESL's analysis also analyses the risks posed by risers in multi-dwelling buildings and low pressure gas holders.

Multi-dwelling buildings

The information provided on risers was too limited to develop any assessments on the risks posed by this class of asset. AESL consider that the number, age, property type should be identified and that a sample of risers should have their condition assessed to facilitate the development of a more considered assessment of the risk posed by this asset.

Low pressure gas holders

No information was provided on either incidents or GIBs associated with low pressure gas holders. However, National Grid provided a detailed report that assessed the risk posed by gas holders. The report suggests that in some cases the risks posed by gas holders was close to unacceptable, but in most cases it was at a broadly acceptable level.

The AESL report suggests that the risks associated with gas holders are influenced greatly by the proximity of occupied buildings, and therefore may grow over time due to encroachment. Going forward it may be necessary that mains schemes be put forward in combination, where appropriate, with any associated holders existing adjacent to the scheme location.

4.5. Summary

The key points raised on the ex-post review of the IMRP are presented in Box 4.1 below.

Box 4.1: Key points to note
Risk removal
• There are no perfect measures available to determine the quantity of risk removed by mains replacement, though in our view GIB information provides the most useful indicator of the impact of mains replacement.
• Over the time period under consideration the number of observed GIBs has generally declined. Observations on GIBs per Km are more volatile, but may also have declined for small diameter low pressure mains and low pressure ductile iron mains.
• In terms of modelled risk removal, around 48% of risk has been removed between 2003 and 2009. Overall the programme has removed 22 modelled incidents over the period, which given assumptions about replacement activity prior to the introduction of the IMRP indicates that the programme has removed a net 9.5 modelled incidents.
• The evidence suggests that overall replacement activity has focused on small diameter mains, which pose the most risk. However, over time replacement activity has focused less intensively on this category of mains. In 2003 over 88% of replacement activity was on small diameter mains, but this fell to 83% in 2009.
• The detailed analysis presented in Annex F suggests that there might be significant benefits, in terms of a reduced number of observed GIBs and failures, if replacement activity focused more intensively on the highest risk scoring mains.
Network deterioration
• The deterioration rate is a key variable for the replacement programme, yet prior to the review it seems that very limited analysis of this issue has been carried out. We suggest that additional research on network deterioration should be carried out.
Risk modelling

• The model is not able to predict incidents effectively. Incidents occur very rarely, and (given a GIB) due to factors exogenous to the model.
• As might be expected the risk model does a better job in predicting GIBs, as there is more GIB data available. This is simply because there are more observations on GIBs and therefore more information available to develop a more effective model.
Other network risks
• There is very limited information available on the risks posed by the other network assets. For instance, it is not even clear that the population of services is known.
• The information provided indicates that PE mains pose a lower risk than the iron mains that they are replacing.

5. VALUE FOR MONEY ANALYSIS

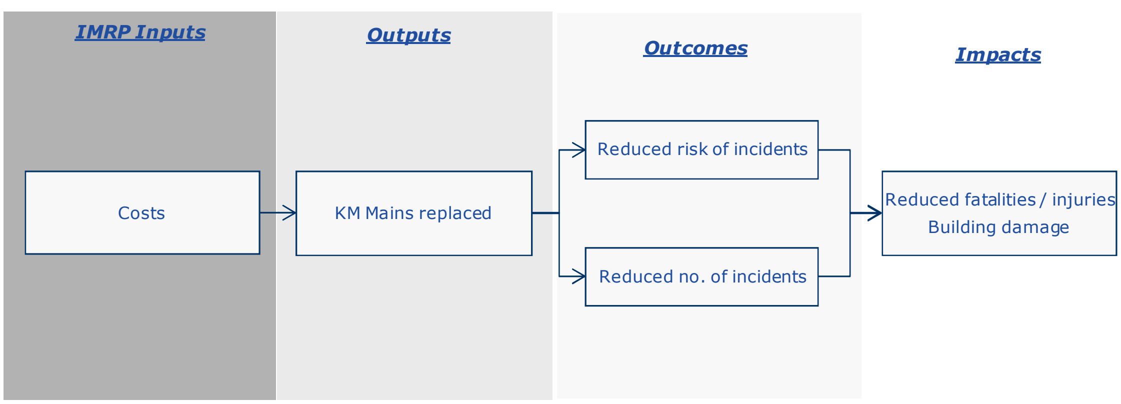
One of the key requirements of the review is to conduct a value for money assessment of the IMRP for the years 2003 to 2009 (the period for which we have data). We understand that the main objective of this analysis is not to validate / invalidate the achievements of the IMRP but instead to provide some of the lessons and evidence that might be used to help shape the project going forward. Further when interpreting the analysis presented below it is crucial to recognise that the IMRP was not originally introduced on the basis of any quantitative assessment.

It is also important to stress that adequate baseline data setting out the level and focus of mains replacement activity before 2002, and the costs of replacement before the introduction of the IMRP were not available at the time of completing the review. Further, no information is available on the specific targets that were put in place for the IMRP to achieve prior to the introduction of the IMRP. As a result the ex-post analysis presented in this section is, by necessity, based on a number of high-level assumptions and is therefore subject to considerable uncertainty and should be interpreted as such.

5.1. Framework for completing the analysis

To consider the value for money for the IMRP we assess what has been achieved by the programme given the level of expenditure. We analyse this within the input, output framework set out in Figure 5.1 below.

Figure 5.1: Inputs, outputs, outcomes and impacts of the IMRP

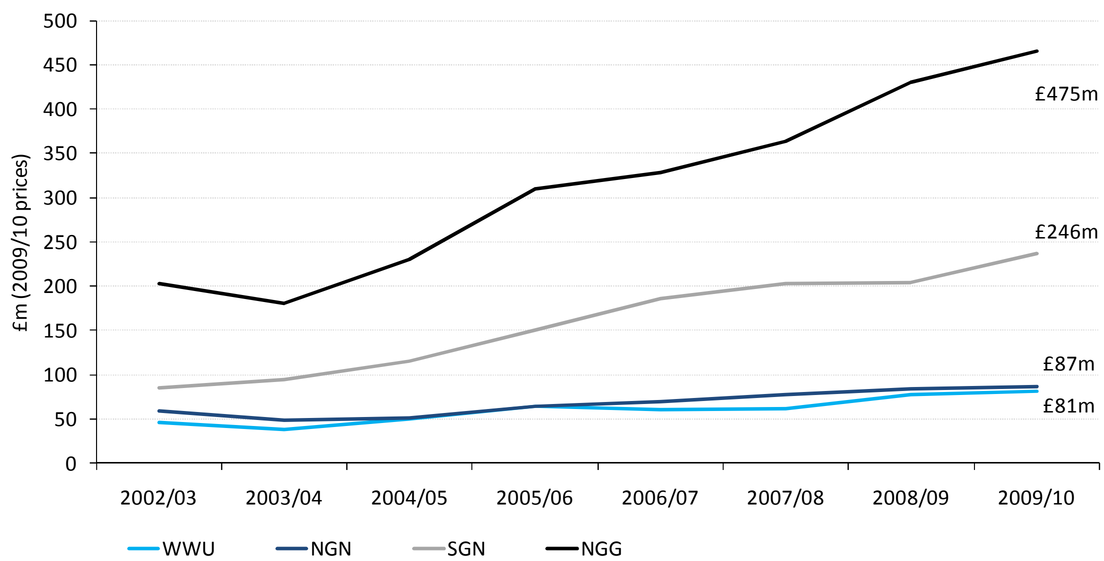


Ideally we would like to consider in detail the marginal costs and benefits achieved by the IMRP compared to the replacement activity that was taking place before 2002. We can, however, only do this at a high-level given a lack of data on mains replacement and the costs of mains replacement before 2002. Therefore in the sub sections we present the analysis at a gross level (i.e. the total costs of mains replacement since 2002) in addition to presenting high-level estimates of the marginal costs and benefits (i.e. the marginal cost of introducing the programme compared to replacement activity pre 2002).

5.2. Costs of the programme (inputs)

An **estimated £4.8bn (2009/10 prices) was spent on the IMRP (both mains, services and overheads) between 2002/03 and 2009/10**. Figure 5.2 below indicates how these costs have varied over time by GDN.

Figure 5.2: Costs of implementing the IMRP 2002/03 – 2009/10 (£m, 2009/10 prices)[17]



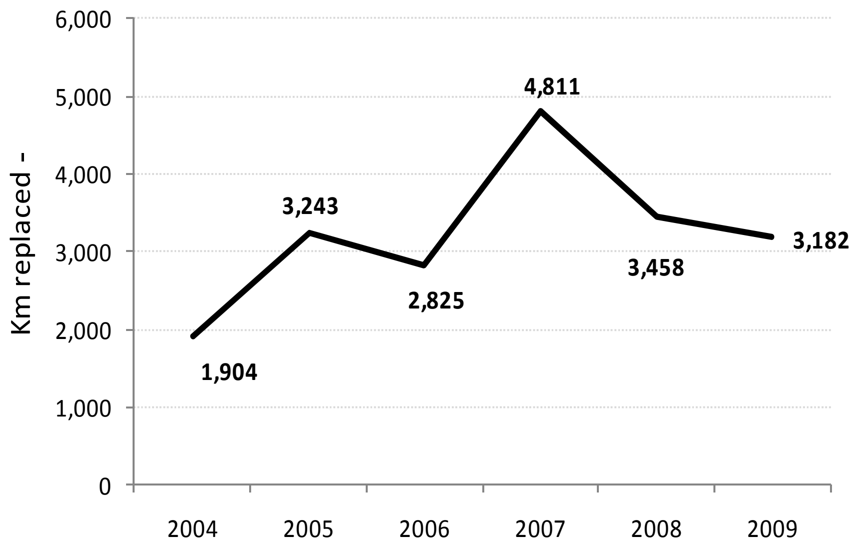
Source: GDN response to Annex C of the Questionnaire

5.3. Km of Mains replaced (outputs)

To put the gross costs discussed above into context it is necessary to consider the level of mains replacement. Figure 5.3 shows that the GDN's have replaced close to 19,426Km of mains (including both cast and ductile iron) in 6 years at an average replacement rate of 3,237Km per annum. According to the GDN data there were 88,394Km of 'at risk' mains as at end 2009. If this is the case it implies that over the next 23 years an average rate of replacement of 3,843Km per annum is required to achieve the objective of removing all 'at risk' mains within 30 years.

[17] The costs in Figure 5.2, are taken from the information provided in the GDNs response to Annex C of the Questionnaire. The costs include the following categories as labelled in the RRP data: HSE's Enforcement Policy for the Replacement of Iron Gas Mains; Other Policy & Condition Mains (incl. MPDI); capitalised overheads for repex mains;

*Figure 5.3: Km of mains replaced 2004 – 2009**



Source: GDN response to Annex D

**In addition to the 'at risk' population according to their responses up to 5% of the iron mains network currently is currently greater than 30m away from buildings and therefore not included in the IMRP. However, these mains could be included in the programme given the potential for encroachment over time.*

Marginal cost and marginal Km of mains replacement

To develop an estimate of the marginal cost of the programme it is necessary to consider the level of mains replacement that might have occurred in the absence of the IMRP. As shown in the figure above the programme has resulted in the replacement of 19,426km of mains and an estimated 1.2m service pipes over 2004-2009.[18] The average rate of replacement for these years was 3,237km per year.

This represents a 75 percent increase on the average annual replacement rate of 1,840km deemed to be necessary to achieve HSE safety outputs in the five years prior to the introduction of the IMRP.[19]

The effect of scale economies on unit costs at these levels is unclear given the available data, but free from the constraint to replace pipe based on cost rather than risk characteristics, it is likely that the per unit costs of replacement would have been lower than or equal to outturn costs had they been replaced at pre-2001 levels of replacement.

Therefore, assuming the same profile of work, scaling-up the programme from an average of 1,840km over these six years to 3,237km **increased total costs from £2.78bn to £4.89bn; an incremental cost of the IMRP (both mains, services and overheads) of at least £2.1bn over six years**. This incremental cost of mains replacement alone is estimated to be around £1.3bn over six years.

[18] Based on an assumed rate of replacing approximately 62 services for each mains km replaced.

[19] HSE (2001) "The Health and Safety Executive's Enforcement Policy for the Replacement of Iron Gas Mains" http://www.hse.gov.uk/gas/domestic/gasmain.pdf

5.4. Outcomes of mains replacement

The reduction in the "at-risk" pipe population as a result of the IMRP has delivered benefits in terms of reduced operational costs for GDNs, and environmental and private benefits of reduced leakage of gas from these mains.[20] However, safety benefits were the driving factor behind initiating the programme and therefore provide the most important benchmark for how the programme has delivered value for money.

As discussed in Section 4 there is no completely satisfactory indicator of the risk removed by replacement activity available. In our view it is most informative to consider the impact of replacement the observed number of GIBs, however there is no information available to provide sensible estimates on the impact of replacement activity on observed GIBs, it is more useful to consider the trend of GIB data over time.

We therefore present information on the modelled risk reduction as a proxy for the impact of the mains replacement programme on risk removal.[21] Table 5.1 presents this information and shows that the IMRP has prevented a total of 9.5 modelled incidents since its introduction.

Table 5.1: Evidence of risk removal by replacement activity

Sample	Total outcome of IMRP	Marginal outcome of IMRP
Modelled risk removed	4.5	2
Modelled incidents averted	22	9.5

Using the same assumptions on the number of fatalities per incident as used in the CBA (we have assumed one fatality for every two incidents), this suggests that in net terms the iron mains replacement activity has prevented around five fatalities at a cost of just over £1.3bn over the period 2003 – 2009.

To provide a high-level estimate of the cost per life saved of the IMRP in the period 2003 – 2009 we need to take account of the wider benefits associated with the programme (as discussed in the CBA these include reduced repair costs and reduced environmental emissions). For the purposes of this review we have not developed a detailed assessment of these benefits for the period 2003 – 2009 but can take some account of them by using the analysis in our forward-looking assessment, which suggests that the wider benefits account for around 20% of the total costs incurred.

Overall, taking account (albeit based on a high-level assumption) of the wider benefits of the programme, the **cost per life saved of the programme over the period 2003 – 2009 might be in the region of £211m**. This is based on a number of conservative assumptions; and is based on the outputs of the model, which as discussed in Section 4 likely systematically overestimates the risk of an incident. Therefore in practice we would expect this estimate to be at the low end of a potential range estimating the cost per life saved of the programme and note that the estimated value of a life saved by the programme is very high.

[20] The wider benefits of the IMRP are discussed in more detail in the cost benefit analysis section of the report, we attempt to quantify the wide benefits of mains replacement in Section 6 of this report.

[21] As we do not have a comparable estimates of modelled risk removed from services replacement in this part of the analysis we focus on the modelled risk removed by iron mains replacement alone.

5.5. Summary

The key issues raised in this section are presented in Box 5.1 below. -

Box 4.1: Key points to note
• There is very limited information available about that details the costs, targeting and level of mains replacement per annum prior to the introduction of the IMRP. In addition the documentation that we have had available provides no specific targets for the IMRP to achieve over a given timeframe, other than to replace Kms of iron mains. As a result the ex-post review presented is assumption drive and is therefore subject to uncertainty.
• According to the information provided by the GDNs 19,426Km of mains have been replaced between 2003 – 2009 at a total cost of £4.8bn (including services and overheads)
• According to the GDN data there were 88,394Km of 'at risk' mains as at end 2009. If this is the case it implies that over the next 23 years an average rate of replacement of 3,843Km per annum is required to achieve the objective of removing all 'at risk' mains within 30 years.
• Drawing any detailed inferences from the value for money assessment is difficult given the lack of baseline data, and lack of specific targets for the programme. However, conservative assumptions suggest that cost per life saved through the introduction of the IMRP over the period 2003 – 2009 might be upwards of £200 million. It is important to note that this is based on the outputs of the model, which as discussed in Section 4 likely overestimates the risk of an incident. Therefore in practice we would expect this estimate to be at the low end of a potential range, and note that the estimate suggests that the value of a life saved by the programme has been very high.

6. CBA AND OPTIONS APPRAISAL

One of the core objectives of this review is to conduct a CBA of the IMRP. In carrying out this exercise we understand that the introduction of the IMRP was not initially based on a cost-benefit assessment. However, given the costs associated with delivering the project over the next twenty years it is reasonable that a CBA be used as part of a the analysis necessary to consider how the IMRP might be structured going forward.

This section details our approach to completing the CBA and options appraisal and presents the emerging findings from the analysis. In particular it:

- describes our understanding of the objectives behind completing the CBA and options appraisal;
- sets out the approach and methodology for completing the analysis; and
- presents the results.

The drafting in this section has focused on the key parts of the approach and the results. Additional detail is provided in the supporting Annex E, which provides more detail on our approach to modelling the CBA and the assumptions used in the analysis.

6.1. Objectives of the CBA

In our view, completing a CBA of the future costs and benefits of the IMRP is subject to considerable uncertainty. The analysis is carried out over a long time horizon and involves assumptions on a number of variables which are both un-known and potentially subject to significant volatility. Therefore the CBA that we present is demonstrated to provide an illustrative view on the potential future costs and benefits of the IMRP in its current form (the counterfactual scenario) compared to a selected range of options for potentially updating the programme. As such, its results should be interpreted as orders of magnitude, rather than precise figures.

The objective of the CBA is therefore to <u>provide an illustrative assessment of selected alternative options for implementing the IMRP going forward and should be interpreted as such.</u> At a high level, the options selected for analysis are indicative of the general directions in which the programme could move in future, rather than highly calibrated policies which would run the risk of being spuriously accurate given the data on which they would be based..

However, here is a range of reasonable assumptions that could be made about a number of the key underlying variables. <u>As such, we present the results of our analysis as a range based on different assumptions for the key underlying variables.</u>

Overall we have therefore developed the analysis to help identify:

- if a new approach can be developed that delivers the overarching objectives of the IMRP, while achieving potential cost savings; and
- the scope of potential savings for the consumer through the implementation of possible changes to the IMRP.

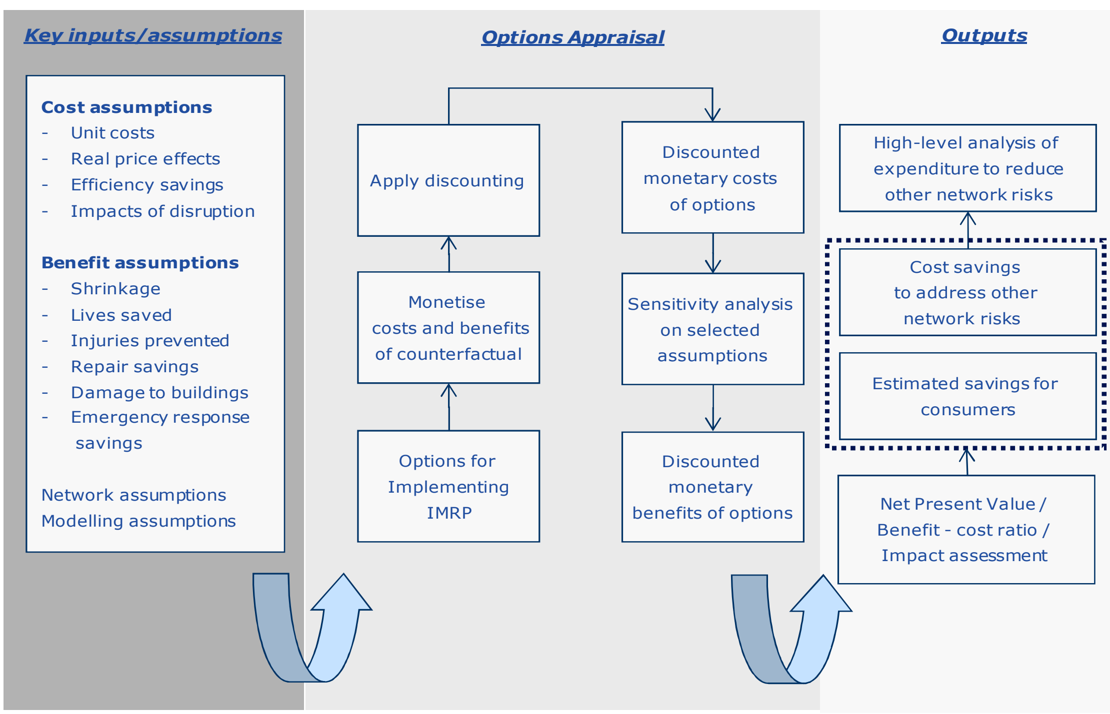
6.2. Approach and methodology

Our approach to completing the CBA of the IMRP is consistent with HM Treasury Green Book and HSE CBA guidelines.[22]

1. - In the first stage of our analysis we describe the options to include in the options appraisal. This includes the IMRP in its current form (the counterfactual) and other potential policy options for the IMRP.
2. - We then identify the material costs and benefits associated with each of these policy options and where possible attach monetary values to them.
3. - The next stage of the analysis is to estimate the Net Present Value (NPV) of each of the policy options. As stated in the previous section we present these results based on the scenarios that are discussed in the managing uncertainty section below.
4. - Finally the results of the analysis to compare each of the options to identify if there is an 'optimal' approach in cost-benefit terms that is robust to changes in the underlying assumptions. Overall we also consider the implied savings for consumers and / or cost savings to address other network risks (covered in Section 6.6).

Figure 6.1 summarises our framework for completing the CBA.

Figure 6.1: Framework for the CBA and options appraisal



We discuss each of these steps involved in completing the CBA in the sub sections below. -

[22] http://www.hm-treasury.gov.uk/data_greenbook_index.htm

6.2.1. Choice of Policy Options

To carry out the options appraisal we have identified a range of high level options for taking forward the IMRP. These draw on some of the key findings of the review, but their main purpose is to illustrate order of magnitude differences between broad policy approaches, rather than assessments of finely-tuned strategies (which would require a much greater granularity of analysis).

We provide a brief description of each of these high level options below.

The counterfactual

This analysis assesses the costs and benefits involved in implementing the IMRP in its current form based on our understanding of the Km of iron mains due for replacement by end 2032. In analysing the costs and benefits of the counterfactual it is necessary to define the **'notional do nothing option'.** In doing so, we are not proposing stopping all mains replacement activity, as a potential option for the future of the programme, we are simply seeking to provide a hypothetical point of comparison for the counterfactual.

Varying the replacement rate

We have also considered the impact of varying the replacement rate on the costs and benefits associated with the IMRP, through two main options. First, we have presented the costs and benefits involved with reducing the replacement rate such that the programme is completed at end 2039 (which enables some comparison with the results presented in Frontier (2010)).[23] Second, we have also presented the impact of accelerating the replacement rate to enable the programme to be completed by end 2025.

The specific time periods chosen for analysis are purely to illustrate if increasing or decreasing the replacement rate might confer net costs or benefits for a given range of assumptions. The model that has been developed to carry out the CBA, and has been circulated to the HSE and Ofgem, can look at the costs and benefits across a range of different time horizons for completing the IMRP and in theory could be used to identify an 'optimal' time period for analysis in cost benefit terms.

Altering the focus of the IMRP to smaller diameter mains

We have also considered the likely costs and benefits arising from refocusing the IMRP on small diameter iron mains and excluding the large diameter iron mains from the replacement programme. The rationale for looking at this option derives from the analysis presented in the AESL's analysis presented in Section 7 of Annex F.

The AESL report discusses the potential for implementing different replacement strategies for different diameter sizes. The AESL analysis discusses potential replacement strategies for the following categories of the iron mains population:

- **≤ 8" mains:** replacement activity continues in current form, i.e. all iron mains below 8" replaced by 2032.

[23] Frontier (2010), Evaluating the gas mains replacement programme – preliminary findings.

- **> 8 - <18” mains**: Mains in this group would have their risk score assessed and if high considered for replacement, if low replacement activity would be deferred.
- **≥ 18” mains**: Alternative methods other than mains replacement could be considered.

The CBA modelling approach is not sophisticated enough to model the above suggestions in detail, however the analysis can show:

- The costs and benefits of excluding all mains for replacement > 8”, all other iron mains would be replaced by 2032.
- The costs and benefits of excluding all mains for replacement ≥ 18”, all other iron mains would be replaced by 2032.

We therefore consider these two additional options to provide an illustration of the costs and benefits that might arise if the two alternative replacement strategies set out above.

Targeting iron mains prone to failure

At present we understand that the GDNs manage their respective replacement programmes using the 20:70:10, 20:80 and zonal replacement models using the outputs of the risk model to guide their strategies. As we have discussed in Section 4, it may be that the replacement strategies have over time led replacement activity to be less focused on the replacement of the highest risk mains.

This option illustrates the potential costs and benefits that might arise if the GDNs were to focus their replacement activity more intensively on mains that are more likely to fail – and therefore potentially deliver a reduction in the observed level of mains failure more quickly.

Our modelling analysis works by using the information supplied by the GDNs in response to Annex D of the Questionnaire, to estimate the proportion of failures that each category of mains accounts for (i.e. by diameter and pressure) in a given year.[24] Using the illustrative modelling approach if a category of mains (say for instance a 3” low pressure main) had accounted for 15% of all failures in the previous year, in our model 15% of the next year’s replacement activity would focus on removing that category of iron mains. Alternatively, if the main (for instance an 18” low pressure main) had accounted for 0% of failures in the previous year, the GDNs would not be required to replace any Km of that category of main in the next year.

To enable the analysis to identify the benefits specific to targeting mains failure, the other parameters of the programme have been left largely unchanged compared to the counterfactual, i.e. the programme is expected to finish the replacement of all ‘at risk’ mains by 2032.[25]

We understand that the GDNs could face significantly higher costs if they were to implement a new replacement strategy - for instance if the mains prone to failure were dispersed widely making it necessary to mobilise a significantly higher number of replacement schemes. We have

[24] We had access to failure rate data for 2003 – 2009 for National Grid, SGN and NGN and were therefore able to estimate historic failure rates per Km for the different categories of iron mains.

[25] Using the modelling approach there is a small residual of mains left over at the end of 2032. This is because a small proportion of mains in the data that we were given have no history of failing and would therefore not be replaced in a programme designed to remove mains failure.

not had access to the information necessary to develop a credible assumption on the potential increase in costs arising from the implementation of an alternative approach to replacing mains in this analysis, but recognise that it could be an important factor and therefore this option should be interpreted with this in mind.

6.2.2. Costs and benefits associated with the IMRP

We developed our understanding of the costs and benefits associated with each of the options listed above through a combination of independent research and analysis of the information provided by the GDNs in response to the Questionnaire. The analysis focuses on the most material costs and benefits to make the analysis more transparent, and as far as possible, to avoid introducing spurious accuracy into the model given the range of uncertainties involved.

Table 6.1 below sets out the costs and benefits related to the IMRP. These have been placed in specific categories, which focus attention on the different outcomes being achieved by the IMRP, which can help to identify if the IMRP as currently structured is the most cost effective way to deliver each of the different types of benefit going forwards.

Table 6.1: Costs and benefits associated with mains and services replacement

Category	Costs & benefits
Direct costs	The costs of iron mains and services replacement, and the associated overhead costs.
Indirect costs	The wider traffic and disruption costs associated with a given level of mains and services replacement. For the purposes of this review we have assumed that these costs are represented by the Traffic Management Act costs that are included in the direct costs of the programme. This may understate the social disruption costs caused by mains and services replacement.
Health & safety benefits	The estimated number of incidents and therefore fatalities, injuries and building damage attributable to the iron mains and services in the 30:30 programme
Network efficiency benefits	The following benefits from the replacement of iron mains and steel services with PE mains and services: • Repair costs gas mains • Emergency response costs • Private shrinkage
Environmental benefits	The environmental shrinkage costs caused by leakage from the iron mains and services in the 30:30 programme

In simple terms our approach to modelling each of the costs and benefits has been to build a bottom up estimate of the marginal costs and benefits of iron mains replacement per Km of iron mains and per unit of services. This has required us to develop an estimate both the number and unit costs / price of each of the costs and benefits per Km of iron mains and per unit of services in the 30:30 programme over the given time-frame (we also estimate this for the PE mains and services that are used to replace the iron mains).

Box 6.1 gives a simple example of our approach to modelling the costs and benefits. -

Box 6.1: Example of our approach to modelling
We set out briefly our approach to estimating the reduction in the repair costs for iron mains arising as a result of the IMRP. • We first analyse the GDN's response to the Questionnaire and carried out our own analysis to estimate the number of repairs per Km of iron mains and per unit of services in the 30:30 programme. • Based on our unit repair cost assumption we estimate the marginal cost of mains and services repairs at end 2009. • We then carry out the same analysis for the PE mains and services used to replace the iron mains • For a given repair cost for PE mains we can therefore estimate the marginal benefit, in terms of repair cost savings, per Km of iron mains and per unit of services replaced.

6.2.3. Managing uncertainty

As discussed the CBA is subject to significant uncertainty. The time period for analysis is over twenty years, and involves a range of costs and benefits which might experience significant variation over time for a number of reasons.

Based on our analysis the main areas of uncertainty in the analysis include:[26]

- The underlying deterioration rate of the network (defined for modelling purposes as changes in the rate of occurrence of failure per Km of iron mains or unit of services).
- The unit price of private shrinkage (price per MWh of shrinkage).
- The unit price of environmental shrinkage (the non-traded price of carbon).[27]
- The real price effects; that is price movements relative to inflation.

In our main report we present the results based around different assumptions for the deterioration rate. We have focused particularly on the potential impact of varying the rate of deterioration because the results are significantly more sensitive to changes in the assumed deterioration rate than for the other variables under consideration.

We therefore present the results of the CBA for each of the options for the following scenarios:

- **Deterioration rate at 0%.**
- **Deterioration rate at 5%.**
- **Deterioration rate at 10%.**

<u>In presenting the results of this analysis we are not making any assumptions on which one of the scenarios is the best approximation to the actual deterioration rate - hence we have presented our results as a range</u>.

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[26] We have developed an economic model that has enabled us to analyse the impact of varying each of the key underlying assumptions.

[27] Taken from DECC assumptions, discussed further in Annex E, and see www.decc.gov.uk.

However, we are aware that as part of this review some work has been carried out to begin to estimate the potential level of deterioration. For instance, some of the GDN's responses to the Questionnaire have suggested that broadly speaking the replacement rate has kept pace with underlying deterioration rate of the network.[28] If this were the case, all things being equal, we would expect to observe that the rate of failure per Km would remain broadly stable over time. Historical evidence on failure rates suggests that this may be the case, though as noted the dataset that we had available to present the chart has some data omitted and is potentially inconsistent.

In contrast other analysis that has been carried out during the review process has suggested that the rate of deterioration might lie somewhere between 5 – 10% per annum. However, this analysis has had to rely on a more limited dataset than would ideally be available to conduct the analysis.

While over a short period of time it might be possible to experience a high deterioration rate; it should be noted that, for instance, a 10% rate of deterioration – defined as an increase in the rate of incidence of failure per Km – would imply quite extreme outcomes in the observed number of iron mains failures if applied over any length of time. It is not clear that the current observed level of failure rate across the network support the assertion that the network has been subject to a significant and positive deterioration rate over time.

We present a simple example of what different deterioration rates might mean for the observed level of failure in Box 6.2 below.

Box 6.2: Illustration of the impact of the deterioration rate assumption

In this box we illustrate the impact of a 5% and 10% deterioration rate assumption over a long time period using a set of stylised assumptions.

Starting in 1990 we assume an:

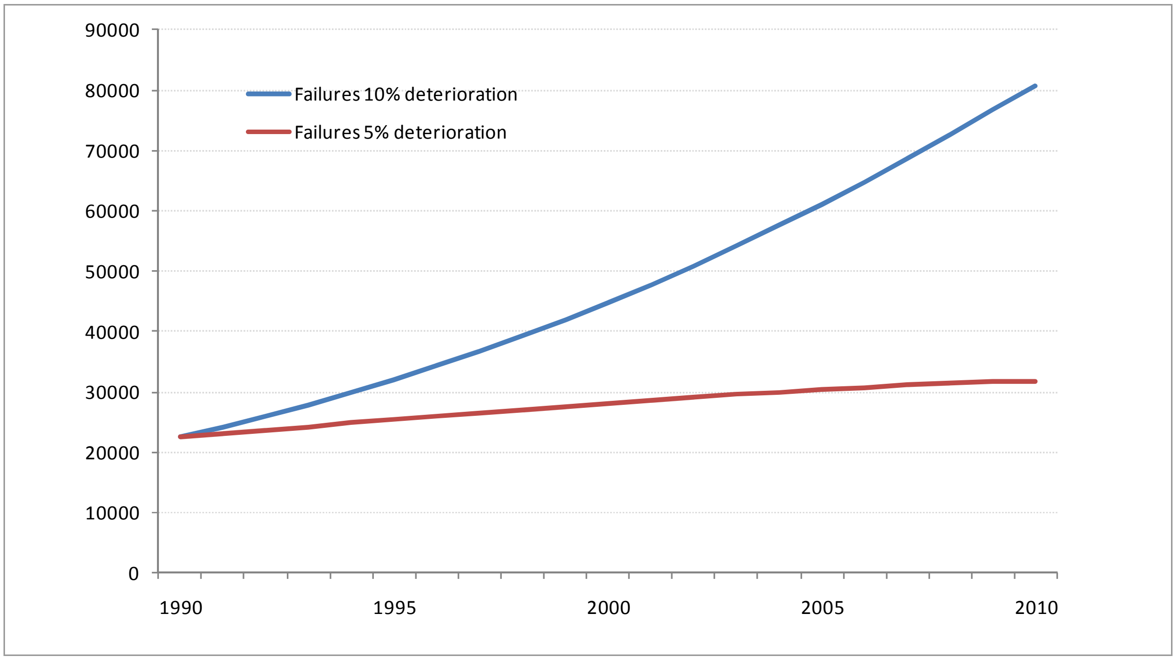
- iron mains network of 150,000Km;
- a failure rate of 15 per 100Km per annum; and
- 3,500 Km of mains being replaced each year.

With these assumptions we would observe 22,500 failures in 1990.

The figure below illustrates what would happen if the deterioration rate was 5% or 10% per annum. It shows that with a 10% per annum deterioration rate assumption we would expect to observe over 80,000 failures in 2010. With a 5% deterioration rate the number of failures would be over 33,000 in 2010 – a greater than 50% increase in the observed number of failures, despite the overall size of the network having declined by nearly 50% due to replacement activity over time.

It is not clear that the observed number of failures across the network has increased by the amount that would have occurred if the deterioration rate was in the 5 to 10% range. While completing this analysis we have not had access to a consistent historic failure rate dataset that would enable us to observe long-term trends in observed failures.

[28] For instance, see National Grid response to question 19 of the Questionnaire.



Overall, it would seem unlikely that the deterioration rate (as defined in this report) of the network is as high as 10% per annum over any long time period. However, it may be that some parts of the network are deteriorating more quickly than others or that the deterioration rate may itself change over time.

Given both the availability of data to us when carrying out the review and our understanding of the level of research carried out on the deterioration rate before the start of this review (based on the responses to the Questionnaire) additional analysis and research is needed to develop a clearer understanding on the underlying deterioration rate of the network. Thus the deterioration rate of the network is treated as an uncertain variable for the purpose of this analysis.

It should be noted that there are a range of other uncertainties in the analysis – even around the Km of iron mains that still needs to be replaced. When the IMRP was introduced in 2002 it was assumed that there were approx 91,000Km of 'at risk' iron mains that needed to be replaced, based on the GDN's data by end 2009 this figure has been revised to over 107,000, which represents an increase in the 'at risk' population of over 17% in eight years. It is unclear if the growth of the 'at risk' mains population will be at a similar level in the future, but it would have a significant impact on costs and might make it difficult to practicably achieve replacement by a given date.

6.3. Results

The results generated from our CBA are subject to considerable uncertainty, as such they are primarily illustrative and should be interpreted as providing a guide on the potential orders of magnitude of the costs and benefits of the different options considered. As discussed above we have presented the results for the three different deterioration rate assumptions (0%, 5% and 10%).

Moreover, we would note that whilst it may be possible to assign a monetary value to the different benefits, they are not necessarily the same "currency". In other words, whist is interesting to see how the different categories of benefit stack up against the costs involved, arguably there may be limits to which health and safety, efficiency and environmental can be essentially traded-off against each other. To summarise, it is important to consider the different benefit categories individually as well as collectively.

The results section is split into two sections:

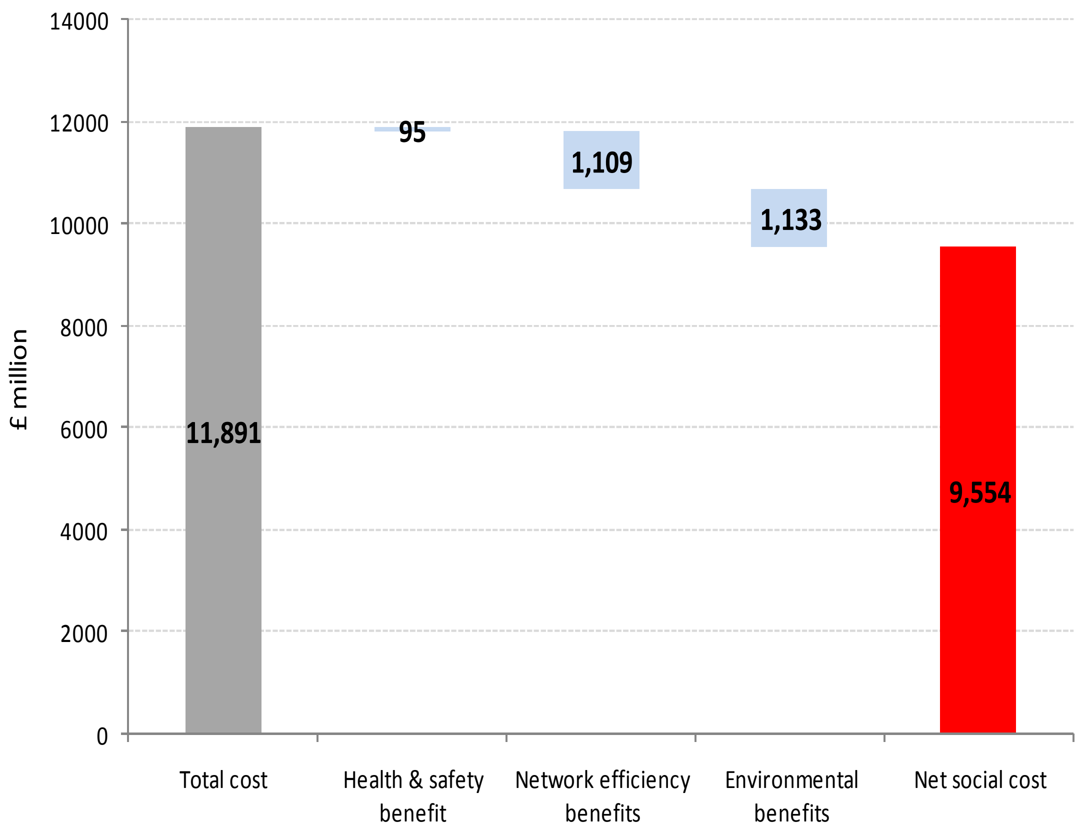
- We first present the NPV of continuing with the IMRP in its current form for the next 20 years. This provides an analysis of the counterfactual against the 'notional do nothing scenario' and helps to illustrate the potential quantum of the social costs and benefits implied by the IMRP.
- We then present the results of the options appraisal which indicates the *incremental* costs and benefits the different options compared to the counterfactual that we have outlined in this section.

6.4. NPV analysis

The results of the NPV analysis compare the counterfactual (i.e. completing mains replacement by 2032) to the 'notional do nothing' state of the world i.e. leaving the remaining 'at risk' mains in the ground and stopping the replacement programme. As we have stated analysis of this nature cannot be taken to suggest that the IMRP should be stopped as it is not sophisticated enough to take account of the surrounding legal and regulatory framework, which implies obligations and indeed costs and benefits on both the GDNs and society. However, the analysis can indicate whether the programme in its current form potentially confers significant social costs or benefits, which may indicate that the structure of the programme – or potentially the legal and regulatory framework needs to be considered for reform.

Figure 6.2 shows that we estimate the implementation of the counterfactual as against stopping the programme would create net costs in excess of £9.5bn (2009/10 prices). The figure is also interesting as it indicates that the significant majority of the total benefits derived from the programme relate to network efficiency (primarily repairs and private shrinkage) and reduced environmental emissions, rather than from health and safety benefits.

Figure 6.2: Total discounted costs and benefits of the counterfactual relative to 'do noting' option (£m, 2009/10 prices)



The analysis in Table 6.2 presents the NPV of the counterfactual for the three different deterioration rate assumptions. The analysis suggests that the **counterfactual imposes a net cost of £2.1 - £9.6bn,** with the greater the deterioration rate, the lower the cost**.** This implies that the finding that the counterfactual imposes a significant net cost is robust to different assumptions on the deterioration rate.

Table 6.2: Costs and benefits of the counterfactual across the different scenarios (£bn, 2009/10 prices)

	Total costs	**Total benefits**	**Net (cost)/ benefit**
0% deterioration	£11.9bn	£2.3bn	(- £9.6bn)
5% deterioration	£11.9bn	£4.7bn	(- £7.2bn)
10% deterioration	£11.9bn	£9.8bn	(- £2.1bn)
Range of net costs of the counterfactual: (- £9.6bn to - £2.1bn)			

As acknowledged throughout this section, there is significant uncertainty involved in completing a CBA of the IMRP. However, the illustrative results of the analysis presented suggests that in its current form the IMRP imposes significant net costs, which does provide some justification for considering alternative ways to deliver the objectives of the IMRP.

6.5. Options appraisal

The results of the options appraisal help to indicate the potential costs and benefits that might arise if the IMRP were to be changed. We have compared the counterfactual against the following options:

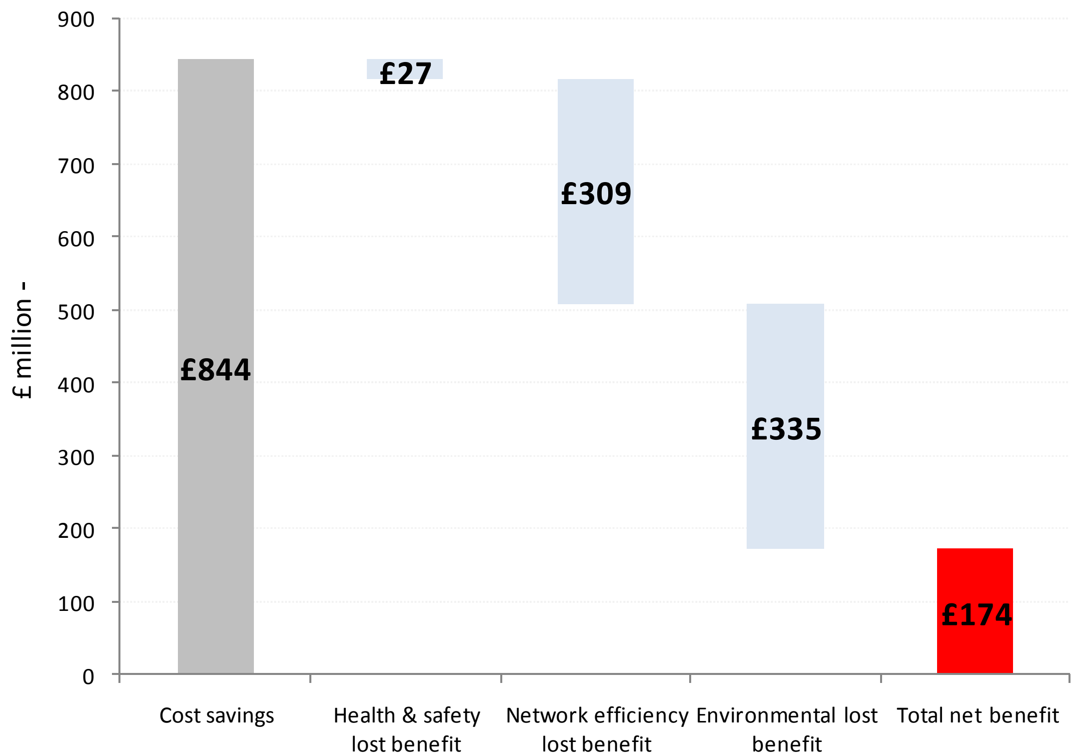
- Option A - Decreasing the rate of replacement to complete the removal of all 'at risk' mains by 2039 instead of 2032.
- Option B - Increasing the rate of replacement to complete the removal of all 'at risk' mains by 2025 instead of 2032.
- Option C – Restricting replacement activity to all mains ≤ 8".
- Option D – Restricting replacement activity to all mains < 18".
- Option E - Increasing the intensity of replacement activity on mains prone to failure.

6.5.1. Option A - Decreasing the replacement rate

In simple terms delaying the replacement of the 'at risk' mains would be expected to reduce the total costs of completing the programme because of the impact of discounting (that is, the value of money tomorrow, is less than it is today). However, it would also reduce the benefits achieved from completing the programme as the risk would be removed from the network more slowly. Further, the other benefits from completing the programme derived from improved network efficiency and reduced environmental damage would also be delayed. The modelling approach, however, does not take account of the possibility that decreasing the replacement rate might ease pressure on contractor rates and therefore deliver greater cost savings.

In Figure 6.3 below we present the estimated incremental cost savings and lost benefit that might arise if the IMRP was completed by end 2039 compared to the counterfactual (of completing replacement in 2032). The figure indicates that there may be only marginal social benefits – in the region of £175m – from reducing the replacement rate to delay the completion of the IMRP given a 0% deterioration rate. The benefits lost from extending the programme are due largely to the lost environmental and network efficiency benefits of maintaining the implied replacement rate. Based on an illustrative cost benefit assessment the health and safety benefits would not play a material role in determining whether or not to delay the completion of the programme.

Figure 6.3: Incremental cost savings and lost benefit of completing the IMRP in 2039



It is important to note that the positive benefits of delaying the completion of the IMRP are not robust to changes in the deterioration rate, as increasing the deterioration rate assumption increases the size of the benefits lost from delaying the completion of the programme.

Table 6.3 below compares the estimated size of the total benefits lost from delaying the programme against the cost savings, for each of the three deterioration rate assumptions. The table shows that decelerating the mains replacement programme might create a net cost of £2.7bn assuming a 10% deterioration rate. While it might deliver a net benefit of £174m if the deterioration rate is 0%.

Table 6.3: Costs and benefits of Option A across the different scenarios (£, 2009/10 prices)

	Total cost savings	**Total benefit lost**	**Net (cost)/ benefit**
0% deterioration	£844m	£671m	£174m
5% deterioration	£844m	£1,513m	(- £669m)
10% deterioration	£844m	£3,587m	(- £2,742m)
Range of cost / benefit of accelerating replacement: (- £2.7bn) to £174m			

The findings from our analysis of the net costs and benefits involved in slowing down the replacement rate against the counterfactual are as follows:

- The potential health and safety benefits, though clearly important, would not appear to be material if a decision was made on cost-benefit terms to slow down the replacement rate.

- The analysis also indicates that slowing down the replacement rate to complete the programme in 2039 **might deliver between a net benefit of approx £170m to a net cost of £2.7 billion.** This might suggest that the potential to derive benefits from slowing down the replacement rate is dependent on the deterioration rate.

6.5.2. Option B - Increasing the replacement rate

Within the simple modelling framework increasing the replacement rate in our analysis increases the costs of delivering the programme but also increases the benefits by removing risk and improving network efficiency etc. more quickly. Of course, this does not account for the potential increase in costs and disruption that might occur if the replacement rate was increased significantly. In particular it might be expected that an increased rate of replacement would lead to significant cost pressure on contractor rates.

In Figure 6.4 below we present the net costs and benefits that might arise if the IMRP was accelerated to be completed in 2025, compared to the counterfactual. The figure indicates that, assuming a 0% deterioration rate, accelerating the IMRP would create a net cost of £388m.

Figure 6.4: Incremental cost savings and lost benefit of completing the IMRP in 2025

Table 6.4 below presents the results of the net costs and benefits involved if the replacement rate was increased to complete the replacement of 'at risk' mains by 2025 for the three deterioration rate assumptions. We would expect that with a high deterioration rate assumption the benefits from completing mains replacement earlier would increase. In the simple modelling approach replacing the mains earlier would prevent the occurrence of the level of repairs / leakage associated with the higher deterioration rate.

The table shows that depending on the assumed rate of deterioration, accelerating the replacement programme imposes either net costs to society of £388m (assuming a 0% deterioration rate) or benefits of up to £488m (assuming 10% deterioration rate).

Table 6.4: Incremental costs and savings of completing replacement of 'at risk' mains by 2025 (£m, 2009/10 prices)

	Increased costs	**Increased benefits**	**Net (cost)/ benefit**
0% deterioration	£937m	£550m	(- £388m)
5% deterioration	£937m	£880m	(- £57m)
10% deterioration	£937m	£1,425m	£488m
Range of cost / benefit of accelerating replacement: (- £387m) to £488m			

6.5.3. Option C – Restricting replacement activity to all mains ≤ 8".

We have also considered the costs and benefits involved in focusing the IMRP on all iron mains ≤ 8". In this option all iron mains ≤ 8" would be replaced by 2032, and all other iron mains excluded from replacement activity. Removing >8" diameter mains from the replacement programme would be expected to deliver significant cost savings:

- It would mean excluding 15,774Km of iron mains from the replacement programme.[29]
- In addition the unit cost of larger diameter mains is significantly higher than for small diameter mains. For instance, the cost of replacing one Km of 12" mains is almost double the cost of replacing one Km of 8" mains.

Further as discussed in the AESL report historic evidence suggests that large diameter mains may be less prone to failure and causing incidents; therefore the benefits lost from focusing on small diameter mains might be expected to be relatively low in practice.

Figure 6.5 presents the results of the analysis on the incremental costs and benefits that might arise from refocusing the IMRP on all iron mains ≤ 8". The figure shows that focusing replacement activity on all iron mains ≤ 8" would deliver over £4bn in benefits compared to the counterfactual assuming a 0% deterioration rate.

[29] According to the information sent from the GDNs there iron mains population at end 2009 is 88,394Km, while the population of mains ≤ 8" is 72,620Km.

Figure 6.5: Incremental savings and lost benefits of focusing on ≤ 8" diameter iron mains(£m, 2009/10 prices)

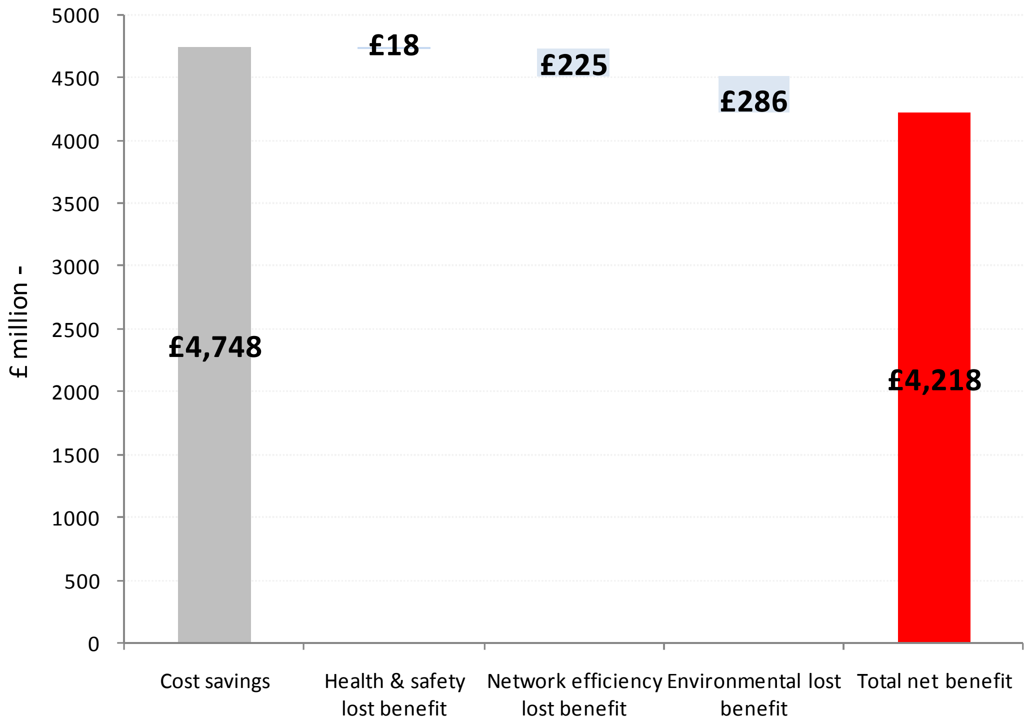


Table 6.5 below presents the results of focusing on small diameter mains for the three different deterioration rate assumptions. The table shows that based on our three scenarios, focusing on **all iron mains ≤ 8"mains could potentially deliver £2.5bn - £4.2bn in net social benefits**. In a simple cost-benefit assessment, <u>focusing on all iron mains ≤ 8"mains would deliver significant benefits robust to the different deterioration rate assumptions</u>.

Table 6.5: Incremental costs and benefits of focusing on ≤ 8" diameter mains (£, 2009/10 prices)

	Cost savings	**Lost benefits**	**Net (cost)/ benefit**
0% deterioration	£4,748m	£529m	£4,218m
5% deterioration	£4,748m	£1,072m	£3,676m
10% deterioration	£4,748m	£2,242m	£2,506m
Range of benefits of focusing on ≤ 8" diameter mains: £2.5bn to £4.2bn			

It is important to note that our simple cost-benefit model does not take account of the existing legal and regulatory framework, which would need to be considered if it was decided to exclude certain categories of iron mains from the IMRP.

6.5.4. Option D Restricting replacement activity to all mains < 18".

We have also considered the costs and benefits involved in focusing the IMRP on all iron mains < 18". In this option all iron mains < 18" would be replaced by 2032, and all other iron mains excluded from replacement activity. Removing ≥ 18" diameter mains from the replacement programme would be expected to deliver significant cost savings, though the cost savings would be lower than observed for Option C (focusing on ≤ 8"):

- It would mean excluding 1,868Km of iron mains from the replacement programme.[30]
- In addition the unit cost of larger diameter mains is significantly higher than for small diameter mains. For instance the cost of replacing one Km of 18" mains is over 50% higher than the cost of replacing one Km of 12" mains.

Further as discussed in the AESL report historic evidence suggests that larger diameter mains may be less prone to failure and causing incidents; therefore the benefits lost from focusing on < 18" diameter mains might be expected to be relatively low in practice.

Figure 6.6 presents the results of the analysis on the incremental costs and benefits that might arise from refocusing the IMRP on all iron mains < 18". The figure shows that focusing replacement activity on all iron mains < 18" would deliver over £950m in benefits compared to the counterfactual assuming a 0% deterioration rate.

Figure 6.6: Incremental savings and lost benefits of focusing on < 18" diameter iron mains(£m, 2009/10 prices)

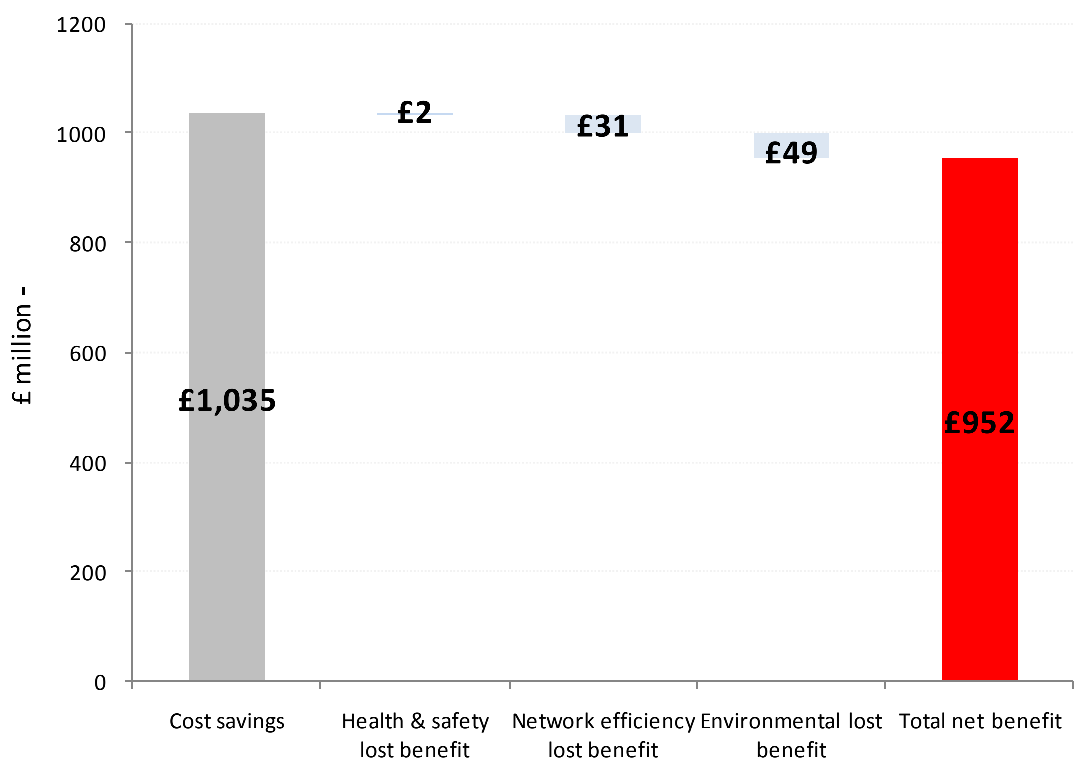


Table 6.6 below presents the results of focusing on small diameter mains for the three different deterioration rate assumptions. The table shows that based on our three scenarios, focusing on **all iron mains <18"mains could potentially deliver £683m to £952m in net social benefits**. In a simple cost-benefit assessment, <u>focusing on all iron mains < 18"mains would deliver significant benefits robust to the different deterioration rate assumptions</u>.

Table 6.5: Incremental costs and benefits of focusing on < 18" diameter mains (£, 2009/10 prices)

[30] According to the information sent from the GDNs there iron mains population at end 2009 is 88,394Km, while the population of mains < 18" is 86,526Km.

	Cost savings	Lost benefits	Net (cost)/ benefit
0% deterioration	£1,035m	£82m	£952m
5% deterioration	£1,035m	£168m	£867m
10% deterioration	£1,035m	£352m	£683m
Range of benefits of focusing on < 18" diameter mains: £683m to £952m			

As noted in the analysis for Option C it is important to note that our simple cost-benefit model does not take account of the existing legal and regulatory framework, which would need to be considered if it was decided to exclude certain categories of iron mains from the IMRP.

6.5.5. Option E - Increasing the intensity of replacement activity on mains prone to failure

This option provides analysis of what might happen if the IMRP were to be targeted more specifically on some of the benefits that arise from mains replacement but leaving other parts of the programme unchanged such as the 2032 end date for the programme. In this case, replacement activity is focused more intensively on mains failure - we would therefore expect the analysis to show some additional benefits arising from improved network efficiency (in terms of reduced expenditure on repairs and emergency services). The results presented below have to be taken in context; we have made no assumption on the additional costs that might arise if this option were implemented, these costs would be an important consideration for the GDNs if they were to be required to refocus their replacement strategy.

Figure 6.7 below illustrates the potential cost savings from implementing Option E. It shows that assuming a 0% deterioration, the option delivers a net cost saving of approaching £700m. The main cost savings derive from a reduction in the costs of replacement activity, which arise because a programme focused more intensively on mains prone to failure would delay the replacement of large diameter mains until towards the end of the programme in 2032. In addition, Option E is also shown to deliver savings from improved network efficiency compared to the counterfactual. These savings occur as the programme delivers a reduction in the number of mains failures more quickly, reducing repair and emergency costs. These savings are estimated to be around £20m with a 0% deterioration assumption.

Figure 6.7: Incremental savings and lost benefits of increasing replacement of mains prone to failure (£m, 2009/10 prices)

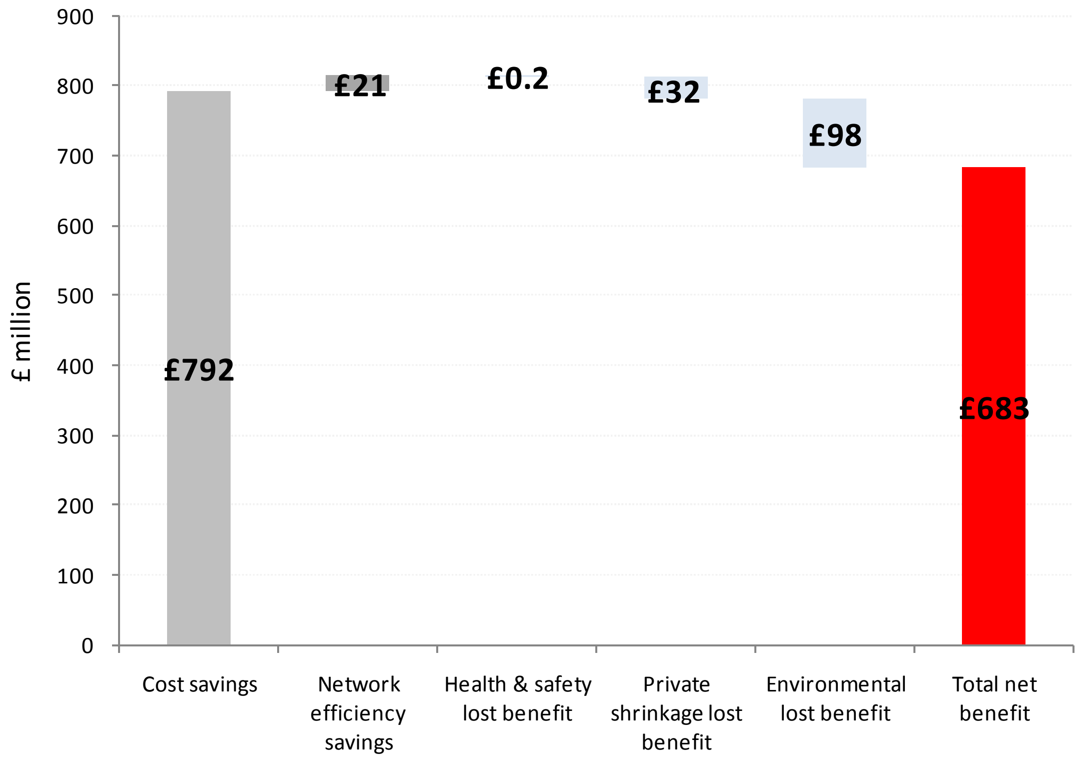


Table 6.7 below presents the results for Option E for the different deterioration rate assumptions. The table shows that **refocusing replacement activity on mains prone to failure might deliver net benefits ranging from £411m - £683m**. The analysis shows that Option E can deliver net benefits to that are robust to different assumptions on the deterioration rate.

Table 6.7: Incremental costs and savings of increasing replacement of mains prone to failure (£m, 2009/10 prices)

	Cost savings	**Lost benefits**	**Net benefit**
0% deterioration	£814m	£131m	£683m
5% deterioration	£833m	£240m	£593m
10% deterioration	£869m	£457m	£411m
Range of benefits of Option D: £411m - £683m			

Whilst as stated, we do not know the costs involved in such greater targeting, on efficiency grounds, as long as the costs involved were less than the level of benefits identified, the approach would be worth implementing. Moreover, although not fully captured in the above analysis, it might also be expected that there would be an additional reduction in GIB events and potential incidents.

6.5.6. Summary of the results

Table 6.8 below summarises the range of results from the different options considered for each of the three different deterioration rate assumptions. Please note that Annex E of the report presents the net benefit / (- cost) for each of the options across the three different deterioration rate assumptions in more detail. Table 6.8 shows that:

- The largest potential net benefit to society arises from Option C (focusing on ≤ 8" diameter mains). For this case and assuming a 0% underlying deterioration rate, we estimate the potential net benefit at £4.2bn.
- The largest net social cost arises from Option A (extending the replacement period by 7 years). For this case and assuming a 10% deterioration rate, we estimate the potential net cost at £2.7bn.

Table 6.8: Summary of the results of the different options (£m, 2009/10 prices)

	0% deterioration	**5% deterioration**	**10% deterioration**
Option A	£174m	(- £669m)	(- £2,742m)
Option B	(- £388m)	(- £57m)	£488m
Option C	£4,218m	£3,676m	£2,506m
Option D	£952m	£867m	£683m
Option E	£683m	£593m	£411m

6.6. Indicative consumer savings

The analysis that we have presented above provides an illustrative range of the net costs and benefits that might arise if the IMRP were to be reformed to take account of the different options considered. We can use the estimates to calculate the range of potential impacts (positive and negative) on household bills.

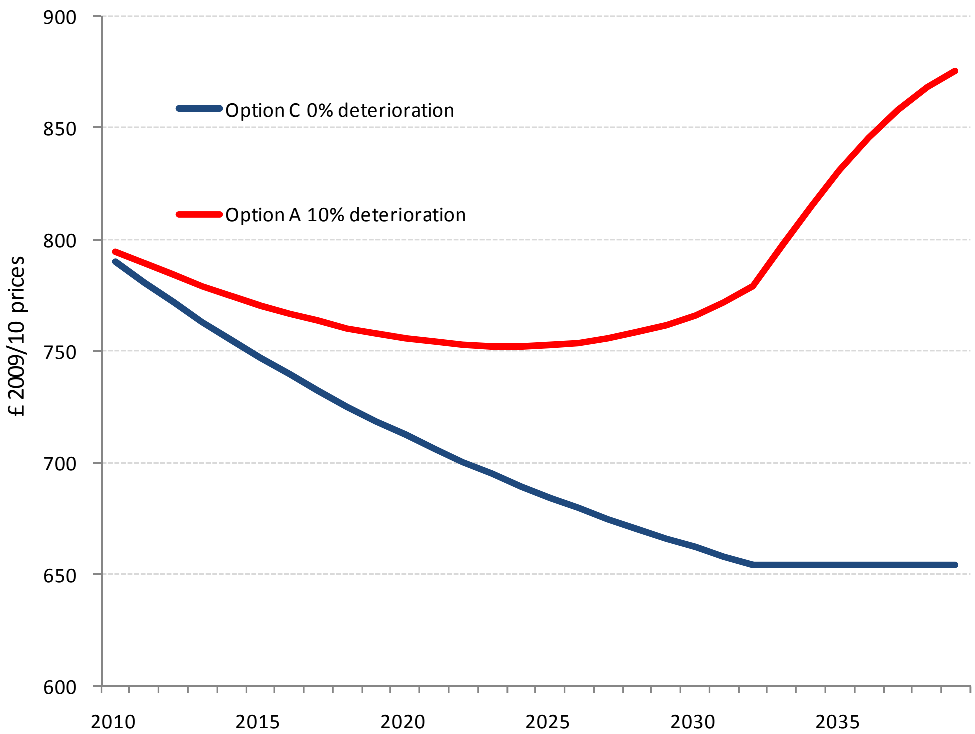
Table 6.8 shows the range of costs and benefits that might arise following the introduction of the different options considered for reforming the IMRP. This range is a net benefit of £4.2bn (Option C & 0% deterioration rate) to a net cost of £2.7bn (Option A & 10% deterioration rate).

Based on the above range we carry out some high-level analysis to estimate the range of the potential increase / decrease in consumer bills that might occur if the options were to be implemented. The analysis makes the highly simplifying assumption that the increase / decrease in distribution costs will be passed directly onto consumers. The change in costs are divided by the number of households to give the potential impact on consumer bills.[31]

Figure 6.8 below indicates the potential range of the impact of reforming the IMRP on consumer bills. It shows that reforming the IMRP could deliver between around a 10% increase or an 18% decrease in expected household bills, all other things remaining equal.

[31] We have taken assumptions on household size and growth over time from ONS data. Assumptions on the average household gas bill were taken from Ofgem – in 2009 the average household gas bill was estimated to be £800 per annum.

Figure 6.8: Indicative impact of reforming the IMRP on consumer bills[32]



6.7. Summary and conclusions of CBA

The CBA and options appraisal presented in this section is dependent on the underlying assumptions made on a number of variables that are subject to uncertainty over the time period under consideration.

To help manage the unknowns in the analysis we have built an economic model that enables the key variables to be changed so that we can observe the impact of the results, albeit at an order of magnitude rather than fine-tuned results Moreover, results are presented in the aggregate for the network as a whole, rather than at a detailed, regional level. It is highly likely that average results will miss significant differences that might be observable at a detailed local level.

The underlying deterioration rate of the network (which more than anything is likely to differ taking into account local climate, soil and other conditions), has been treated as an uncertain variable for the purposes of this analysis and, is the most significant of these uncertain variables. As such we have presented the results of our CBA based on three different scenarios on the deterioration rate.

Based on our analysis the key findings from our analysis of the counterfactual compared to the hypothetical 'do nothing' option are as follows:

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[32] The shape of the chart for Option A 10% deterioration is influenced by the DECC non-traded carbon price assumptions in the years after 2030. The DECC non-traded carbon price assumptions increase significantly post 2030.

- ***The IMRP in its current form may impose significant net costs.*** In pure cost-benefit terms this suggests that there may be scope to improve the design and implementation of the IMRP to deliver better outcomes, not withstanding that it was always anticipated to be expensive.

- ***In cost-benefit terms the health & safety benefits that are derived from the IMRP are not material when set against costs.*** This does not suggest that the health and safety benefits are not important, but it does indicate that there might be some scope to redesign the IMRP to achieve the health and safety benefits more cost effectively. Again, however, despite what the analysis shows, care must be taken in equating the same monetary amount of the different benefits identified.

- ***The analysis indicates that majority of the benefits from the IMRP derive from network efficiency gains (primarily reduced repair costs and reductions in private shrinkage) and environmental benefits.*** However, even for these there is a question mark about the extent to which the programme as currently designed delivers the network efficiency and environmental gains cost effectively.

The key findings from our analysis of the various options considered are as follows:

- ***The potential to achieve costs or benefits from speeding up or slowing down the replacement rate may be dependent on the assumed underlying deterioration rate of the network.*** Given the potential importance of the underlying deterioration rate on all the different options it will be important for additional analysis to improve the understanding of pipe deterioration rates and how these rates might be better predicted and reduced. This analysis needs to be disaggregated to a more local level, rather than being undertaken on the basis of national averages.

- ***Our analysis suggests that in simple cost-benefit terms there may be a significant social benefit from restricting replacement activity to the smaller diameter mains.*** This result is robust to different assumptions on the deterioration rate. There may be scope to consider further where the boundary for the definition of a 'large diameter main' might lie.

- ***The results indicate that net benefits could be achieved if replacement activity was focused more intensively on mains prone to failure, this result is robust to changes in the underlying deterioration rate assumption***. Though it should be noted that in this analysis we have not accounted for the possibility that refocusing replacement activity would lead to higher replacement costs, although in providing the level of benefit, it is clear what the cap would be on the cost increases, if it were to be viable.

As we have stated many times in this section, the analysis presented is subject to considerable uncertainty and should be interpreted as such. However, the analysis has provided an illustration of the costs and benefits associated with the IMRP in its current form, and what might happen if the programme was revised. We therefore draw on the key findings of the analysis in the overall conclusions section presented in the review.

7. CONCLUSIONS

We provide our conclusions following a discussion of the issues arising during the course of the study, which revolve largely around data availability and consistency.

We provide our conclusions following a discussion of the issues arising during the course of the study, which revolve largely around data availability and consistency.

7.1. Issues arising

7.1.1. Data availability, quality and usage

A significant issue that has arisen during the study has been the availability of the data required to address many of the questions asked in the terms of reference, particularly those questions relating to network assets outside of the IMRP. Even with the IMRP related data, whilst the GDNs have been responsive to us within a relatively short space of time, the information received was sometimes incomplete or incorrect and often in inconsistent formats. In particular it was difficult to establish data consistency across the different sources of information available. For instance, we would expect that the data on the 'at risk' mains population from the MRPS would be broadly consistent with the data presented in the Business Plan Questionnaires (BPQs) – however, this was not always the case.

We were surprised to find that GL Noble who run the MRPS on behalf of the GDNs, were in possession of much better, longer term data series which would have been very useful to have had access to early on in the study. The impression created is that data capture over the life of the IMRP, which could have been used to evaluate it, has not been a priority. However, in part, this may be a result of the programme failing to stipulate these monitoring requirements, as well as an absence of more general regulatory requirements for such data to be kept.

A recommendation going forward, is therefore that much greater effort is made to capture the types of data necessary to optimising the programme on a year to year basis and to be used in any future appraisal / review of the programme. In particular, we would also recommend that a much greater awareness is developed amongst stakeholders of both the capabilities and limitations of the model and the data it contains. The fact that there appeared to be something of a lack of awareness amongst stakeholders as to what data was held by GL Noble, might suggest that the general governance of the model and its data is improved in future, especially given its importance. As a starting point, this might involve regular reporting on data trends and analyses undertaken. In addition, an independent expert panel might be able to provide all stakeholders with advice as to how data collection might be improved and what could potentially be done with it.

7.1.2. Future utilisation of gas network

It should be noted that our conclusions assume a continued, high level utilisation of the gas network. If, as we understand is the case under certain planning scenarios, this were to be materially curtailed in order to meet environmental obligations, this would be a further consideration in any optimal mains replacement programme going forward.

7.2. Evidence of the effectiveness of the programme to date and robustness of the risk modelling

7.2.1. Evidence of effectiveness of the programme to date

Determining the effectiveness of the programme to date has several aspects. At the highest level this might be taken as to whether the programme has reduced unfavourable outcomes and impacts arising from the remaining "at risk" iron mains network. At another, it involves whether it has been undertaken in the most effective manner, particularly from a cost perspective.

The extent to which the programme has been effective at removing the risk of an incident arising from the network is difficult to observe directly. The two main approaches are to try to observe the direct outcomes in terms of fracture rates, GIBs and incidents and impacts, after controlling for other influences; and the second, is to try and model the level of risk removed. As we discuss – the latter in the next sub-section – these are very difficult to do.

Outcomes and impacts

Whilst the ultimate objective of the IMRP may have been to avoid undesired impacts of network failure, such as damage to property and other infrastructure, personal injury and death, because of other contributing factors, these may not necessarily be the best measures of the success of the programme per se. Indeed, even favourable outcomes in reducing GIBs and incidents are downstream benefits from the direct outcome of the IMRP which is to reduce the chances of mains fracture or other means of failure. In other words, the direct influence of the IMRP is on reducing the number of fractures from what might otherwise have been the case, if the mains in question had not been removed and the probabilities of GIBs and potentially incidents that this would then give rise to.

However, even when attempting to calculate the influence of the IMRP on reducing the number of fractures, isolating the influence of other factors is far from trivial. Such factors would include the impact of weather and other factors involved in deterioration, which remains a highly controversial point. Indeed, there are many views on the extent of and rate of deterioration of the remaining network. As set out, it is also important to consider the variance in the deterioration rate by area, which could range significantly. Obviously, though, the greater the extent of deterioration in a given area and overall, the more difficult it is for replacement activity to keep pace, as illustrated in the CBA.

Although subject to varying finite "engineering" lives, not all mains have been subject to failure and some have been much more problematic than others. Therefore another aspect of effectiveness is whether those most problematic mains have been removed, at least within the parameters placed on them. Whether this has occurred is linked to the accuracy of the model which is discussed below.

A further method of assessing the success of the programme would be for a more systematic checking of the conditions of mains that have been decommissioned either by inserts or full replacement. Although this analysis may be partial, it may give some idea of the condition of the mains being replaced. However, the medium pressure ductile iron mains which were linked to a number of incidents were removed early on in the programme.

Therefore, the evidence for the effectiveness of the programme to date remains mixed; although it is difficult to be completely definitive without being able to control for other factors, particularly deterioration.

7.2.2. Risk model

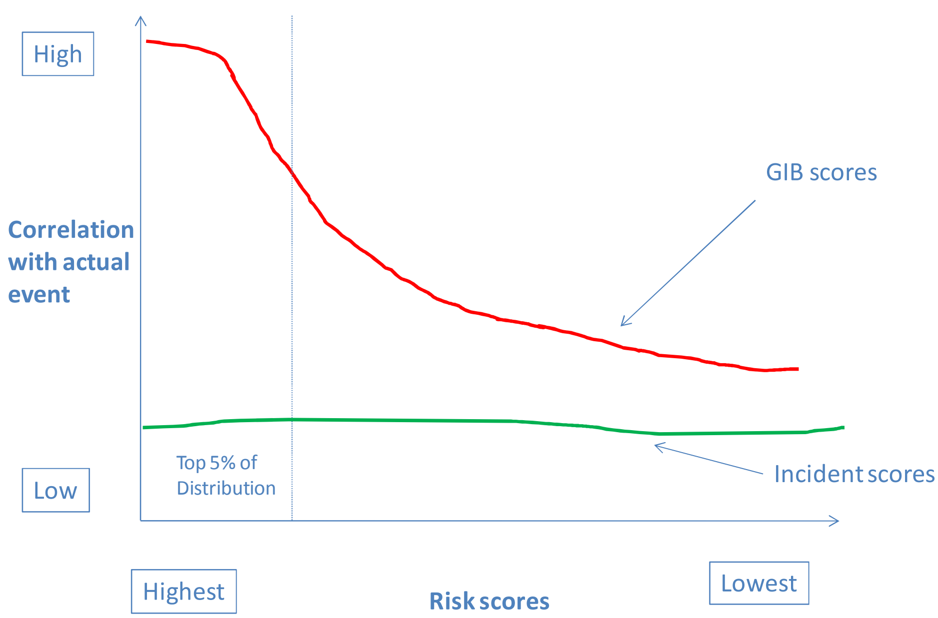
The role of the risk model is central to IMRP for the reasons described earlier and summaries below. Our analyses would suggest that the MRPS and its outputs are not necessarily being used in the most appropriate way, that the data contained in the model could potentially be used more effectively to address many of the issues raised in the terms of reference.

Calculating a risk of incident

The direct output from the MPRS is a measure or score, for each mains remaining in the ground, of the risk of an incident occurring. As explained elsewhere, the score is a function of fracture, GIB and consequence factors.

The analysis conducted by AESL would seem to suggest the risk scores show a good correlation with GIB events (and by inference fractures) but less so with incidents, as illustrated in Figure 7.1.

Figure 7.1: Correlation between the risk score and both GIBs and incidents



The extent to which the consequence factor changes the risk ranking of mains is not entirely clear, but it does suggest that there is not much mileage in focusing on the risk of incident, where the model has much more power in predicting fracture and GIBs.

Risk removed

The model has also been used as a means by which to estimate how much risk of incident has been removed from the network. It suggests that a considerable proportion of the quantum of risk of an incident arising from the network has been removed. However, a reliance on this measure seems to be even more problematic, both in terms of estimating the risk removed as well as using such measures to construct equivalent repex programmes.

We would argue, that there is quite a substantial difference between using the risk scores as a *relative* measure that can be used to rank the relative riskiness of different means as opposed to assessing using them as a measure of *absolute* risk. The first is clearly a useful basis on which to prioritise those mains which appear most likely to be the source of problems (although as discussed above, attempting to predict incidents may not be the best approach); however, treating risk scores as absolute measures may be a step too far.

The fact that these risk scores move up and down as and when the models are re-run tends to undermine their usefulness as a consistent measure. Thus when a given percentage of risk has been said to have been removed, it is not clear of what. Overall, we would argue, that using the scores in such a way bestows a level of accuracy on them which cannot be justified, particularly given the extreme difficulties in calculating a risk of an incident on which the scores are based. We would consider that using these scores for purposes of trading equivalent amounts of risk; for instance, substituting a higher risk mains for a similar equivalent sum of lower risk scored mains; is highly spurious (especially as higher risk scores would still appear to have a higher correlation with actual GIBs).

Potential of the model

The risk model does, however, include substantial amounts of potentially highly useful data, although it is not clear that optimum use is made of this. Because risk ranking is based on risk of incidents – which to a degree is understandable because of the existing health and safety framework, there is a chance that disproportionate amount of time is focused on trying to increase the model's ability to predict incidents, rather than in interrogating the other information it holds. Although there are some bespoke projects being looked at there are several things that might be examined, not least attempting to identify national, regional and local evidence of deterioration.[33]

Focusing on fractures and GIBs is likely to be much more fruitful given the substantial data that exists. This could be used to provide historical and distributional trends in fractures and GIBs which could help to fine tune replacement expenditure based, for instance, on clusters of fractures and or GIBs, a theme we return to in options going forward. This could help in the development of understanding of deterioration and where it is worst, thus potentially helping to make the replacement more targeted and /or cost effective.

In addition, it might also make sense to expand the remit of information capture to include services and other potential at risk network assets. The case for a central repository would be that it would then be easier to run more comprehensive analyses.

[33] Such as the Advantica (2004) report into large diameter cast iron mains. Advantica (2004), Large diameter cast iron mains failure investigations.

In going forward, ideally governance structures should be constructed that provide for the data contained within the model to be exploited to the full.

7.3. Future development of the programme

7.3.1. Cost benefit analysis

The CBA and options appraisal that is presented in the report is subject to uncertainty and should be interpreted as such. However, it does provide an illustration of the magnitude of costs and benefits that might arise from reforming the structure and or surrounding legal and regulatory framework of the IMRP.

In the first part of the analysis presented the IMRP in its current form is compared against a hypothetical 'do nothing' option. To reiterate what is stated in the main text the inclusion of the do nothing option is to provide a point of comparison to the IMRP and does not mean that we are suggesting that the IMRP should be stopped completely.

The main findings from the comparison of the IMRP against the do nothing option suggest that the main benefits arising from the IMRP relate to network efficiency (reduced repair and reductions in private shrinkage) and environmental benefits (lower emissions). Health and safety benefits, although clearly important, are not material when set against the costs of the programme. However despite what the analysis shows, care must be taken in equating the same monetary amount of the different benefits identified.

In the second part of the analysis we compared the IMRP in its current form to a number of potential options for reforming the programme. The analysis shows that the potential to achieve costs or benefits from speeding up or slowing down the replacement rate is dependent on the assumed underlying deterioration rate of the network – as we have discussed in some detail the deterioration rate is treated as an uncertain variable for the purposes of the review.

The options appraisal also suggests that in simple cost-benefit terms there may be a significant benefit arising from restricting replacement activity to focus on smaller diameter mains. Importantly these benefits are robust to the different deterioration rate assumptions.

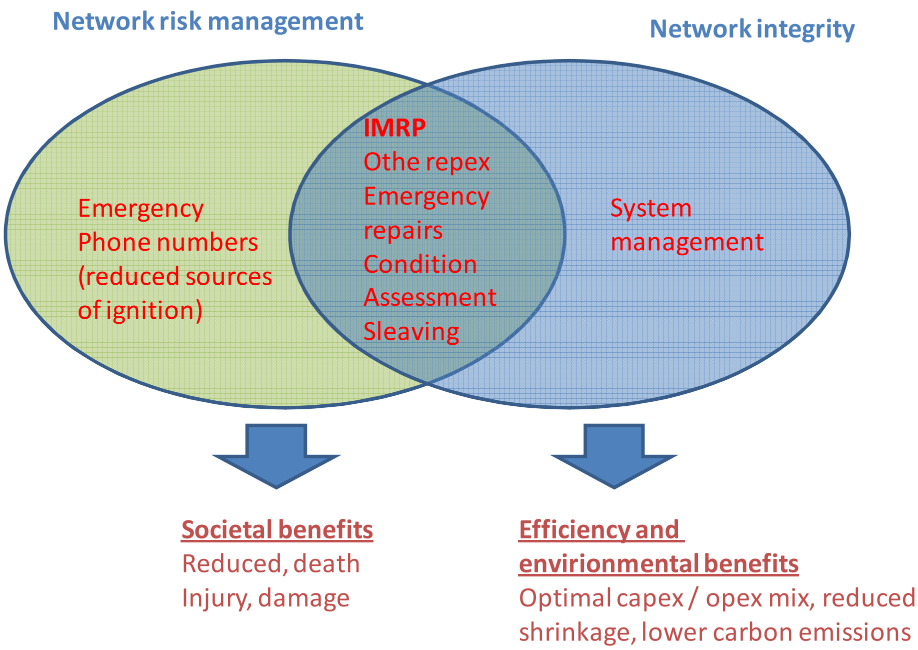
The options appraisal also shows that net benefits might be achievable if replacement activity was focused more intensively on mains prone to failure. This result is also robust to changes in the underlying deterioration rate assumption. Though it should be noted that in this analysis we have not accounted for the possibility that refocusing replacement activity would lead to higher replacement costs, although in providing the level of benefit, it is clear what the cap would be on the cost increases, if it were to be viable.

7.4. Options for delivering risk removal more effectively

Taking the network as a whole, the issue of risk removal is effectively part of how to manage overall network risk in terms of avoiding incidents, irrespective of from where they arise. The IMRP as regards replacing the iron mains and repex more broadly, are major tools in this risk management, although they are not the only ones. For instance, it is possible that fewer ignitions of gas have occurred in recent years due to prompter reporting of gas leaks (through the availability of emergency phone numbers) and possibly reduced sources of ignition (for instance, plugs being sold with appliances rather than fitted by home-owners, reduced numbers of pilot lights).

These risk management policies also overlap to a high degree with other policies undertaken by the GDNs to maintain network integrity; for instance, so as to reduce shrinkage, including overall system management, pressure control etc) as illustrated in Figure 7.2.

Figure 7.2 Approach to risk management



These two different strategies contribute to the societal benefits arising from risk management and efficiency and environmental benefits that arise through maintaining overall network integrity.

To date, the IMRP is supposed to be focused very much on risk management, whereas as shown in the CBA most of its future likely benefits relate to efficiency and particularly environmental benefits. Indeed, as it has been deemed that all cast iron is not fit for purpose, all IMRP repex is based on a de facto safety grounds, when the real case is likely to be more nuanced.

In consideration of these observations, in addition to maintaining the IMRP as it is, we put forward two main alternative options for the taking forward the IMRP, which try to unpick and reconstitute safety and efficiency / environmental objectives, albeit in different ways. One is based on revisions to the existing approach, the other involves a more radical rethink of how repex is treated in general. Elements of either, however, could be incorporated into the other.

7.4.1. Revising the existing IMRP

This option is based on the recommendations made by AESL as presented in Section 7 of Annex F. This would involve limiting the IMRP primarily to mains below 8” in diameter, where deterioration and failure are most observed. In other words, larger diameter mains would be dealt with separately outside of the programme, as are currently other elements of repex, as they are not considered to represent the same degree of problem as smaller diameter mains.

Within this, however, replacement schemes would be undertaken on zonal basis in which a greater proportion of high risk mains would be incorporated, on the basis of either probability of fracture or GIB, rather than incident. This would make such schemes much more safety targeted, whilst trying to ensure that they remain as economical as possible.

The scale of the programme would continue as current, although may be accelerated if there is evidence of increasing deterioration, such that the replacement programme cannot keep pace.

7.4.2. An investment case approach to repex

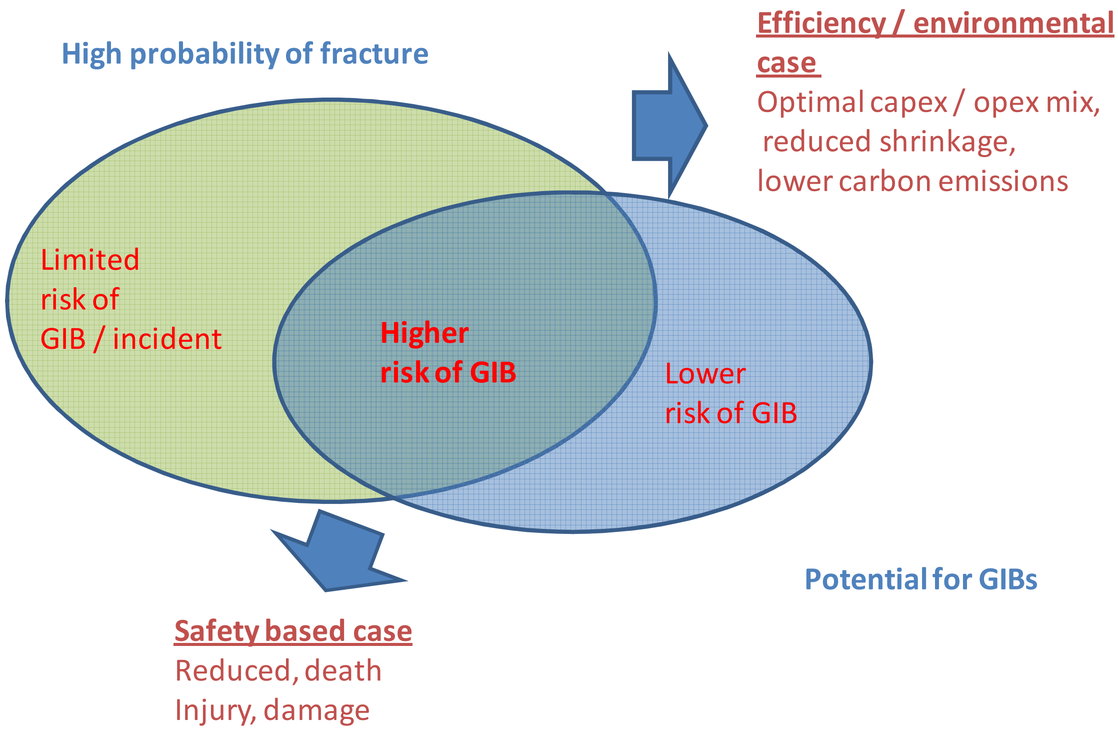
In the second option, rather than having a single monolithic IMRP which focuses exclusively on iron mains replacement, it may be desirable to have a more broad-based approach to repex, which covers all network assets, but which prioritises such expenditure on one of two bases; either safety or efficiency, rather than wrapping both up together as is arguably the case with the existing IMRP.

This might involve an overall estimate of expenditure, but would be subject to change depending upon the evidence provided. However, within this, significant amounts of repex, of whatever kind, would need to be justified on the basis of either an explicit efficiency or safety based investment case, which would have to be agreed by either HSE or Ofgem as appropriate. Therefore, one off fractures might be dealt with by repair. But more systematic failures and significant risk of GIBs should be prioritised for replacement. Where there is a significant risk of GIB, this might be addressed by a safety-based case. This might also be based around potential impacts as well as risk.

Efficiency-based cases should demonstrate the favourable economics and wider cost benefits of doing so. For instance, it is possible that a group of mains could be problematic in terms of repeated failure (by whatever means), but they might not necessarily pose such a risk in terms of the potential for a GIB, because say, the gas might be likely to be released slowly in an area with few cellars. None-the-less there would be a case for prioritising a zonal replacement programme on basis of cost effectiveness of repex as opposed to just repair. This might contrast with a situation in which repeated fracture was less of a problem but where there was still a relatively high possibility of a GIB occurring.

Both situations would have a strong case for prioritisation, but the criteria for assessing them might be different, the former being more cost based, whereas the latter would emphasise risk management / risk removal, with a commensurately higher tolerance of cost. This is illustrated in Figure 7.3.

Figure 7.3: Efficiency versus safety based investment cases



Joint targets, on the part of Ofgem, HSE and the GDNs might provide a framework for approaching these issues. Regulatory performance targets might be applied to support these objectives, although the impact of external factors – such as weather or differing deterioration rates, would ideally need to be factored in.

ANNEX A: TERMS OF REFERENCE

Iron Mains Replacement Programme – 10-year Review

Background

The 30-year iron mains replacement programme began in 2002 in response to evidence that part of the natural gas distribution network comprised of iron mains which were subject to catastrophic failure. These failures, then and now, give rise to gas escapes and the consequent risk of fire and explosion. At the time the original programme was approved steel mains and services were excluded as the risks at that time were not at the same level as the iron population.

In 2001 HSE, Ofgem and Transco agreed to develop a mains replacement programme to achieve the decommissioning within 30 years of all 'at risk' iron mains laid within 30 metres of buildings. Hence the programme is commonly referred to as the '30/30 programme'. This timescale was considered practicable with the resources available. A 25-year option was discounted on the basis that the annual decommissioning rates required would not be practical. A 35-year option was discounted on the grounds that it did not meet the standard of 'practicability' imposed by the Pipelines Safety Regulations (PSR).

Associated costs for the programme were included within the financial arrangements between Ofgem and Transco (and now between Ofgem and all of the gas Distribution Network Operators (DNOs)). These arrangements take account of the improvements in the continuity of supply.

Health and Safety Legislation

The arrangements for meeting the risk-based decommissioning of parts of the network are included in the Gas Safety (Management) Regulations (GSMR) safety case held by each gas DNO. To comply with the safety case each DNO must submit an iron mains decommissioning programme for approval by HSE. This approved 30/30 programme forms the basis for a defence under PSR if a part of the network covered by programme fails and if the DNO has done all that is reasonably practicable to comply with their programme.

Regulation 13 of the Pipeline Safety Regulations 1996 provides an absolute duty that 'The operator shall ensure that a pipeline is maintained in an efficient state, in efficient working order and in good repair'

DNO compliance with the approved programmes does not guarantee the prevention of fractures and explosions. However, it does ensure that the integrity of the remaining 'at risk' iron mains population is suitably and sufficiently managed to ensure associated risks are minimised across the network as a whole.

Risk Removal

The delivery of the 30/30 programme is based on an assessment of the risks posed by particular parts of the network and takes account of pipework diameter and pressure, ground conditions, previous fracture/gas in building history, proximity to buildings, presence of cellars and failures of adjacent pipes. Those parts of the network posing the highest risk were programmed for earliest decommissioning and replacement with PE pipework. Initially replacement projects were based on a 20/70/10 model where 20% of the total length of 'at risk' mains decommissioned each year were selected from the highest risk population; 70% from the secondary risk population and 10% from the remaining risk population. As the highest and secondary risk scores have been gradually reduced a 20/80 model is now more generally applied to improve overall efficiency of the programme.

Since 2002 approximately 20% of the 'at risk' iron mains population has been decommissioned. Although dynamic risk growth remains a feature of the 'at risk' iron mains population a proportion of the higher risk iron mains have now been decommissioned. This has allowed HSE to accept longer planning timescales for zonal replacement projects and to approve DNO decommissioning programmes for periods of up to three years.

Purpose of the 10-year Review

The aims of the review will be to:

- Review whether the objective of avoiding deterioration of the iron system is being achieved and how that may be achieved in the future.
- Assess whether the 30/30 programme has secured the decommissioning of the highest risk iron mains (including the impact on numbers of fractures, gas in buildings and explosions)
- Validate the rationale for initiating the 30/30 programme, including the progressive amendments to the replacement procedures that changed the programme outputs.
- Consider if the programme has delivered value for money with risk being reduced and integrity increased in proportion to the money spent and an evaluation of the other benefits of the programme. This will include the value delivered to consumers; society and the environment.
- Review how further priorities for decommissioning or other risk mitigation initiatives should be identified and work programmed to deliver maximum value and benefit
- Consider if there should be changes to how the programme should structured as it enters its second 10-year period.
- Consider and evaluate any proposed changes to the existing delivery - process, for example specific risk removal and fluctuating workloads. -

In particular the review will include (and provide the necessary resources to undertake) a full Impact Assessment and Cost Benefit Analysis of future approved Reg 13A programmes that HSE are likely to view as being compliant with PSR 1996.' and examine the following issues:

Risk Removal

- Has the decommissioning work been targeted at the highest risk pipework?
- If not, what needs to be done to ensure remaining high risk pipework is - decommissioned? -
- To what extent is the 30/30 programme keeping pace with the deteriorating ‘at risk’ population of iron mains?
- If the highest risk pipes have been successfully removed, and taking account of future dynamic growth in risk, does the risk from the remaining iron pipe population justify mitigating expenditure that may be higher than HSE’s reference of Value for Preventing a Fatality (VPF)?
- Are any areas of known risk currently included within the programme being overlooked or delayed (e.g. >12” mains)?
- Should consideration of the next ten years include the decommissioning of other assets, including other pipe assets outwith the 30/30 programme and other ageing infrastructure.
- What can be done to incentivise progress in these areas?
- Are any areas of known risk currently excluded from the programme in need of reconsideration (e.g. steel pipes)?

Risk Modelling

- Has the risk modelling process (MRPS) been successful in identifying the highest risk ‘at risk’ mains?
- If not, what further developments are needed?
- Does the risk modelling process accurately predict the deterioration of the network as a whole?
- What is the current state of risk modelling with respect to steel service pipes and does this demonstrate any significant change since 2002?

Future Development

- How should the programme be developed to ensure that, as work progresses, it continues to meet the requirements of PSR, it is done as cost-effectively as possible and that work planning is linked to the wider strategic needs of the network?
- Specific consideration of the effects of changing the delivery timescale of the programme, including indirect effects upon steel service replacement and specific evaluation of moving to different delivery models for example, zonal replacement to more focused risk removal.
- Determination as to how Distribution Networks can ensure that any proposals for fine-tuning the programme are consistent with ensuring that network operators can continue to demonstrate they are taking all practicable precautions to manage the risks from their networks by compliance with any revised regime and appropriate maintenance operations.
- Ensure that HSE and Ofgem share a consistent understanding of the risks associated with the deteriorating network, the risk mitigation costs and how these can be most effectively addressed prior to the Ofgem price control review (to be in place for April 2013).
- Understand the additional ongoing benefits of the 30:30 programme, such as the reduction in public reported escapes, green house gas emissions and the abatement value of carbon reduction.

Demands for data/involvement of third parties

The review will require:

HSE/SI3

- Validation of the existing principles of the programme
- Economic Analysis Unit – advice on review methodology and contractor selection
- Information regarding compliance with:
    - GSMR safety cases
    - PSR Approved Programmes
    - 30/30 Programme overall progress

Distribution Network Operators

- Update on programme progress (geographical and risk-profile)
- Emerging data linking predicted risk vs. actual risk (MRPS validation)
- Views on more efficient ways of structuring future work (e.g. planning timescales and length of approved programmes)
- Views on more efficient and proportionate ways of mitigating network risks
- Indications of planned investment and future costs
- Evidence of steel pipe deterioration and societal risk
- Evidence of other benefits accrued for example, environmental carbon abatement values, reduction in shrinkage gas costs, and avoidance of ad-hoc emergency repairs to the network.

GL Noble Denton (Managers of the MRPS)

- Update on risk assessment criteria for decommissioning decision-making
- Consideration of the effectiveness of large diameter (>12") risk modelling
- Information on the risk of steel pipes.
- Consideration of available models predicting steel pipe deterioration and risk growth

Ofgem

- Views on costs of risk mitigation
- Views on how decommissioning work could be structured, future usage and demands upon the network
- Views on alternative risk mitigation output measures and strategies

Deliverables

The work will be undertaken by researchers independent of HSE and Ofgem, but acceptable to both. They will produce a report to HSE and Ofgem:

- Reviewing the effectiveness of the decommissioning programme in reducing risks associated with the aging gas distribution network.
- Reviewing absolute risk levels of iron pipes, other network causal risks and their relativity to other societal risks

- Validation of the additional benefits of the programme.
- Setting out options for future work.

Timescales (provisional)

Progress report – end November 2010

Research completed - end January 2011

Draft report end - February 2011

Final report end - March 2011

In view of the relatively short timeframe of the review, there will be defined stages/milestones/deliverables incorporated into the specification with joint HSE/Ofgem progress meetings with the consultancy/researchers such that appropriate direction and any necessary adaptation can be incorporated.

The following structure is suggested for the work areas:

1. <u>Preparation</u>

Early background/preparations session(s) with Ofgem/HSE/DNOs/other relevant parties to get an understanding of the key issues

2. <u>Evidence gathering</u>

Collect appropriate evidence and other information to inform each of the key research work areas below.

3. <u>Evidence of the effectiveness of the programme to date/delivery & robustness of the risk modelling</u>

i. Assess whether the 30/30 programme has secured the decommissioning of the highest risk mains as per the original objectives and in removing the maximum quantity of risk, reflecting the move to 20/70/10

ii. What is the net impact of the 30/30 programme on risk removal? i.e. by considering:

- What level of risk has been removed from the abandonment to-date of - cast/spun/ductile iron mains? -
- What has been the increase in risk through the deterioration of the remaining iron mains?

iii. What proportion of the gas in building occurrences have occurred on high risk mains and those targeted for replacement and how many have occurred in the remaining population and due to other sources such as service pipe leakage?

iv. Has the mains replacement risk model been successful in appropriately prioritising the mains to be removed as part of overall programme?

v. What is the best available evidence on the degradation of the iron mains population and failure modes profile and how well does the risk modelling process predict the deterioration of these mains?

vi. Taking account of questions (iv) and (v), what further developments are needed in the model?

vii. How does the risk from the steel mains and services population compare to that from iron mains?

ix. What is the current state of risk modelling with respect to steel mains and service pipes and what would need to be done in order to model other network risks?

4. <u>Review of initial assumptions and objectives behind the repex programme and confirming if these are still appropriate</u>

i. What were the amendments made to the programme eg. from the precautionary approach, societal concerns and tolerability?

ii. Taking into account the answers to 3 above, do these still hold/are they empirically justified?

5. <u>Assess whether the mains replacement programme is proportionate to the risk involved, and what is the impact of changes in the rate of replacement or the target population [changing the rate of replacement only represents one option for adjusting the impact (CBA)]?</u>

i. In the Impact Assessment, all relevant costs should be considered, including:

- Direct costs of the programme
- Overheads associated with the work
- Traffic management costs (current and future requirements)
- Other disruption costs

- Negative impacts on the environment (environmental impact of undertaking the operational works/venting of mains prior to decommissioning/waste /spoil resulting from reinstatement, impact of asphalt etc)

ii. How this is offset by benefits from the programme?

- Safety benefits in terms of reduced incidents, fatalities, injuries and possible cases of ill health.
- Environmental benefits in terms of reduced green house gas emissions and particularly the value of the carbon dioxide equivalent abatement.
- Economic benefits in terms of avoided building damage and avoided disruption to local traffic, households and businesses.
- Reduction in shrinkage gas costs from iron mains replaced with PE.
- Reduction in external mains and service escapes and associated costs/safety implications etc.

- Increased public assurance and so reduced societal concern costs...

iii. Using the impact assessment, gain an understanding of the cost / benefit ratio of the 30/30 programme, how this varies under different option scenarios for replacement and how this compares to other prescriptive safety interventions .

iv. Is there a tipping point beyond which (even though the PSR’s duty to maintain is absolute and has no ‘so far as is reasonably practical’ caveat) the cost / benefit ratio no longer supports the case for intervention?

v. What would be the cost associated with not undertaking a mains replacement programme, ie. the implications of network failure, leading to network isolation?

vi. Is the programme still value for money and are other comparable industries subject to this level of prescriptive work activity and consequent expenditure to deliver similar benefits?

vii. How should the recommendations of Lord Gill’s enquiry into the gas explosion at Grovepark Mills (published in 2009), which claimed the lives of 9 people, and the recommendations of other relevant investigations, be applied to the natural gas industry? (The explosion was caused by the same failure mode as apparent in the natural gas industry, (an aging metallic propane gas pipe which failed) resulting in gas entering a building and a subsequent explosion. The inquiry made some immediate recommendations, the first and most urgent priority was to immediately identify and replace all underground metallic pipe work with polyethylene on a systematic and prioritised basis).

viii. The cost of decommissioning gas mains, particularly those with a diameter of 12“ or greater, is significant. Does the impact assessment show that this cost is justified compared to the benefits to society that the programme is delivering?

ix. Now that a proportion of the higher risk 'at risk' mains have been de-commissioned, is there a case for a more holistic and fundamental view of all the risks associated with the gas industry and assessing whether iron main breakages still constitute the greatest risk?

6. <u>Options for delivering reductions in risk more effectively</u>

i. Impacts on rates of risk reduction of moving from 20/80 annual targets to more flexible programmes delivered over 2/3/5 or more years?

ii. Impact of greater levels of flexibility on costs (e.g. through more zonal work), whilst maintaining a programme that remains practicable and that can be safely and efficiently delivered.

iii. Benefits of greater flexibility in terms of strategic development of the network (e.g. ability to coordinate with removal of holders, ability to increase pressure and raise capacity)

iv. Alternative risk reduction programmes including prioritising risk across wider range of assets including for example steel mains and services.

ANNEX B : SUMMARY OF GDN'S RESPONSE TO CEPA QUESTIONNAIRE

In this annex we present a summary of the GDN's responses to the Questionnaire. Where the GDNs have divergent responses we have sought to capture this in the summary.

General overview

The West & Wales response provided a general overview of the Questionnaire, the main points referenced were as follows:

- States that a precautionary approach is the correct one for the programme.
- Their experience is that the network is continuing to deteriorate – as implied by the key performance indicators (what are they?)
- Their indicators suggest that steel network is also deteriorating, they replacing 56km per annum?

Q.1 What research and evidence has been generated to determine the types of iron mains failure that are associated with injuries / fatalities and damage to buildings, and to what extent do these types of failure vary with the age of the iron pipes?

- In the 11 years prior to the implementation of the IMRP there had been 56 gas mains related incidents occurring at a rate of 4.7 per annum. These incidents led to 14 fatalities. (The table below shows the source of these incidents, and the cause of the gas mains failures)

Source of incident	Number of incidents	Cause of failure
Cast iron<12"	41	Fracture all cases
Cast iron>12"	4	Fracture all cases
Ductile iron	3	Corrosion all cases
Steel mains	0	n/a
Steel services	8	Corrosion all cases

- **Fractures of cast iron mains are primarily non-age related** the cause is mainly ground movement. However, corrosion of the pipes make them more susceptible to failure (what evidence is there of this?)
- The *age of cast iron pipes is not included in the MRPS for cast iron mains* as a determining factor. Advantica carried out a report investigating the relationship between age and failure and found no link between age and failure – (see Advantica (2009), Investigation into the effect of age on the fracture rate of pit cast iron mains).
- Age is included in the model for ductile iron mains.
- National Grid states that age is however a major contributory factor for ductile iron, given that ductile pipes are relatively thinner and therefore more susceptible to

corrosion. Therefore age is included in the Mains Corrosion Factor for ductile iron. See Advantica (2003), Update of the ductile iron mains corrosion factor for use within MRPS Version 7.

Q.2 What evidence is there that accelerating the programme from the long term trend, will significantly alter the number of leaks, GIBs and explosions?

National Grid response

- National Grid states that it is impossible to predict or estimate the level of risk removal in the network. The point that they are trying to make is that the model output is just an estimate – they are trying to suggest that despite the model there is still a great deal of uncertainty about the level of risk in the system.
- Also state that "Beyond the current prioritisation year, the risk profile is unknown as the deterioration of the network cannot be predicted", i.e. you cannot predict the future rate of deterioration on the system.
- National Grid state that **65% of risk has not been removed**, instead they suggest that the level of risk is increasing, as shown by the increase in Gas in Buildings and upward trend in the number of fractures.

West & Wales response

- The response quotes the risk model to provide an indication of the beneficial impact of the programme.
- In 2002 the model estimated that there would be 5.93 incidents per annum

Source of incident	Number
Cast iron<12"	4.87
Cast iron>12"	0.74
Ductile iron	0.33

- The IMRP was intended to remove all of that risk. As of 2009 the level of risk remaining in the model is 2.93.

Q.3 What research and development was undertaken to consider alternatives to decommissioning and / or replacement? Were there then, or are there now, alternative practicable solutions that would satisfactorily reduce risks on the iron mains network?

- State that there was no practicable / economic alternative to replacement, but provide no evidence of alternatives considered.
- As pipe buried visual inspection is not possible, sampling not possible / too expensive?
- Clearly state that fractures are largely independent to age or condition of the pipe, but

due to excess loading in the soil surrounding the pipe.

- National Grid and Scotia have initiated a research project with WRC (Water Research Centre) to investigate the potential for further Cure Pipe in Place (CIPP) type technology.
- There is an ongoing programme of research on CIPP technology, through the Innovation Funding Incentive mechanism (IFI). The problem is that current solutions that have been identified have not been proved to reduce the risk of pipe fracture.
- They quote the HSE - quote states that alternative approaches to risk removal will not be acceptable unless they can be shown to remove a higher level of risk.

Q.4 What evidence / rationale was used to support the decision to replace iron mains within 30 metres from buildings? Is this distance still appropriate given the potential risk posed by the remaining iron mains network, in particular:

a. **Is there any evidence to show that 30m is not an appropriate limit?**
b. **Is there evidence to show that the proximity distance rule should be linked to other factors, including the size of the pipe?**

- Negligible evidence that pipes greater than 30m from buildings poses a risk, under normal conditions. They are allocated a risk value of zero and are excluded from the model.
- There are currently 1,190 kilometres of zero rated iron pipes within National Grid. This represents 2.8% of the iron population. They note that some of the pipes will migrate into the programme as new buildings are developed, but that an unknown amount will move out as buildings are destroyed.
- W&W have 581km of zero rate pipe, 5.6% of their network. They note that some of the pipes will migrate into the programme as new buildings are developed, but that an unknown amount will move out as buildings are destroyed.
- NGN have 671km of zero rate pipe, 5% of their network. They note that some of the pipes will migrate into the programme as new buildings are developed, but that an unknown amount will move out as buildings are destroyed.
- Provide no evidence to support the need for 30m as opposed to 20m for instance.
- Find no evidence that distance from buildings is linked to other risk factors.

Q.5 What was the rationale behind each of the different amendments made to the 30/30 programme such as the introduction of the 20/70/10, 80/20 zonal replacement programmes, what was the evidence to support the change, and to what extent have the objectives been delivered?

National Grid

- New programmes introduced to delivery greater economic efficiency in delivery of the

IMRP. -

- The 20/70/10 model was in place at the beginning of the replacement programme.

Main changes to the programme identified as follows:

- **2005/06 (October 2004 version of REP/2)**
    - Much simplified Appendix F calculation - previously required to cost each project and then compare the Networks average cost per unit of risk removed.
- **2006/07 (July 2005 version)**
    - Iron pipes recorded as <3" diameter excluded from selection process – legacy issue of 2" steel pipes incorrectly recorded as being iron
    - Large diameter cast iron (>12") – rules amended to allow complete MP route replacement instead of a top-down piecemeal approach.
- **2007/08 (April 2006 version)**
    - Move away from 20/70/10 to the zonal replacement approach
    - Allowing Operations to leave <3m length of iron stub, avoiding costly cut-outs
- **2007/08 (November 2007)**
    - Appendix F amended to allow the deferment of iron pipes <=100m (from 30m) subject to on-site risk-assessment
- **Latest version - August 2009**
    - Planning horizon extended from 5 to 10 years
    - Asbestos replacement amended to "… as they appear in zones"
    - Annual audit requirements re-written to clarify that only the selection of iron pipes to be audited

- The biggest change was the introduction of National Grid's zonal replacement programme in 2006. National Grid (2006), National Grid Network Strategy, Mains Replacement Review 2007-2013. Some of the key points noted in the report are as follows:
    - At the time National Grid identified the need to increase the rate of replacement of the >12" iron pipe population, to over 130km p.a., significantly more than the current HSE commitment level of 45km per annum.
    - National Grid analysis indicated that increasing the length of >12" iron from the current committed level of 45km per annum to 139km per annum, coupled with the zonal replacement methodology for <=12", could deliver a greater level of

risk reduction than 20/70/10 over a 5-year planning period.

  - Analysis indicates that increasing the length of >12"iron from the current committed level of 45km per annum to 139km per annum, coupled with the zonal replacement methodology for <=12", could deliver a greater level of risk reduction than 20/70/10 over a 5-year planning period.

West & Wales

WWU currently operate a 20/70/10 replacement model on a 5 year SMT with an additional growth area strategy. The current WWU version of Rep 2 facilitates moving to a 20/80 model and this option is always under review.

SGN

- SGN have moved to a 20/80 approach that delivers an equivalent level of risk removal to 20/70/10. Note: 20/80 is not a zonal replacement approach.
- The first 20% remains unchanged. The remaining 80% represents a mix of iron pipes with a positive risk score (within 30m of property) that have been selected using both risk and condition as a means of prioritisation.
- In order to further reduce the number of projects and increase average project lengths, SGN have demonstrated and gained approval to move the SMT threshold from 5 years to 10 years will a negligible impact on annual risk removed. A 10 year SMT increases the group of secondary pipes that can be selected to grow projects from the initial 20% of seed pipes.

Q.6 Are the assessments of risks related to services and the cost of replacing services included as part of the IMRP?

National Grid

- Refer to response to Q.16

West & Wales

- For iron mains within the 30:30 programmes this ensures that all the original steel services connected to these mains will be replaced by the end of the current 30:30 programme.
- Service pipes replaced alongside iron and steel replacement. This is done because it is most economically efficient technique.
- Many steel services are currently not included in any programme, which may introduce additional risks.

Q.7 What are the key factors used to determine the assessment of a probability of failure of the iron mains? How do each of these factors affect the probability of an incident?

There are 3 factors within MRPS that are used to generate a pipe's individual Risk Value detailed below:

1. The mains fracture/corrosion factor (MFF & MCF) - The likelihood of an escape occurring.
2. The gas ingress factors (GIF) - The likelihood of gas entering into a building.
3. The consequence factor (CF) - The consequences of a GIB.

Q.8 Do large diameter iron mains lie outside the model? Is their evidence that large diameter mains have significant fracture probabilities?

- Large diameter pipes are included in the model.
- There are currently four risk models in use:
    - cast iron mains with diameters up to and including 12"
    - cast iron mains with diameters greater than 12"
    - ductile iron mains
    - steel mains.
- The results from the models are directly comparable allowing decisions to be made about the allocation of expenditure for a given level of risk removal.
- The failure rates of the smallest diameter iron pipes are 0.14 (3") and 0.13 (4"), with rates falling steadily until we reach 18" where the failure rate for all of 18" and above remain at around 0.01 fractures per km per annum.
- See study by Advantica (2004), Large diameter cast iron mains failure investigations September 2002 May 2003 Final Report. This provided a survey into the failure mechanisms of large diameter (>12") iron pipes.

Q.9 Is the age of the iron pipes included in the model as a significant determinant of the probability of an incident occurring?

[See response to question 1]

Q.10 What evidence exists to verify that the model has been successful in prioritising the highest risk mains?

- National Grid states that the prioritisation is not predictive and takes no account of future deterioration associated with corrosion or factors such as road traffic loading, third party interference that might lead to future failures. Instead the model can just indicate the immediate level of risks existing on the iron mains at a given point in time.

Q.11 Has the predictive power of the model been evaluated by a third-party? If so what were the results of the analysis?

- The only independent review of the model seems to have been carried out in 2003 in the

Stanger report. Stanger (2003) found that **“*reached the conclusion that TRANSCO’s mains replacement policy is soundly based and not suffering any major shortcomings*”.**

- Based on the responses it is unclear that another independent review has been carried out since then.
- WWU also carried out an analysis in 2010 – see presentation presented in response to Annex D Q.9

Q.12 What analysis is carried out (and sources of evidence generated) on the iron mains that are removed as part of the IMRP to test the accuracy of the current MRPS model?

- Response to Annex D Q.8 suggests that a survey was undertaken of large diameter mains. However, this survey does not appear to be an analysis of the condition of any pipe removed, it is a more general assessment of the condition of large diameter pipes.

Q.13 Is the predictive power of the model subject to any ongoing process to assess its accuracy? How can GL Noble be incentivised to develop further improvements to the model?

- The MRPS model is subject to an annual “Trend Analysis” to confirm that the coefficients contained within the algorithm remain representative and that the model continues to accurately depict the statistical probabilities and frequencies of failures and GIBs observed in the field. Periodically a full coefficient update is carried out.
- The model is the subject of an ongoing 5-year IFI programme for continuing assessment and development. Scope of work for the current programme is indicated below:

Table: five-year cycle of work on risk model

2008/09	2009/10	2010/11	2011/12	2012/13
Trend analysis	Trend analysis	Full co-efficient update	Trend analysis	Trend analysis
Research into link between age and pit cast iron mains fracture	Effect of previous corrosion on failure		Analysis of five-year drop off requirement on fracture	Consider multiple occupancy factor in model
	Examination of application of model to >12” pipes		Research into link between age and spun cast iron mains fracture	Examination of >12” model

				Examination of CI MFF, GIF & DI SF		

Q.14 In the current set of institutional arrangements who has direct institutional responsibility for monitoring and evaluating the outputs of the model?
• The MRPS model is controlled and managed jointly by the GDNs, through the National Replacement Forum (NRF), which reports to the Gas National Collaboration Forum (GNCF).
Q.15 Has there been consideration of the development of models of other risks related to aged networks, for example gas in buildings arising from corrosion, or joint leaks?
• Within the MRPS model, the presence of barrel corrosion and joint leaks in ductile iron contributes to the pipes risk score and is reflected within the model, both for the pipe which has experienced the failure and on other pipes in the vicinity as part of the Background Corrosion Zone. The score is further influenced by the presence of reported GIB resulting from such failures. • The model considers joint leakage it is represented in the condition score; it also considers the risk & condition score for both the non policy condition replacement workload and in the 30:30 policy programme of work.
Q.16 What modelling approaches are used to inform the steel mains and services replacement programmes, and also to manage other risks inherent on the network? In particular what progress has been made in developing models to predict the risks associated with steel mains and services?
National Grid • Steel service pipes are removed based on an agreed process, stated in the National Grid response. • Steel services are replaced alongside the IMRP. As some steel mains are not included in the 30:30 program there is a significant (albeit unknown) population of steel services whose future replacement is not included. • There is a process in place for targeting the replacement of steel mains, as set out in Rep 2. • MRPS has the functionality to measure the risk of >2" steel pipes. *West & Wales* • WWU identifies steel services for replacement using postcode analysis of service leakage data. 2010 data shows there are a total of 4,446 post codes within the WWU network

having more than 1 occurrence of a service escape since 2006.

- WWU have carried out detailed investigations into those post codes above 5 escapes and where appropriate developed mains and service replacement projects in these areas.
- As steel mains are not included in the 30:30 programme there is a significant population of steel services whose future replacement is not included.
- MRPS includes steel mains greater than 2 diameters. WWU target the replacement of steel MP mains prioritised on those within 30m of property and with the highest recorded maintenance history and/or risk score.
- WWU claim that the decommission length for steel mains is insufficient to meet the amount of decommissioning needed. WWU have exceed the required length in 2009/10 by around 15% and expect to do so for the remaining 3 years of the current formula period.

SGN

In addition note that SGN has included into its version of REP/2 an expert led panel (Condition Review Group) that considers information submitted by field operatives relating to the condition of pipes (including steel) that would otherwise be decommissioned as part of the 30/30 iron mains programme.

Q.17 Has decommissioning work been targeted at the pipework at risk of causing failure that leads to incidents? If not what additional work needs to be done to ensure that the remaining high risk pipework is decommissioned quickly?

- If there is any significant growth in the risk associated with a pipe, this dealt with by the dynamic risk growth process – if the pipe's risk score rises above a predetermined level (above twice the 20% risk score) it is decommissioned the following year.

Q.18 What other activities have been undertaken to remove high risk iron mains from the network, and what impact have they had on removing risk, in particular, what was the impact of the Medium Pressure Ductile Iron Notice on risk removal across the network?

- Replacement is also undertaken alongside the IMRP in the following categories:
    - Conditions based replacement – through discovery during other works.
    - Enforced diversions – to accommodate third-party activity.
    - Pipes laid in contravention to required laying standards.

Q.19 What research has been carried out to investigate the rate at which the following parts of the network are deteriorating:

a. Cast iron mains.

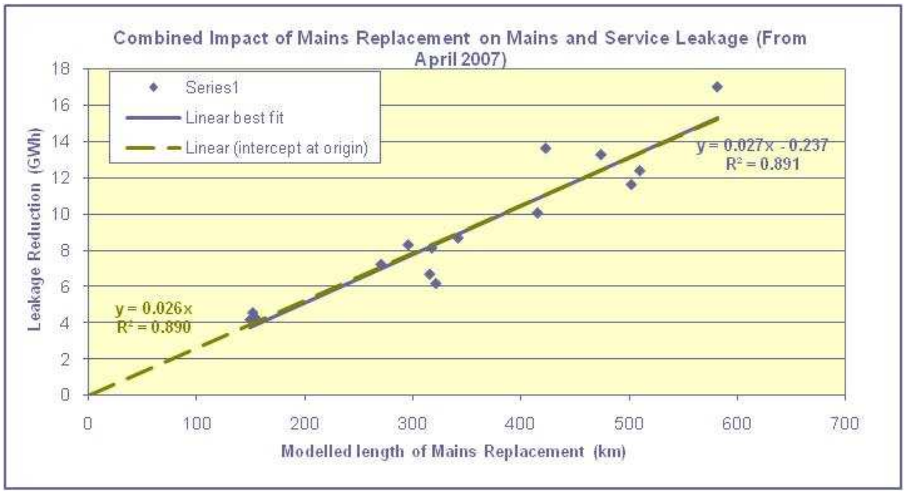
b. Ductile iron mains.

c. **Large diameter mains.** d. **Steel service pipes.** **Which factors do you consider represent metallic mains deterioration?** **To what extent has the replacement rate since 2002 kept up with the rate of deterioration on the above mentioned parts of the network?** **What impact has the rate of deterioration of the iron mains network had on the risk of an incident since 2002?**
National Grid • [refer us to Q.9 1 of Annex D response] • In National Grid response they state that the level of deterioration is indicated by the level of fractures – though note that it is in practice impossible to gauge the level of the condition of the network. • States that the level of replacement is just about keeping pace with the level of deterioration. • For ductile iron they state that the sharp decline in corrosion failure can be attributed to the MPDI. • On the impact of the project on risk reduction National Grid state that the risk profiles detail the **reduction in the estimated levels of annual incident levels, which includes the effects of ongoing deterioration of the Network together with the impact of the 30/30 replacement programme.** *West & Wales and other GDNs* Provided a list of reports that in their view provided analysis on the level of deterioration.
Q.20 What are the additional benefits (in addition to the potential reduction in the risk of incidents) that the IMRP has delivered since its implementation? What research has been carried out to demonstrate that the mains replacement is the most cost effective approach to delivering the wider benefits associated with the IMRP.
National Grid • Additional benefits listed as: 1. Reduced emissions, 2. Reduced operating costs, 3. Improved security of supply, 4. Provision of a buffer for workload peaks, 5. Reduced risks to operatives, and 6. Reduced disruption to the public.

See their response for more detail, but some of the most relevant points highlighted below.

- **Reduced emissions**

The mean achieved emissions benefit during the period was 0.026 GWh pa. for every kilometre of main replaced (2007/08 – 2009/10). See Table in response to Q.24.



There are three other approaches to reducing the level of pressure on metallic pipes: pressure management; the use of gas conditioning (that is to say evaporating mono-ethylene glycol into the gas); and repairing escapes that are detected. They conclude that the only efficient way to reduce emissions is mains replacement.

- **Reduced operating costs**

The replacement programme helps to reduce the costs associated with public reported escapes, which helps to reduce operating costs for the GDNs.

They estimate that by the end of the Iron replacement programme there would be around 9,000 mains escapes per year from the National Grid system compared to around 32,000 per year today.

At around £900 direct cost per escape to complete a repair this reduction in escape numbers resulting from mains replacement makes a significant contribution to ongoing efficiency improvement within NGG. Less replacement would result in less OPEX improvement and in fact in time a worsening position as mains deteriorate and the pipes escape performance worsens.

- **Improved security of supply**

Mains replacement would help to improve the security of supply. National Grid estimates that in 2009/10 NGG connected gas consumers experienced 48,449 unplanned supply interruptions, in their view around 97.5% of them could have been prevented by replacement. However, they also mention that some of them are on multiple occupancy buildings not included in the model.

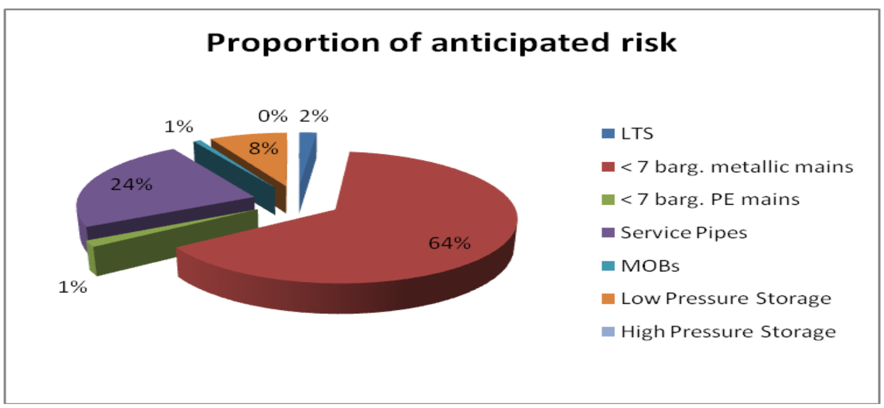
West & Wales

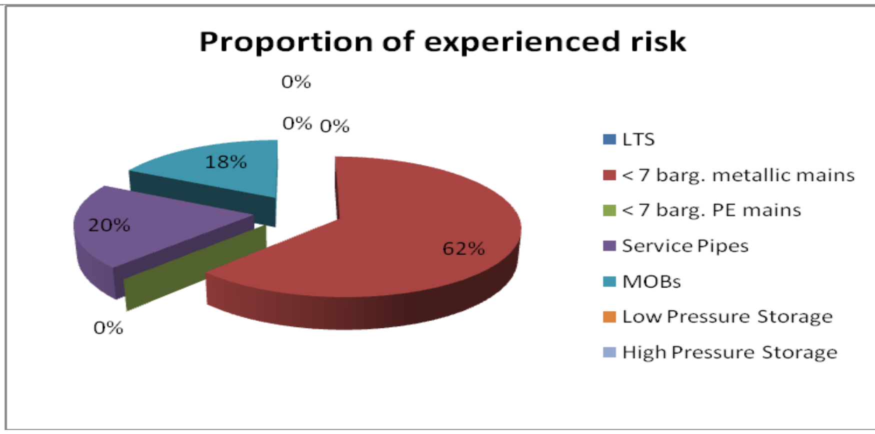
- Additional benefits listed as:
    - Environmental emissions
    - Purchase levels of Shrinkage Gas
    - Volume of network emergency response calls
    - Volume of network repairs
    - Operational Expenditure associated with surveys
    - Insurance Costs
    - Employee Safety
    - Planned Customer interaction

Q.21 What other parts of the network pose a risk of causing incidents? What evidence is available to estimate the level of risk posed by these other parts of the network, and what is the level of spend on addressing the risks?

National Grid

- In 2009 National Grid did a review of other risks (classified as risk of causing fatalities) on the gas network.





- They note the fact that a single incident could cause multiple fatalities and also repeat their analysis indicating potential risks of £1.5bn if a London department store was to be subject to a major incident.
- National Grid evaluated the maximum third party financial loss that might be caused as a result of asset failure (not including failure to supply energy related losses). Their analysis suggested that below 7 bar pipe was the highest risk.
- Approximate level of spend on each type of risk presented below in the table below in £m.

Area of spend	Opex	Capex	Repex
LTS	18.37	44.03	1.56
<7 barg. metallic mains	46.90	12.07	303.22
<7 barg. PE mains			
Service Pipes	7.05	16.20	116.71
MOBs			12.26
Low Pressure Storage	6.29	2.60	
High Pressure Storage		0.60	

West & Wales

- As per response to Annex D Q.9.5 WWU is currently developing DSTs similar to MRPS that support quantifying the risk that different parts of the network pose. Table B.1 below indicates the progress made by WWU.
- The value of risk management spend will be provided in response to Annex C of the Questionnaire.

Table B.1: WWU State of Risk Modelling

Asset group	Current risk model	Future risk model	Timescale
NTS Offtakes	Condition based assessment	CBRM	1-5 years
> 7 bar Pressure Regulators	Condition based assessment	CBRM	1 year
< 7 bar Pressure Regulators (District Governors)	DST	CBRM	1 year
> 7 bar Mains	Condition based assessment	CBRM	1-5 years
Special Fittings, Supports & Crossings	DST	CBRM	1 year
< 7 bar Mains	MRD ST	MRPS and MRP GAS	In place
< 7 bar Storage	Holder DST	Holder DST	In place
> 7 bar Storage	Manual Assessment	Manual Assessment	In place
LPG	Manual Assessment	Manual DST	In place
<7 bar Pressure Regulators (Service Governors)	Risk Matrix	Risk Matrix	5 years +
Services	Postcode analysis of service leakage	Postcode analysis of service leakage	In place

Q.22 To what extent are failures and consequent events caused by deterioration of iron mains and to what extent do they arise from other causes? How is this measured? Are the results captured and monitored?

- As an Iron main corrodes the beam strength of the pipe barrel reduces. Metal is lost through such corrosion. As cast Iron pipes are brittle, any ground movement places significant load on such pipes. If their strength is inadequate they crack, and being brittle the fracture is not arrested and becomes a through wall defect usually severing the pipe circumferentially.
- A combination of ground movement, that may be caused by the weather (in particular very cold or very dry weather), traffic loading or excavation to install other utilities and a weakening pipe results in a heightened propensity to fracture.
- Around a third of explosions result in fatalities.
- Gas escapes may also be caused by **interference damage**, e.g. a contractor using an excavator striking the main. In 2009 National Grid experienced a total of 31,690 gas escapes from below 7 barg. gas mains. Of these just 825 (2.6%) were caused by interference damage; the rest were caused by a combination of the condition of the asset

and its environment.

Q.23 What are the other key aspects of network risk management in addition to the IMRP in terms of identifying and addressing failures; preventing and / or mitigating GIB events? What level of financial resource do they account for relative to the IMRP?

National Grid

- There are no feasible proactive techniques for reducing the probability that an existing Iron pipe gives rise to a GIB other than to replace or abandon it. Improving an existing pipe that is buried under a highway cannot be done without exposing the outside or lining the inside.
- The table below indicates the relative levels of spend (described as approximate annual levels of spend) on different approaches to risk reduction.

Area of spend	Spend (£)
Replacement	430
Maintenance	40
Emergency Response	50
Repair	50
Call Centre	20
Total	590

West & Wales

- Over recent years, WWU has implemented a risk based process for managing gas escapes which now prioritises prevention based on the risk posed by the individual gas escape.

  WWU prioritises its immediate action and repair activity based on a range of factors identified by First Call Operatives which include: the location category; the distance from property; the gas readings; the type of property; the pressure tier of the pipes and the presence of cellars.

Q.24 What programmes have been undertaken to ensure that the risks across network pipelines are addressed in a way that is consistent with the PSR and other safety regulations?

- National Grid includes a detailed discussion of their approach to managing risks across the network.

Q.25 Are there any regulatory incentives to invest in new technological solutions as

alternatives to mains replacement?
• The Innovation Financing Fund is also referenced.
Q.26 What are the existing incentives to address other areas of risk on the network besides the risk posed by iron mains?
• There is a clear financial incentive to reduce risk of all assets, as the penalties (such as fines, restoration costs, and customer compensation payments) are so high. All parts of the network have to meet existing legal obligations. • In addition they state that the IQI includes incentives for the GDNs to invest in new solutions.
Q.27 What should be the key drivers of the next phase of the replacement programme?
Northern Gas Networks • The purpose of the programme should be to address the societal risk associated with iron mains. *National Grid* • In addition to risk removal, the primary driver of the programme is to ensure that NGG remains compliant with UK safety regulation. • NGG state that the following should be taking into consideration in any phase of the replacement programme: o Be economically efficient, over the life of the programme, o Support the interaction with other assets and activities, such as the ability to support peak workload efficiently, o Seek to minimise disruption to consumers and the general public, and o Deliver maximum incremental benefits such as environmental emission reductions, innovation, resilience of a PE network, and cross utility cooperation and efficiencies *SGN* • Safety and legislative requirements are quoted as being the primary driver of the programme and associated HSE requirements. • They also note the other pipes: o Steel mains > 3” o Small diameter mains and services; o Iron mains > 30 m from buildings

- Riser pipes to MOBs

That also pose a risk, they are exploring ways to develop a holistic approach to risk management across all pipe assets.

They also are considering ways to develop a programme that gives them sufficient flexibility to address issues such as poor pressure, water ingress, pipes with high leakage rates etc.

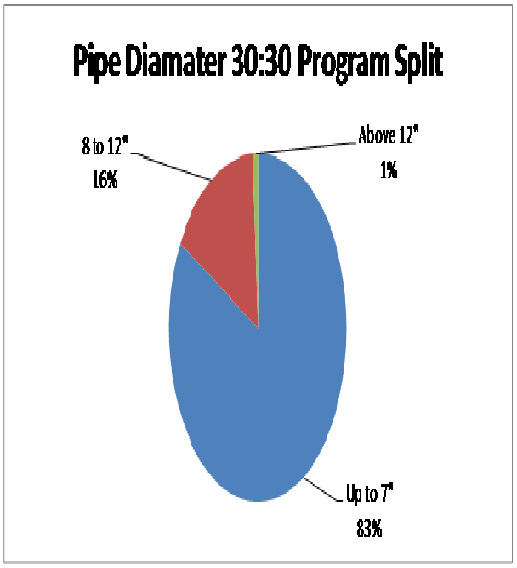
WWU

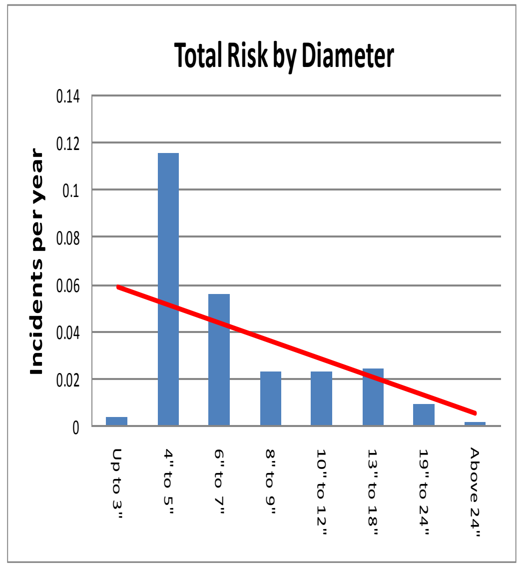
- They are of the view that the following should be the main drivers:
    - Reducing the level of societal risk posed by iron mains – without replacement the level of risk would rise year on year. They note that incidents are more likely to occur on low risk scoring mains (because most of the remaining mains population is scored low risk).
    - Reducing leakage and associated repair – Present evidence to suggest that the level of deterioration on the network has not declined. Similarly they suggest that GIBs have not fallen either. They also note that iron mains pose a risk to their workers when they carry out repairs.
    - Reducing emissions from leakage
    - Compliance with PSR – they state that the primary driver is risk reduction, once the correct approach to managing risk is developed then the costs should be reviewed to ensure the efficient delivery of the programme.

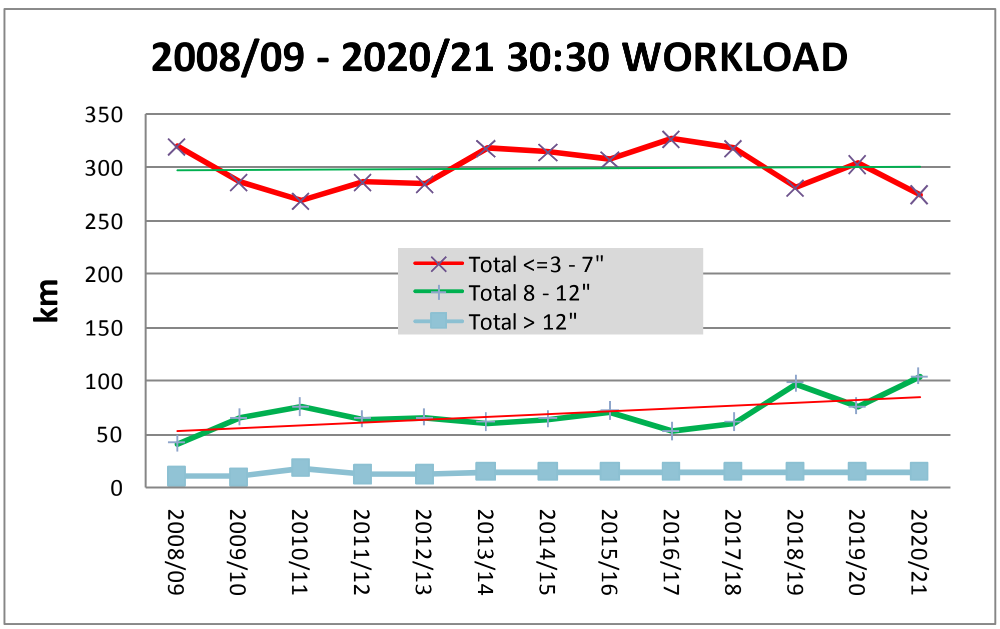
Q.28 What reasons and available evidence is there to indicate that the future replacement programme - on the same lines as the current programme - would require more resources than historically where the programme has targeted smaller pipes?

- SGN, NGN and National Grid all comment on the movement towards large diameter replacement will likely add to the costs of the programme over time – both in terms of money and personnel, particularly because:
    - They are more likely to be found in towns and cities, creating more difficult working conditions, therefore implying longer time / workforce requirements to complete the replacement.
    - Requirements for more plant / material hire to complete the replacement.
    - The need for more specialist skills.
- WWU note that they have a larger proportion of small diameter mains on their network, but even still the next phase of work is likely to require the decommissioning of a greater proportion of large diameter mains, they describe many of the costs associated with large diameter mains replacement as the other GDNs.
- Three charts are presented to show the diameter split of the remaining ‘at risk’ pipes

within the network and the modelled risk per diameter band. Finally they present their estimated workload for the IMRP until 2020/21







- WWU also note that the method of replacement also plays an important role in cost. WWU have the highest rate of replacement using the insertion method, which they state is the most efficient method of replacement. Though they note that insertion rates might be expected to drop off going forward as the percentage of large diameter mains increases, as there is less scope to use the approach on those mains.

Q.29 What will be the cost drivers for future replacement work?

a. How do GDNs expect long term contractor demand to impact on the costs of

the programme? **b. How might existing contractor relationships impact on the programme?**
Northern Gas Networks • The shift towards large diameter replacement • The principal cost drivers will remain the same – cost of contractors; labour; materials etc. In addition new costs such as the Traffic Management Act will be relevant. • They also expect that the recovery of the economy to add further to cost pressures. *SGN* • The principal cost drivers will remain the same – cost of contractors; labour; materials etc. In addition new costs such as the Traffic Management Act will be relevant. • Note that the recovery might lead to significant growth in the construction sector creating additional pressure on their contractor costs. • They have been able to develop long-term relationships with their contractors, which has aided the delivery of the programme. *WWU* • State that labour and materials are likely to be the key drivers - in particular they stress the potential premium attached to labour with the appropriate skills to complete the work. • Traffic management costs and the uncertainty surrounding the costs associated with traffic management are also mentioned. • Market price of PE and steel, they note that PE prices are affected by oil price variations, while steel fluctuates based on demand.
Q.30 In what ways have GDNs started to consider mains replacement as part of the development of their business plans under RIIO?
Northern Gas Networks • NGN is currently engaged with the RIIO process, and are seeking views from stakeholders about the most appropriate way to manage the repex programme. *National Grid* • NGG have undertaken similar stakeholder consultations to consider their business plans in light of RIIO, but are also awaiting the outcome of the review. *SGN* • They are waiting for the results of the current review before re-working their business plan.

WWU • They note that they have considered the extent to which they will meet their legislative obligations. They have also carried out analysis on the costs and benefits associated with the IMRP (a cost benefit analysis model has been provided by WWU and a meeting held on 21st February to discuss the assumptions).
Q.31 Are there constraints under the current programme which prevent more innovative / longer term thinking?
Northern Gas Networks • Are of the view that the current programme is well understood by the GDNs. Though note that the current design of the project does imply constraints to delivery, especially the pipes that have to be included in projects in a given year regardless of location, and a second large category of pipes (around 50% of the iron population) whose availability for inclusion within projects is severely restricted. • The programme could consider introducing more flexibility to enable the delivery of additional societal benefits e.g. targeting poor pressure areas / pipes with high leakage rates that do not drive a 'high' risk score; steel pipes etc. *National Grid* • Do not identify any constraints but are of the view that the programme has encouraged and facilitated the development of new approaches to delivery such as, the 20/70/10 and then the zonal approaches. • They also note that the certainty and stability of the programme has enabled NGG to long-term resourcing and contracting strategies. • To deal with new challenges such as the Traffic Management Act will require long-term planning and management. *SGN* • The current programme is well understood by the GDNs enabling them to develop adequate strategies. The fact that replacement needs to be 'informed by risk' does pose a constraint on replacement activity – particularly pipes that have to be replaced within a given year and a second large category of pies (around 50% of the iron population) whose availability for inclusion within projects is severely restricted. • In addition there are tight budget constraints relating to the replacement of 'non at risk mains', which restricts their ability to deliver other societal benefits from mains replacement (e.g. target water ingress areas). *WWU* • They state that their experience is that if GDNs can demonstrate an appropriate approach to managing risk, while achieving efficiency savings it is likely to be accepted, e.g. 20/70/10 and zonal approaches.

Q.32 What challenges (and opportunities) does an eight-year price control create for the iron mains and repex programme?

Northern Gas Networks

- The eight-year control gives the GDNs an opportunity to seek longer-term contracts, which should enable efficiencies to be generated. It is important that any repex allowance have sufficient flexibility to enable any dynamic changes to the programme to be accommodated.

National Grid

- The longer control gives more certainty to the GDNs enabling them to deliver a more long-term approach to efficient risk removal.
- The scope of the mid-period review will be a crucial consideration and the treatment of uncertainty.

SGN

- Gives opportunities for longer-term contracts and planning, but dyanamic changes in the model are more difficult to predict, which might change the requirements over the price control.

WWU

- The eight year review will create uncertainty over costs for the GDNs given the need for their replacement programmes to take account of dynamic risk growth.

Q.33 Are there more efficient ways of structuring the mains replacement programme going forward? For instance, should there be a greater emphasis on other ways of mitigating gas network risks than at present?

If so, what should be the focus of expenditure to mitigate risks of network failure?

a. What evidence exists currently to address these questions?

b. What additional information would it be helpful to collect?

Northern Gas Networks

- Are of the view that the current system does provide a good balance between risk reduction and providing opportunities for delivering cost efficiencies. Though they note that the current arrangements do provide a degree of constraint.

National Grid

- The risks posed by the network should be the primary focus of the future programme.
- The scale of projects should be sized according to the relative differences in risk posed across the population of remaining pipes. The smaller the differences between individual pipe's risks, the greater the geographical coverage could be, with a corresponding overall financial saving.

- The development of asset condition measures, or asset health indices, should enable the transparent demonstration of gas network risk prioritisation and mitigation.

SGN

- Options to deliver the programme more efficiently would need to be balanced against risk reduction. Examples include:
    - Moving to a zonal approach – but state that they have received opposition from local authorities.
    - Targeting pipes in poor condition to reduce escapes / repairs.
    - Upsizing replacement mains to enable increased levels of downstream insertion, and also to reduce pressure giving reduced leakage in the remainder of the metallic network.
    - Create all-plastic locked-up areas.
    - Target issues with known issues of loss of supplies due to water ingress areas for instance.

WWU

- State that they view the 20/70/10 approach is optimal, but that they continue to review other approaches.

Q.34 Have GDNs undertaken studies to consider relative risks across the gas distribution network? How might 'fine-tuning' or fundamental change to the mains replacement programme affect the requirement that all practicable precautions are being taken to manage risks on the network?

Northern Gas Networks

- NGN have undertaken several projects to improve its understanding of the condition of its asset base and develop enhanced models to inform investment decisions. NGN is of the view that it is at the frontier of developing asset health indices within the gas distribution networks.

National Grid

- See response to Q.21 also
- State that they need to see detailed proposals before responding to the question in full.

SGN

- They are in the early stages of considering an alternative risk measure to apply across all pipe assets.

WWU

- WWU are developing tools to review risk between different asset groups, but they still undertake action to ensure that they satisfy their legal requirements across the different asset classes.

- They state that changes to the IMRP, will require WWU to develop a new safety case that would need to be approved by the HSE. They do not believe that alternative approaches exist that remove the risk of mains within 30m of buildings.

Q.35 If alternative options for structuring the IMRP are to be considered how, should legal, practicality and wider safety considerations be taken into account in the consideration of the options?

Northern Gas Networks

- Depending on the nature of the change the legislation should be formally amended. The GDNs would then need to develop revised safety cases for approval by the HSE.

National Grid

- States that the existing legal requirements should be taken into account.

SGN

- See response to question 27.
- Any fundamental change to the programme should be consistent with safety legislation.
- Are of the view that that it is possible to enable a more holistic approach with increased flexibility within the programme and remain within the confines of the current regime.

WWU

- State that this is an absolute requirement for the programme going forwards.

Q.36 Please provide views on the categories of benefit and associated assumptions that, in your view, our study should consider.

Northern Gas Networks

- The main additional benefits are:
    - Reduction in greenhouse gas emissions
    - Reductions in the number of escapes and repairs that would otherwise be the case
    - The maintenance of highly skilled contractor workforce to deliver operational service to the sector
    - Significant regional economic benefit in terms of employment and local investment

SGN

- SGN state the following as the benefits that should be included:
    - The absolute legal requirements we must comply with

- Societal concern (public willingness / reluctance to accept incidents)
- Views of our stakeholders
- Safety benefits from reducing risk, gas in buildings and pipe failures
- Environmental benefits resulting from reduced gas leakage
- Opportunities to develop more holistic and flexible programmes

WWU

- See response to question 30.
- They suggest that the rate of deterioration might be inferred by looking at GIB data, they suggest 4.5% as a suitable figure. Evidence is quoted to suggest that deterioration of the mains is a continual problem.

Q.37 What statistical evidence is available to the GDNs on the social and economic benefits of the Programme?

Northern Gas Networks

- View the following as relevant:
  - Reduction in gas emissions. State that repex reduces leakage by approx 10GWh per annum. This implies a benefit of £5m over the repex programme.
  - Maintenance of skilled contractor workforce. NGN employs 864 contractors and 104 direct labour employees for the programme. This workforce can be used to deliver other emergency programmes.
  - Regional economic benefits in terms of employment and local investment.

National Grid

- Quote the benefits of reducing the level of GIBs and failures etc.

SGN

- They employ 4,000 direct employees and 2,400 contractors of these around 35% are employed on the IMRP from time to time.
- State that the local economy benefits.
- In addition they restate the safety benefits
- Also note the environmental benefits.

WWU

- See WWU CBA model

Q.38 The GDNs' response to the Frontier Economics study notes a desire to share data captured on network performance and repairs. Please provide us with this data.

Northern Gas Networks / SGN

- Evaluating the data to respond to question.

National Grid

- Provide a table to show how the replacement programme might reduce significantly the number of mains escape repairs from below 7 barg. mains. For iron mains they consider that by the end of the programme the number of repairs will have fallen from 25,637 in 2009 to around 2,050. This may be a conservative assumption as it is based on a 'no further deterioration' assumptions.
- NGG also identify that there were 32,068 service condition repairs in 2009/10. They expect that through the service based mains replacement this will fall to 10,000 – though as a significant proportion of services lie outside the IMRP this will still be a problem.
- They estimate that the reported escapes will decline significantly, reducing pressure on the labour requirements.
- The reduction in escapes will improve security of supply. In 2009 / 10 there were 48,449 unplanned supply interruptions they estimate that in total the programme will reduce the number of unplanned interruptions to around 10,000 a year.

WWU

- Evaluating the data to respond to question.
- WWU also note that the programme was not introduced based on a value for money or CBA assessment but on grounds of practicability. WWU also note that their costs have not doubled since the implementation of the IMRP as suggested by the Frontier report. They also question the assumption that 60% of the modelled risks have been removed from the programme. They also note that Frontier have not accounted for deterioration in their analysis.
- They question Frontier's assumption that efficiency savings associated with the programme are zero, and note that their costs are lower than quoted by Frontier.
- The Frontier model takes no account of encroachment, which in their experience is occurring at around 11Km a year.
- As a result of encroachment WWU have 8,634Km of 'at risk' mains compared to 8,216Km estimated by Frontier.
- They note that all of the benefits estimated by Frontier are an underestimate as they do not take account of deterioration.
- They would expect there to be an exponential trend in the reduction of fatalities rather than a linear one, as Frontier had assumed. They also question Frontier's assumption that the risk of fatalities will ever fall to zero – there will always be an amount of irremovable risk.
- They question the use of the DfT value of a life saved. They quote the Lord Gill report

and suggest that fatalities relating to involuntary risk should be avoided at all cost.

- They question the assumption on the relationship between fatalities and injuries quoted by Frontier – no evidence is given to support the assumption, also they do not agree with the value attached to preventing injuries (the DfT value was again used).
- The injuries relating to the workforce are not included in Frontier's analysis.
- As with injuries, WWU state that Frontier have both underestimated the amount of building damage and the costs associated with it.
- Reduced shrinkage – they question the assumption that the IMRP will only reduce shrinkage levels by 35%. The 35% assumption was based on an extrapolation from the PCR allowances.
- Further they state that according to the National Shrinkage model 66.9% of all leakages can be attributed to iron mains – of which 61.6% will be from mains in the 30:30 programme. In their view it could be assumed that all that leakage will cease when the iron mains are replaced with PE.
- Therefore it is not the total amount of shrinkage that is subject to discussion but the rate. In their estimate this would reduce the benefits of the counterfactual by £187m.
- Also it is assumed in Frontier's analysis of shrinkage that the price of gas is constant.
- Reduced repair costs – they state that more information should be provided to justify Frontier's assumptions of the repair savings costs.
- They also quote various parts of the CBA that Frontier have omitted.
    - Surveys – if the length of the programme is increased it will be necessary to carry out more surveys of at risk mains. This cost should be included in any counterfactual that reduces the speed of the IMRP.
    - Emergency service provision cost savings from implementing the programme more slowly would increase. This needs to be taken into consideration.
    - Suggest that insurance premium costs should also be considered to take account of the costs incurred by the GDNs from potential fatalities, injuries and damage to buildings.
- The overall results of WWU's CBA is presented as follows:
    - They estimate that the Frontier Option would have a net cost of £100m for WWU – for the rest of the GDNs the cost would be in excess of £1bn.
    - They conclude that the programme should not be extended in length.
    - Their analysis indicates that the project should be speeded up.

Q.39 Should the potential for a possibly major reduction in the use of gas in the UK be taken into account when planning future repex?

Northern Gas Networks

- NGN note that there is significant uncertainty about the future of gas networks and in particular a significant possibility of an increasing role for gas in the short to medium term. They are not of the view that these issues should have any impact on the IMRP.

National Grid

- National Grid state their view of the credible possibility that gas networks will still have an important role to at least 2050.

SGN

- They do not believe that these issues are relevant to addressing the safety issues posed by the network.

WWU

- WWU quote analysis that suggests that gas will still have an important role to play well into the future.

ANNEX C: HISTORY OF IRON MAINS REPLACEMENT

This note sets out the timeline behind the implementation of the iron-mains replacement programme.

- Prior to 1974 there was no national replacement programme, mains were generally replaced because of poor condition or in association with reinforcement. About 600km with the system was replaced each year in the preceding decade.

- The **King Enquiry was held in 1977**, following the Christmas period of 1976 / 77 when a number of severe gas explosions occurred. The Enquiry recommended that the replacement of higher risk priority mains by 1984 formed a reasonable minimum approach.

- The **(King) Iron Mains Replacement Programme** was originally introduced in **1977**, under the programme Transco used polyethylene (PE) pipelines to replace the iron mains. PE was considered to be the most suitable material for this application as it exhibits high resistance to fracture under-ground loading and corrosion.

  The introduction of the programme increased the rate of replacement of the highest risk priority mains with the objective of removing all of the mains 1984. The mains targeted were small diameter cast iron mains and steel mains in the most hazardous locations.[34]

- **1984 – 1989 Post King Replacement Programme.** A study was carried out in 1980 to identify secondary risk mains for replacement, based on this study it was determined that it was necessary to decommission 2,600km per annum of mains. A five year time period (1984 – 1989) for this programme was agreed at the time.

- **The Marchant Report (1985),** was used to inform the replacement policy to be introduced post 1989. The report recommended that there were a wider range of factors that should be considered when identifying mains that were at risk of failure (including breakage/corrosion history, nature of adjacent buildings, and evidence of subsidence). The Marchant review led to an improvement of the way in which 'risky' iron mains were identified.

- In 1995/96 Transco carried out a review of its mains and service replacement programmes. Transco determined that their overall objective should be to achieve a 95% confidence level of achieving a maximum of three mains related incidents per annum by 2006 – increasingly the level from the 42% confidence interval that it had achieved at the time.

- **1996 – 2000 Replacement Strategy.** The replacement strategy for 1996 – 2000 determined that the replacement level for iron mains for the next 10 years should be 2,500km per annum.

- The **Pipeline Safety Regulations (PSR) were introduced in 1996**. The PSR includes an absolute duty that the 'operator shall ensure that pipeline is maintained in an efficient

[34] Hazardous locations were defined as: places of public assembly; buildings with basements or cellars; places where the ground surface is completely sealed; and for a given set of conditions buildings very close to mains.

state, in efficient working order and in good repair'. In addition the Gas Safety (Management) Regulations 1996. GSMR require gas conveyors to operate their networks in accordance with an accepted safety case. The Mains replacement programmes form part of the safety case.

- In **1999 the risk model was updated** following a Tripartite Review (HSE, Ofgem and Transco) of Transco's replacement methodology, as a result the **Mains Risk Prioritisation System (MRPS)** system was introduced. The MRPS assigns a risk score to the iron mains, providing the GDNs with a list of mains to be replaced.

  Originally Transco simply replaced the mains according to the prioritised list. However this was not an efficient way to manage the replacement programme, as such following agreement with the HSE the **20/70/10 replacement** approach was introduced in which 20% of the total mains decommissioned each year where selected from the highest risk population of the 'at risk' mains, 70% from the secondary risk population and 10% from the remaining risk population. To provide the GDNs with greater flexibility to deliver efficiencies in the implementation of the programme some of the GDNs have been able to implement the 20 / 80 zonal replacement model.

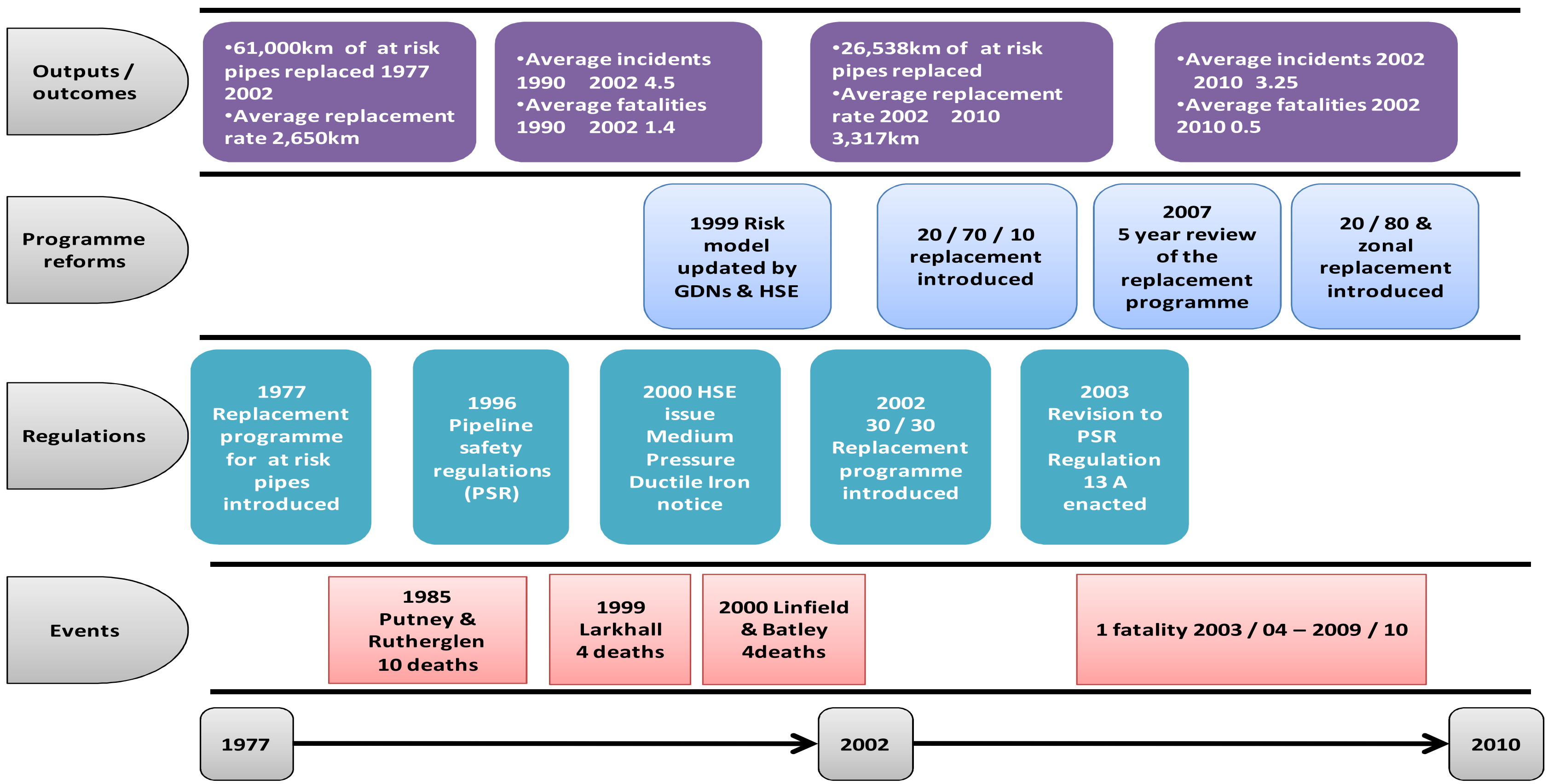
  Improvements to the risk model were complemented with reforms to improve Transco's management and storage of data related to mains failures – one of the findings of the Larkhall incident were that Transco had lost its records on the mains surrounding the programme. These data improvements may have improved significantly Transco's ability to identify the 'at risk' mains.

- Serious concerns arose about the integrity of **medium pressure ductile iron (MPDI) mains** arose as a result of the Larkhall incident in Scotland in December 1999, which involved four fatalities. As a result, in **2000** the HSE issued the **MPDI Improvement Notice**. This notice introduced a requirement for Transco to accelerate the Mains Replacement programme with respect to MPDI, subsequently Ofgem agreed to increase the relevant repex allowances to cover the associated expenditure. Transco was required to cease conveying gas at medium pressure in ductile iron pipes within 30 metres of buildings by December 2002 – this was subsequently extended to April 2003. Ductile iron pipes known to have been operating at medium pressure within 30 metres of buildings were either decommissioned or down rated to low pressure in accordance with requirements.

- Three incidents occurred that caused multiple fatalities in 1999 (Larkhall) and 2000 (Linfield and Batley). Eight people died in the three events, creating concerns about the general condition of the remaining mains network. It may have been this cluster of incidents that created the environment necessary to facilitate the introduction of the IMRP.

Figure C.1 below summarises the timeline for the main events of relevance to the iron mains replacement programme.

Figure C.1: Timeline of the replacement programme



In Table C.1 below we summarise the available information on the fatalities related to iron mains failure since 1995. The key points to note are as follows:

- Since 1995 a total of 14 individuals have died as a result of iron mains failures (1 individual has died as a result of steel mains failures. Of these deaths only 1 has occurred since the introduction of the replacement programme – 8 individuals died in 3 events that occurred in 1999 and 2000 (Larkhill, Linfield and Batley).
- In addition to the fatalities caused by iron mains failures there have been 3 deaths caused by failures in steel pipe services in 1996 and 97 (not included in the table).
- All of the fatalities relating to iron mains were due to fracture / corrosion in ion mains with a small diameter <12".
- In most of the events there was no history of fracture in the mains and the mains were not classified as high risk.
- Only one of the fractures that have to a fatality occurred >15m from a building (26m in 2002).

Table C.1: Mains explosions leading to fatalities since 1995 (Ashton-U-lyne (1 fatality) not included as information not available)

	Pipe	**Size**	**Pipe laid**	**Distance from building**	**Surrounding soil**	**Causes of incident**	**Fatalities, injuries, property damage**
Ilkeston 1995	Medium pressure ductile iron pipe	8"	1971	n/a	Silty clay	Graphitic corrosion, potentially caused by the surrounding soil conditions. There had been recorded incidents of corrosion (86 and 91 and potentially a fracture in 91) prior to explosion	• 1 fatality • 1 serious injury • 4 minor injuries • Property destroyed
Grangetown 1996	Low pressure cast iron pipe	4"	1905	2.9m	Silty sand and gravel	Fracture of pipe caused by severe corrosion, surrounding ground conditions	• 1 fatality • 1 minor burns • Internal walls of property damaged, and fire damage
Ecclestone 1999	Low pressure spun iron main	4"	1962	15m	Reddish brown clay	Fracture caused by ground movement and stress corrosion There was no history of corrosion or fracture on the pipe Gas likely to have been ignited by light switch	• 1 fatality • 1 injury • Extensive damage from explosion and fire to property
Larkhall 1999	Medium pressure ductile iron	250 mm	1974	10m	clay	Cause of fracture recorded as unknown – court case suggested that the soil conditions may have been a factor Fracture history of pipe was unknown as Transco did not have appropriate records Court case ensued. Transco fined £15m, as Judge ruled that they should have been aware that iron	• 4 fatalities • 1 house destroyed • damage to nearby properties

	Pipe	Size	Pipe laid	Distance from building	Surrounding soil	Causes of incident	Fatalities, injuries, property damage
						mains could corrode in adverse soil conditions within ten years and the problem had been highlighted by fatal blasts at Warrington and Ilkeston	
Linfield street, Dundee 2000	Cast iron low-pressure gas mains.	4"	1967	0.8m	'clayey fine sandy to coarse gravel'	Fracture of gas pipe caused by: • stresses caused by uneven settlement of supporting soil over the sewer connections • stresses associated with tapered service connection • two previous fractures of 4" cast iron mains in local area • drainage in the area had not been constructed to correct standards. Gas most likely ignited due to someone lighting a cigarette Previous fractures had occurred in 1957 and 1996 – but the mains that fractured had not been scheduled for replacement	• 2 killed • 1 serious injury • 3 other injuries
Batley 2000	Low pressure spun iron	4"	1960	3.5m	'made up ground', brick and clay	Uneven support to main and also ground movement due to the surrounding soils Had a risk score of 84 prior to incident – the mains were not due for replacement under the 'at risk' replacement policies in place at the time	• 2 fatalities • 1 property destroyed, 1 damaged
Clitheroe 2002	**Steel pipe**	2"	n/a	0.2m	Brown clay	Corrosion of 1" siphon standpipe. Ignition due to use of cooker or washing machine	• 1 fatality • 3 injuries

	Pipe	Size	Pipe laid	Distance from building	Surrounding soil	Causes of incident	Fatalities, injuries, property damage
							• Fire damage to property
West Bridgford 2002	Low pressure spun iron pipe	8"	1960	26m	Clay	Uneven support due to concrete around the main. There was no history of fracture or corrosion	• 2 fatalities • 1 injury • 2 flats destroyed • 2 flats partially destroyed
Buckstone Grove Edinburgh 2006	low pressure cast iron	4"	n/a	n/a	n/a	Fracture caused by: • Ground instability caused by the nature of local ground • A concrete section water valve chamber positioned in close proximity to the gas main may also have contributed to the failure by acting as a pivot point The fracture led to an explosion because of an unsealed service entry point following permeation through the soil. The main was targeted in the replacement programme, but had a low risk rating and was therefore not scheduled for removal for a number of years (primarily because no history of failure on that part of the mains)	• 1 serious injury, • serious damage to building

Source: HSE Summary of UK Gas Distribution Mains and Service Related Incidents 1990 – present

Annex D: Case Studies of other safety related programmes

This Annex presents a number case studies on a number of programmes / policies that have been implemented in the UK (and other developed economies) with the aim of reducing the incidence of fatalities / injuries. In the case studies we include a wider discussion of the major incident that preceded the implementation of the programme and discuss where relevant any implications for the IMRP.

The following case studies are discussed:

- Grovepark Mills
- Hatfield train derailment
- The various mains replacement programme in Australia
- The replacement programme in the USA
- Department for Transport guidance on the value of preventing a fatality

Box D.1: LPG Explosion at Grovepark Mills

A replacement programme has been implemented for certain classes for Liquid Petroleum Gas (LPG) piping following the explosion in a factory at Grovepark Mills, Maryhill, Glasgow on 11th May 2004. Nine were killed and 33 seriously injured as leaked (LPG) ignited in the basement and resulted in the catastrophic collapse of the four storey building. The leak came from a crack in a corroded unprotected underground pipeline laid 35 years earlier. Following this disaster a programme to replace all pipes similar to the one in question has been introduced.

Legal outcome

ICL Technical Plastics Limited and ICL Plastics Ltd manufactured plastics products and coatings in the factory. Both were fined £200,000 at the Glasgow High Court. ICL Plastics Limited pleaded guilty to breaches of Sections 2 and 4 of the Health and Safety at Work Act 1974. ICL Technical Plastics Limited pleaded guilty to Sections 2 and 3.

The Gill report

The ICL Inquiry Report led by Lord Gill, a Senior Scottish Judge, was published in 2007. His conclusion was that this was an avoidable tragedy. The enquiry heard that the faulty pipe work could have been replaced for as little as £400. While the companies were clearly at fault, the health and safety regime and also came under fire. According to the Gill report the risks had been misunderstood, mis-communicated and ignored. A four stage plan was proposed to avoid the repetition of the tragedy again in the future:

1. Identify and replace underground metallic pipe work between tank and appliance with polyethylene on a systematic and prioritised basis, with polyethylene. Early inspection of all buildings with LPG supply to identify hazardous features.
2. Establishment of a permanent and uniform safety regime governing the installation, maintenance, monitoring and replacement of all LPG systems.
3. Continuing and planned development of the safety regime, particularly in relation to the use of polyethylene pipes.
4. Development of a permanent system to review and deal with safety questions across the industry.

Replacement programme

At the time of the report it was estimated that there were 60,000 commercial and 150,000 domestic installations across England, Scotland and Wales. Replacing the pipes has been seen as an urgent priority and in June 2009 the industry agreed a timetable *for the accelerated replacement of the underground metallic service pipe work carrying LPG*. The LPG suppliers, the industry body UKLPG and HSE have been working together to develop a risk-based approach, that will prioritise the removal of the riskiest pipes first. Replacements were accelerated following the collection of preparatory data, risk assessments and a promotional campaign. A training programme to increase the number of qualified Gas Safe engineers available to carry out the replacement work was also proposed. Businesses are required to replace their buried metallic service pipe work with more durable materials, such as polyethylene. Higher risk pipe work is targeted to be replaced by the end of 2013.

A reaction to uncertainty, not risk

An important finding from the enquiry is that the **recommendation to replace LPG pipe work does not appear to be based on any cost-benefit** analysis. Instead it appears to be a risk-averse response to uncertainty. While Lord Gill conceded that the reoccurrence of an LPG explosion was unlikely, ***in justifying the need for intervention he stressed not the probability of the explosion occurring but the potential impact if it did*.**

Indeed Lord Gill appears to find the consideration of costs as being secondary to the concerns posed by the potential risks posed by the LPG pipes. "I recognise that in relation to my proposed metallic pipe work replacement programme, the cost implications may well be significant. Having regard to the potential risks that now exist, I do not consider that on this aspect of my recommendations cost can constitute a reasonable ground of objection."

The Lord Gill report goes on to state that "A sense of urgency would be an appropriate response to the serious issue of public confidence that this disaster has raised." However this may be more reasonable in the context of the paucity of data for the pipes in question. "The clear and overriding hazard which this disaster has highlighted is that there is, to an extent that is yet to be exactly determined, a considerable amount of underground metallic LPG pipe work whose state of integrity is unknown. None of this pipe work is subject to any systematic regime of inspection and maintenance; nor subject to systematic data recording. As matters now stand, there is every possibility that a similar disaster could occur again."

Relevance for the IMRP

The results of the Lord Gill inquiry have important implications for the IMRP, given the similarity of the industry and the fact that the inquiry was published relatively recently. The key finding from the Gill inquiry were the consideration that the costs of implementing the replacement programme should be considered secondary to addressing the unknown risks posed by the LPG pipes.

However, any inferences drawn from the findings of the Gill inquiry for the IMRP should be tempered by the fact that the level of understanding of the potential risks posed by the LPG pipes was at the time of the inquiry lower than was the case for iron mains – as discussed in Annex C iron mains replacement has been ongoing in some form since the 1970s and a significant amount of research / analysis on the risks posed by the iron mains network - much of the justification for Gill's recommendations and subsequent replacement programme is based on the level of uncertainty surrounding the scale of the risks posed by the LPG pipes. Furthermore, although the costs imposed by the accelerated LPG replacement programme are high, they are significantly smaller than the costs of the IMRP given the size of the iron mains network.

Box D.2: Hatfield Train Derailment

The 12.10 GNER train heading from London Kings Cross to Leeds on the 17th of October 2000 derailed at high speed half a mile south of Hatfield station resulting in four fatalities and injuring over 70. While other rail accidents have resulted in greater loss of life, this disaster remains high in public consciousness a decade later. Because the train derailed due to the disintegration of open track, rather than direct human or signalling error, the safety of the whole network came into doubt. The uncertainty that this created resulted in a highly risk averse reaction including blanket speed limitations causing disruption across the country for an extended period and accelerated rail replacement programmes. It was clear that this reaction was designed to reduce the risk of a similar tragedy happening again as this would be intolerable in the eyes of the public.

Investigation

The HSE and British Transport Police (BTP) jointly undertook the investigation into the cause of the derailment. BTP were involved as the death of two GNER staff members required investigation of manslaughter offences. The HSE established an Independent Investigation Board (IIB) to oversee the investigation into the derailment.

The Crown Prosecution Service prosecuted six men, and Railtrack (the infrastructure controller) and Balfour Beatty Rail Limited (BBRML) (the maintenance contractor) for gross negligence and offences under the Health and Safety at Work Act. All individuals were acquitted of their charges but both Railtrack and BBRML were found guilty of Health and Safety offences. BBRML was fined £10m (subsequently reduced to £7.5m) and Network Rail (formerly Railtrack) was fined £3.5m.[35] The largest Health and Safety fine imposed before these charges was £2m for Thames Trains' role in the 1999 Paddington rail crash.

HSE investigation

The Office of Rail Regulation (ORR), who gained Health and Safety responsibility following the 2004 White Paper "The Future of Rail," published the IIB report in July 2006[36] following the conclusion of all legal proceedings and appeals.

While the immediate cause of the derailment was the "fracture and subsequent fragmentation of the high rail" which was "due to the presence of multiple and pre-existing fatigue cracks in the rail," the HSE investigation found that the underlying cause was that the maintenance contractor had "failed to manage effectively, in accordance with industry standards, the inspection and maintenance of the rail at the site of the accident" and that the infrastructure controller had "failed to manage effectively the work of BBRML and failed to implement an effective rail renewal operation at the same location."

The report found that while BBRML had identified their non-compliance with required standards and procedures at the location of the crash, they had not taken reasonably reasonably practicable precautions to control the risk.

Health and Safety requirements

The Health and Safety at Work Act requires companies to do what is "reasonably practicable" to ensure health and safety. Companies must "ensure the health and safety of themselves and others who may be affected by what is done, or not done." Management of Health and Safety at Work Regulations 1999 also requires all risks to be assessed and controlled. Railways are also covered by the "Railway (Safety Case) Regulations 1994 requiring the infrastructure controller to set out and comply with their own policies, risk assessment, safety management system, operational, maintenance and audit arrangements relating to health and safety.

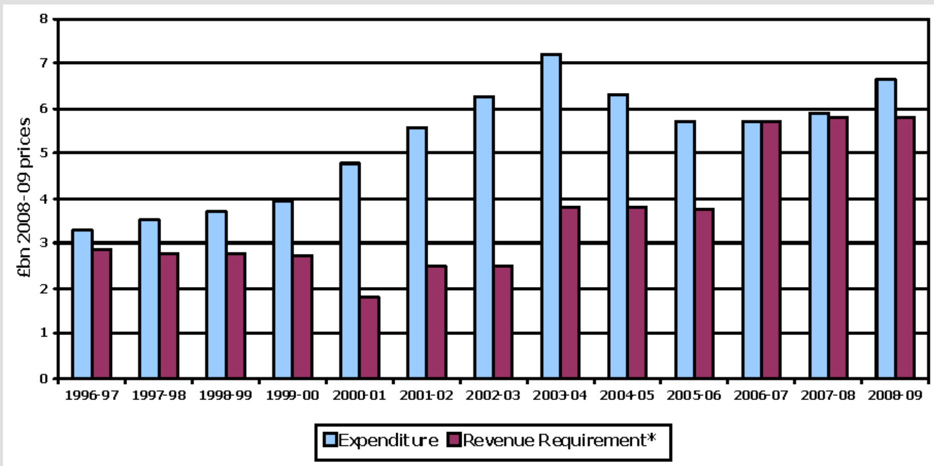
Reaction

While rail safety awareness had been heightened by the Ladbroke Grove and Southall rail crashes, the Hatfield derailment precipitated "a significant increase in spending on rail infrastructure," in particular a

reg.gov.uk/upload/pdf/297.pdf

National Rail Replacement Programme was implemented together with wider infrastructure expenditure. It is difficult to estimate precisely the level of expenditure directly attributable to national rail replacement programme that was implemented following Hatfield, however at the time Railtrack estimated that the replacement programme would cost £580m (in 2001 prices). More generally there was a 53 percent increase in the annual rail industry infrastructure costs from the year before the accident 1999/00 to the year after 2001/02. This increase was comprised of a 53 percent increase in infrastructure capex (£1.4bn to £2.0bn (2001/02 prices)) and a 42 percent increase in infrastructure operating costs (£1.7bn to £2.8bn).[37] Figure D.1 shows the hump of investment that followed the accident, showing that legacy on costs for a number of years.

Figure D.1: Network Rail expenditure and revenue requirement



Source: DfT[38]

A presentation by Sir Christopher Foster and Chris Castles to the Secretary of State for Transport on Reform of the UK Railways in 2004 argued that the increase in costs was due to risk aversion, rather than safety.[39] They argued that many of the "post-Hatfield schemes" implied more than a tenfold increase in the cost per life saved compared to the Rail Safety Standards Board's suggested benchmark of £3.36m per life.

Lessons for the IMRP

While industry-specific determinations of what is reasonably practicable for a company to do are important, this event shows how the heightened risk aversion following a tragedy can lead to large volumes of asset replacement regardless of how much value for money it may cost to deliver. Much of the increase in spending after the disaster may have been a rational response to deficiencies that came to light under closer scrutiny, therefore it is important to ensure that in all industries not only is there technically sound health and safety procedures in place, but that they are used effectively.

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[37] Smith (2004) "Are Britain's railways costing too much? Perspectives based on TFP comparisons with British rail 1963-2002" Institute of Transport Studies, Working Paper 585 (http://eprints.whiterose.ac.uk/2518/1/ITS2085-WP585_uploadable.pdf)

[38] DfT/ORR (2010) "Rail value for money study Scoping study report" (http://www.dft.gov.uk/pgr/rail/strategyfinance/railvaluemoneystudyscopingreport.pdf)

[39] Foster and Castles (2004) "Presentation of the submission to the Secretary of State for Transport on Reform of the UK Railways" (http://www.icea.co.uk/archive/Reform%20of%20UK%20railways%20presentation.ppt)

Box D.3:Mains replacement programmes in Australia

In various States in Australia replacement programmes have been implemented. In this case study we focus on detail on the low-pressure replacement programme in Victoria and also provide some discussion of recent debates around accelerating the rate of mains replacement in South Australia.

Victoria low-pressure replacement programme

In Victoria there are approximately 24,000km of gas distribution piplelines, the majority of which are constructed of plastic, but there are also some steel and cast iron mains pipes.

Energy Safe Victoria (ESV) and the Essential Services Commission is currently working with the three Victorian gas distribution businesses: Alinta/Multinet Gas; Envestra; and SP AusNet to replace the older gas mains with new yellow plastic pipe.

In 2007 the ESV made a draft regulatory determination on the length and cost of pipe to be replaced by each of the three distributors over the period 2008 – 2012.[40] The table below summarises the length of low pressure pipe each distributor agreed to replace and the costs of replacing the pipe.

Table D.1: Low pressure mains replacement programme, Victoria, Australia ($A 2006 prices)

	2003 - 06	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
SP AusNet							
Length (km)	253	75	90	90	90	90	90
Unit cost ($/km)	113	96	116	117	119	120	122
Total cost ($m)	28.4	7.2		10.6	10.7	10.8	11
Multinent							
Length (km)	421	117	108	111	112	112	114
Unit cost ($/km)	138	193	157	148	151	152	152
Total cost ($m)	57.9	22.6	17	16.4	16.9	17.0	17.3
Envestra							
Length (km)	118	58	90	90	90	90	90
Unit cost ($/km)	103	160	140	142	143	145	147
Total cost ($m)	12.1	9.4	12.6	12.8	12.9	13.0	12.8

Source: Essential Services Commission (2007), "Gas access arrangement review 2008 – 2012", Draft Decision.

Perhaps the most interest in the last review determination surrounds Envestra's proposals to accelerate its replacement programme. In its proposals to the Essential Services Commission Envestra intended to increase the replacement rate to an average of 137km per annum of the period 2008 – 2012 (compared to an average of around 35km over the period 2003 – 2007). This acceleration (which would be continued over future review periods) would see Envestra complete its replacement programme by 2020 as opposed to sometime in the 2040s. The main justifications for the acceleration were to:

- Reduce risks to customers by improving the condition of its network.

[40] Essential Services Commission (2007), "Gas access arrangement review 2008 – 2012", Draft Decision.

- Reduce the level of unaccounted for gas (gas leaks).
- Reduce greenhouse gas emissions.
- To meet better consumer requirements given the increasing need for low pressure mains.

In its response to Envestra's proposals the Essential Services Commission noted that Envestra had not provided "information to demonstrate that pipe replacement is a cost effective way of reducing unaccounted for gas or greenhouse gas emissions". The Commission determined that Envestra's proposals to increase the replacement rate were sensible, but that the proposed acceleration rate was too high given associated costs, as a result in the determination the Commission allowed a rate of 90km per annum (as shown in Table D.1 above) compared to the proposed 137km.

In this case it is interesting to note that although Envestra believed that a faster rate of replacement was practicable, their proposals were rejected on cost grounds. Based on the evidence of this issue that we have surveyed it is also interesting to note the limited discussion on safety concerns as the driver for the acceleration of replacement.

Mains replacement in South Australia

There is currently an ongoing debate around Envestra accelerating its rate of replacement in South Australia. For the price control period 2011 – 2016 Envestra has proposed to accelerate significantly the rate of replacement of mains to around 100km per annum, from previously realised rates of around 65km per annum (the total replacement programme over the review period was expected to cost in the region of $A 227m).

In proposing to increase the rate of replacement Envestra has been responding to the concerns posed by the Technical Regulator and the Essential Services Commission of South Australia (which regulate Envestra's gas distribution services in the State of South Australia). Both the Technical Regulator and the Commission have been concerned about the level of gas leaks in the State, as they had increased from 4.2% to 7.2% (percentage of gas leakages in the Envestra's system) over the period 2005 – 2010.

The regulators were of the view that the low the low level of replacement achieved by Envestra in the current review period has contributed to an acceleration in the rate of deterioration in the cast iron and steel mains network – which explains the high levels of gas leaks in the State. The Commission's determination explicitly states that "Envestra would be required to do all that a gas distribution business in the circumstances could reasonably do"…. "Envestra could be require to go to considerable lengths to overcome problems in implementation, including the spending of substantial amounts of money and /or management time".

In addition to allowing Envestra to increase the rate of mains replacement, the regulators also implemented a target for the level of gas leaks – set at 4% by 2016. This is perhaps the most interesting feature of the recent price control review, as the regulators rejected the idea of introducing a direct target for the replacement rate in favour of a target for reducing gas leaks. In this way they may have given Envesta a direct incentive to address the problem of gas leaks, rather than focusing on the replacement programme.

It is also worth noting that as part of the discussion around increasing the replacement rate in South Australia the Energy Consumers Coalition of South Australia were strongly opposed to the proposals. In a submission to the regulators they stated that:

- The Envestra had quoted expected asset lives of 85 years (in documentation from 1999) for its cast iron pipes, yet were being replaced significantly earlier than would be expected based on this life duration.
- The replacement programme had been ongoing for a number of years but had yet to achieve many of the benefits that had originally justified its inception – in particular any reduction in the level of gas leaks.
- In particular the Consumer group were keen that any increase in the replacement programme should be linked to a reduction in gas leaks which should be of a level large enough to compensate for the increase in expenditure on the replacement programme.

Implications for IMRP

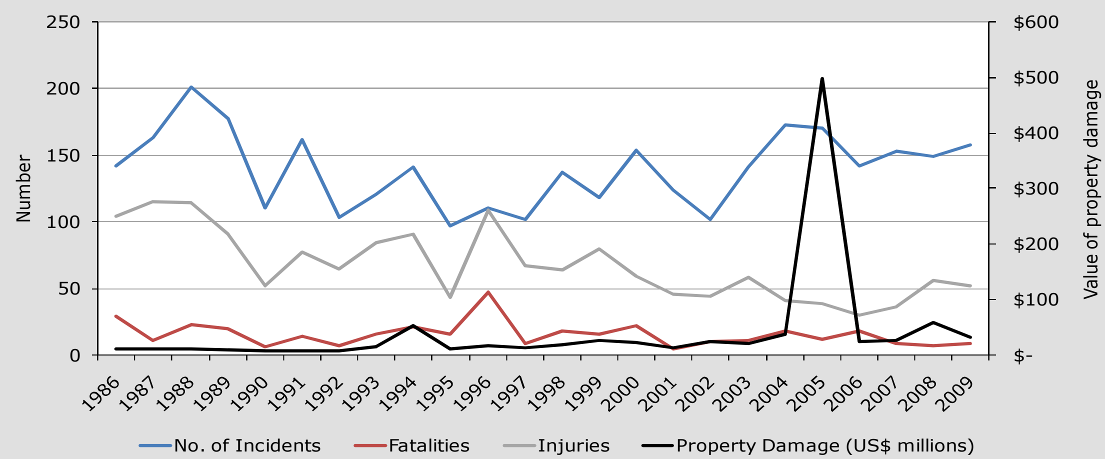
Both the Victoria and South Australian mains replacement programme is of a much lower scale than the IMRP, thus it is difficult to make direct comparisons with the IMRP. However, it is interesting to note some of the discussions around the potential acceleration of Envestra's replacement programme in both regions. In particular:

- The focus in South Australia on setting a target for a reduction in gas leaks, rather than a target for the level of mains replaced.
- The relative lack of focus on safety concerns, particularly in Victoria (when compared to the UK) – though this may be because Australia does not have the same history of experiencing fatalities related to gas pipe explosions as the UK.
- The fact that Envestra's planned replacement programme in Victoria was scaled back because of concerns about the cost of their proposed programme.
- The potential contradiction in the decisions made by regulators in the two different regions: in Victoria the regulator was concerned about the lack of information to provide the evidence that replacement was the most cost effective way to reduce leaks; while in South Australia the regulators effectively required Envestra to increase its rate of replacement, with the primary objective of reducing the level of leaks.

Box D.4: Cast iron mains replacement programmes in the US

The issue of pipeline safety is an important one in the US given that there is approx 2m km of gas distribution pipelines in place and over 65 million gas customers. According to information published by the Pipeline and Hazardous Materials Safety Materials agency (PHMSA) there remains a significant problem with incidents related to the existing gas network in the USA. [41] Figure D.2 below illustrates the number of incidents, fatalities, injuries and the amount of building damage that has occurred in the USA in the period 1986 – 2009. Overall throughout the period there have been some **374 fatalities and over 1,500 injuries related to gas distribution incidents, in addition total building damage attributed to incidents totals over $950m ($2009 prices) in the same period**. It is also interesting to note that while there may have been a slight downward trend in the number of injuries and fatalities since the 1990s, the number of incidents has generally risen since the early 2000s.

Figure D.2: Gas Distribution System Operators Incident Summary Statistics by Year 1/1/1986 - 12/31/2009



Source: U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration[42]

[41] The PHMSA is the agency with overall responsibility for regulating the distribution of gas in the US, and is supported by the State level Pipeline Safety Agencies

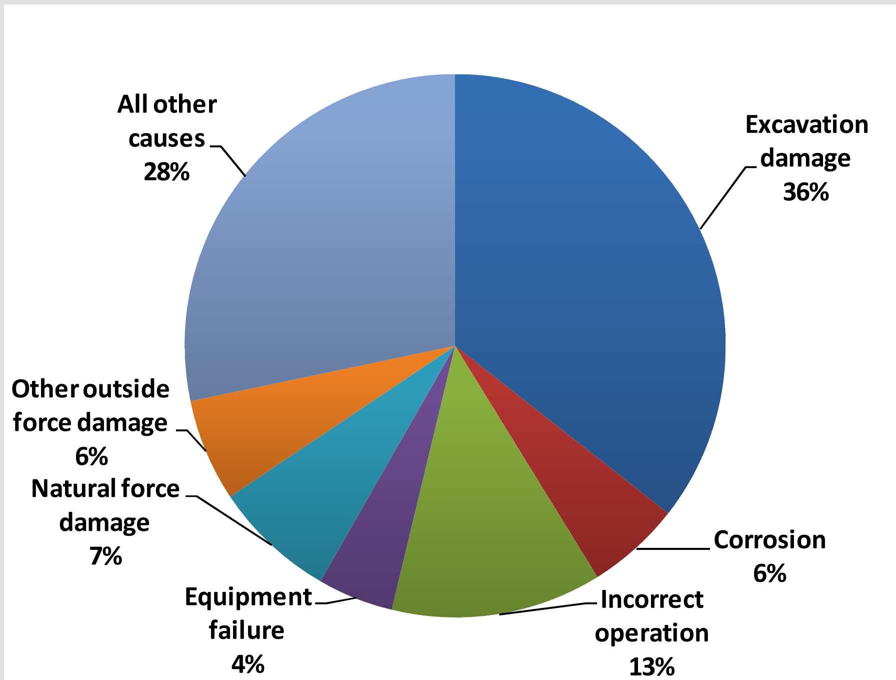
[42] Source: PHMSA website (http://www.phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=04bb52edc3c3e110VgnVCM1000001ecb7898RCRD&vgnextchannel=3b6c03347e4d8210VgnVCM1000001ecb7898RCRD&vgnextfmt=print)

Research into the causes of Gas Distribution Incidents

The PHMSA (primarily through its Office of Pipeline Safety) and other relevant stakeholders has carried out research to identify the causes of incidents in the US. In interpreting the results it should be noted that the majority of the distribution network is either steel or plastic, only around 4% is cast iron mains.

Figure D.3 below identifies the recorded causes of gas incidents in the USA between 1988 – 2009 as published on the PHMSA website.[43] The figure shows that the excavation damage was the largest single cause of the incidents – it is interesting to note that only 6% of incidents were recorded to have been caused by corrosion.

Figure D.3: Recorded causes of gas distribution incidents



Source: PHMSA website

Mains replacement programmes

Given the evidence on the number of incidents caused by factors such as excavation, other outside forces, and natural force damage efforts to reduce the number of incidents have naturally focused on addressing these issues. A number of programmes have focused on improving the safety related to excavations and other associated activities.

The iron mains replacement programme has represented a much smaller proportion of activities related to reducing gas pipe incidents in the US; iron replacement it is not required by US Federal law. Despite this many gas distribution companies have replacement programmes in place to remove their remaining cast iron and bare steel pipes.

The companies have targeted these pipes to reduce the risk of incidents caused by corrosion. According to the 2005 Safety Performance and Integrity of the Natural Gas Distribution Infrastructure report, out of a survey of 23 companies 15 of gas distribution companies have replacement programmes in place, of which 9 of the companies have formal written replacement programmes agreed with their State Regulator.[44]

Examples of replacement programmes are as follows:

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[43] Source: PHMSA website http://primis.phmsa.dot.gov/comm/reports/safety/SerPSIDet_1990_2009_US.html?nocache=1355#_ngdistrib

[44] American Gas Foundation (2005), Safety Performance and Integrity of the Natural Gas Distribution Infrastructure.

- Cinenergy, which distributes gas to over half a million customers in Ohio, USA, has a replacement programme in place to replace over 1,500km of iron and bare steel pipes over a 90 year period.
- Enbridge is a distribution company that operates in parts of New York and Canada, implemented an accelerated replacement programme to remove 635km of cast iron mains in 3 years (the status quo would have seen the mains replaced in 8 years) between 2005 – 2008 at an estimated cost of $249m.

Implications for the IMRP

It is important to note that the vast majority of gas pipes in the US are made of steel or plastic. As a result the risk profile of pipes in the US is different to the UK. Perhaps the most interesting point to note is the way that the PHMSA keeps a transparent record of the causes of gas distribution incidents, which naturally leads to an appropriate focus of safety related activity on the most significant causes of incidents.

Box D.5: Department for Transport Guidance on the value of a life

The Transport Analysis Guidance Unit at the Department for Transport (DfT) provides estimates of the "benefits to society arising from prevention of road accidents and casualties." These values are used to aid appraisals of transport interventions against the Government's "sub-objective" to reduce transport accidents. Their valuation has been derived for the specific case of road schemes, but their valuation has been used as a benchmark valuation in a number of policy contexts.

The DfT valuations cover both injuries and fatalities, where fatalities are defined as "any death that occurs within 30 days from causes arising out of the accident." The valuations published in draft guidance in January 2010 are summarised in Table D.2 below.

Table D.2: Average value of prevention per casualty by severity and element of cost (June 2008 prices)[45]

Injury severity	Lost output	Human costs	Medical and ambulance	Total
Fatal	£578,840	£1,103,980	£990	£1,683,810
Serious	£22,300	£153,400	£13,510	£189,200
Slight	£2,360	£11,230	£1,000	£14,590
Average, all casualties	£10,940	£39,270	£2,410	£52,620

This analysis provides an average value of prevention per statistical fatality of £1.68m (June 2008 prices)

The three components:

- lost output – present value of expected lost earnings and non-wage payments – representing the lost consumption of goods and services
- human costs – based on willingness to pay estimates of the pain, grief and suffering; and the "intrinsic loss of enjoyment of life, excepting consumption of goods and services" in the case of fatalities; and
- medical and ambulance – costs of medical treatment

The basis for the human costs is based on a 1997 article in *Road Accidents Great Britain* which used a "stated preference method to estimate the values for the prevention of road casualties." The study found a value in the range of £750,000 to £1,250,000 (1997 prices) would be acceptable as the cost of preventing a fatality. The mid-point of this range was used by DfT to start this index, a change from the previous value used, originally set in 1988 as £500,000 (1987 prices). This 1997 value has been "up-rated"

[45] DfT (2010) "The Accidents Sub-Objective - TAG Unit 3.4.1 - IN DRAFT" Transport Analysis Guidance (http://www.dft.gov.uk/webtag/documents/expert/pdf/unit3.4.1d.pdf)

by growth in nominal GDP growth per capita.

The DfT valuation is used by the Office for Rail Regulation for rail CBAs. DfT also recommend their numbers to be used for Air Transport and Maritime situations, but with adjustments for lost output and medical and ambulance costs.

Annex E: CBA Approach, Methodology and Assumptions

E.1: Introduction

This annex details the approach, methodology and assumptions used to develop our analysis of the costs and benefits associated with the counterfactual and the different options considered for reforming the IMRP.

As noted in the main text there is significant uncertainty surrounding the analysis, as such we would welcome additional detail to support the assumptions used where better information is available.

E.2 Methodology & approach to the CBA

Our CBA is based around an economic model, which can be used to build up an assessment of the costs and benefits associated with the following options:

- The counterfactual - The IMRP in its current form.
- Option A – Increasing the replacement rate.
- Option B – Decreasing the replacement rate.
- Option C – Focusing replacement on small diameter mains.
- Option D – Targeting replacement activity.

For each of these options we have sought to quantify the associated costs and benefits. For the purposes of the analysis the relevant costs and benefits have been categorised as follows:

Table E.1: Costs and benefits associated with mains and services replacement

Category	Costs & benefits
Direct costs	The costs of iron mains and services replacement, and the associated overhead costs.
Indirect costs	The wider traffic and disruption costs associated with a given level of mains and services replacement. For the purposes of this review we have assumed that these costs are represented by the Traffic Management Act costs that are included in the direct costs of the programme. This may understate the social disruption costs caused by mains and services replacement.
Health & safety benefits	The estimated number of incidents and therefore fatalities, injuries and building damage attributable to the iron mains and services in the 30:30 programme
Network efficiency benefits	The following benefits from the replacement of iron mains and steel services with PE mains and services: • Repair costs gas mains • Emergency response costs • Private shrinkage
Environmental benefits	The environmental shrinkage costs caused by leakage from the iron

Category	Costs & benefits
	mains and services in the 30:30 programme

To quantify each of the costs and benefits included in the above table we have sought to identify and estimate of the rate per Km for iron mains and services and where relevant the comparable rate per Km for PE mains and services e.g. we have sought to estimate the number of repairs per Km of iron mains and the number of repairs per Km of PE mains. That information combined with information on the unit cost of repairs of the two types of material will enable an estimate of the marginal benefit (in terms of reduced repair costs) of replacing 1 Km of iron mains with 1Km of PE mains.

This analysis has inevitably required the use of a number of assumptions (described in Table E.3), which can be updated given improved access to information.

The number of assumptions required to complete the CBA introduces uncertainty into the process. To manage this uncertainty we have developed flexibility into the economic model that we have used to carry out the analysis. In the model the key underlying variables can be varied and the impact on the overall costs and benefits identified for each of the different options. The key variables that are subject to uncertainty are as follows:

- **The underlying deterioration rate of the network** (defined for modelling purposes as changes in the rate of occurrence of failure per Km of iron mains or unit of services). We have applied the deterioration rate in the same way to the rate of occurrence of repairs, PREs and shrinkage in the model. The model is designed to enable the deterioration rate to be varied between 1 – 20% per annum
- **The unit price of private shrinkage** (price per MWh of shrinkage). The unit price of shrinkage used in the analysis is based on the DECC central assumption.[46] The model can illustrate the impact of using the DECC low and high assumptions and the assumptions used in the Frontier report and the WWU analysis.
- **The unit price of environmental shrinkage** (the non-traded price of carbon). The unit price of non-traded carbon used in the analysis is based on the DECC central assumption. The model can illustrate the impact of using the DECC high and low assumptions.
- **The real price effects** (above economy wide inflation). The real price effect assumed in the model is 1.1%. The model can illustrate the impact of using a range of 0 - 3%.

In addition to this we can illustrate the impact of varying the time period for completing mains replacement over the period 2020 – 2040.

E.3: Assumptions

In this section we detail the assumptions used in the analysis.

Table E.2 details the key underlying assumptions of model.

[46] See DECC website for additional information

Table E.2: Key underlying modelling assumptions

Key parameter	Assumption	Source / comments
Size of 'at risk' iron mains population as of end 2009	88,394Km	GDNs' responses to Annex D
Size of 'at risk' iron mains population ≤8" as of end 2009	72,620Km	GDNs' responses to Annex D
Size of 'at risk' iron mains population < 18" as of end 2009	86,526Km	GDNs' responses to Annex D
Number of 'at risk' services associated with the 30:30 programme	5,500,000	High-level internal assumption based on information provided by National Grid and Wales & West
Diameter / material / pressure profile of iron mains as of end 2009	Derived from GDN responses	GDNs' responses to Annex D
Discount rate	3.5%	HM Treasury Green Book
Discount rate for health and safety benefits	1.5%	HSE discount rate
Real price effects	1.1%	DPCR5 assumption

The following table provides details on the assumptions used to model the costs and benefits included in the CBA model that we have developed.

Table E.3: Costs and benefits associated with the IMRP (all in 2009/10 prices)

Costs	**Monetary cost**	**Source**	**Comments**
Direct costs			
Unit costs of mains and services replacement	£ average costs per Km of mains replaced for different mains diameters and £ replacement costs for steel services within the 30:30 programme	GDPCR assumptions and GDN response to Annex C	We have cross-checked GDPCR assumptions with the unit costs implied by the GDNs' responses to Annex C. Their unit cost data presented in the GDN responses seem significantly higher than the GDPCR assumptions. For service replacement costs we have developed an estimate based on the financial information provided by the GDNs in response to Annex C
Overheads associated with mains and services	5% of mains and services replacement costs	GDN response to Annex C	Assumption based on historical cost evidence sourced from Can update assumption when in receipt of additional information from the GDNs
Indirect costs			
Traffic / disruption costs	£ per Km of mains replaced	GDN response to Annex C	Our model assumes that these costs are captured in the Traffic Management Act (TMA) costs, which are included in GDN unit costs. It is not clear that these costs represent in full the social costs associated with traffic / disruption caused by mains replacement. This is an area that could be taken forwards in the next phase of the analysis
Benefits	**Monetary benefit**	**Source**	
Health & safety benefits			
No. of incidents associated with mains and services	N/A	HSE Incident records 1990 - 2010	We develop a high-level estimate of the overall risk of incidents posed by the iron mains network based on historical evidence of number of incidents per annum attributable to iron mains. In period 1990 – 2010 there have been around 3.2 incidents per annum. For the purposes of the analysis <u>we have assumed 5 incidents</u> per annum for iron mains at end 2009. We also carried out an analysis of the historical incident rate for steel services. Over the last twenty years there have been over 1 incident every two years. For the purposes of the analysis <u>we have assumed 2 incidents</u> per annum for steel services within the 30:30 programme at end 2009. The model also makes the simplifying assumption that the risk of incidents are distributed equally across all the iron mains and services.
Reduction in	£1.6m per life	HSE	We have analysed historic information to estimate

the no. of fatalities caused by incidents	saved	reference value and HSE Incident records 1990 - 2010	the number of fatalities per incident. Based on historical evidence there have been around 1 fatality for every 4 incidents. For the purposes of the analysis we <u>have assumed 1 fatality for every 2 incidents</u>
Reduction in the number of injuries caused by incidents	£185k per injury averted	HSE reference value and HSE Incident records 1995 - 2010	We have analysed historic information to estimate the number of fatalities per incident. Based on historical evidence there have been slightly over 1 injury associated with every incident (this includes both serious and minor injuries). For the purposes of the analysis we <u>have assumed 2 injuries for every incident</u>
Reduction in the number of buildings damaged	£226k per building damage averted	Department of Local Government and Communities and HSE Incident records 1995 - 2010	We have analysed historic information to estimate the number of fatalities per incident. Based on historical evidence there has been less than 1 building damaged per incident For the purposes of the analysis we <u>have assumed 1 building damaged for every incident</u>
Network efficiency benefits			
Private cost of MWh of shrinkage	£21.28 per MWh in 2011 and £26.21 in 2030 saved per MWh of averted shrinkage by replacement of iron mains with PE	DECC central assumption	We have built variant assumptions into the model for this variable (including the DECC low and high assumptions, and the assumptions used in both the Frontier analysis and in the WWU analysis).
Shrinkage rates for iron mains, services and PE		GDN's National Leakage Assessment models	Shrinkage rates are given by material and diameter which enables, an estimate of the marginal reduction in shrinkage through replacing 1Km of iron mains with PE and of the marginal reduction in shrinkage through the replacement of a steel service with a PE service. At the time of completing the analysis we did not have sight of WWU's model so had to make an assessment of the leakage rates on the WWU network based on the other GDN's information
Reduced repair costs for mains and services	Approx £670 saved per Km of iron mains replaced with PE	GDN response to Annex C and PB (2007) Gas distribution price control five year control	Our estimate of repair cost savings per Km of mains replacement is based on estimating the rate of repairs per Km of iron mains and the rate of repairs per Km of PE. For a given unit cost of repairs we can estimate the marginal cost savings derived per Km of mains replacement. We have included a similar analysis for services, but do not have any information available to estimate

		analysis of opex costs	the repair rate for PE services.
Reduction in Emergency response costs	Approx £ saved per Km of iron mains replaced with PE	GDN response to Annex C and PB (2007) Gas distribution price control five year control analysis of opex costs	Our estimate of the emergency response costs is based on estimating the rate of external Public Reported Escapes (PRE) per Km of iron mains and per Km of PE. For a given unit cost of a PRE we estimate the marginal cost savings derived from mains replacement. We have included a similar analysis for services, but do not have any information available to estimate the emergency repairs per unit of PE services.
Environmental benefits			
Environmental Shrinkage	£53.01 per tCO2e saved in 2010 and £70.68 in 2030.	DECC non traded carbon price	We have built the DECC low and high assumptions for the price of non-traded carbon into the model to illustrate the sensitivity of the results to the assumption
Shrinkage rates for iron mains, services and PE		National Leakage Assessment model	Shrinkage rates are given by material and diameter which enables, an estimate of the marginal reduction in shrinkage through replacing 1Km of iron mains with PE and of the marginal reduction in shrinkage through the replacement of a steel service with a PE service. Shrinkage rates are given by material and diameter which enables, for instance, an estimate of the marginal reduction in shrinkage through replacing 1Km of iron mains with PE and through replacing a steel service with a PE service

E.4: Additional results

In the following tables we present additional detail on the results of the analysis presented in Section 6.

- Tables E.4 to E.6 present the results of the CBA for the counterfactual against the 'notional do nothing' case for each of the three different deterioration rate assumptions.
- Tables E.7 to E.9 present the results of the CBA for the counterfactual against Option A for each of the three different deterioration rate assumptions.
- Tables E.10 to E.12 present the results of the CBA for the counterfactual against Option B for each of the three different deterioration rate assumptions.
- Tables E.13 to E.15 present the results of the CBA for the counterfactual against Option C for each of the three different deterioration rate assumptions.
- Tables E.16 to E.18 present the results of the CBA for the counterfactual against Option D for each of the three different deterioration rate assumptions.

- Tables E.19 to E.21 present the results of the CBA for the counterfactual against Option E for each of the three different deterioration rate assumptions.

Table E.4: NPV of IMRP in its current form (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Costs																								
Cost savings	661	646	631	616	602	588	574	561	548	535	523	511	499	487	476	465	454	444	433	423	414	404	395	**11,891**
Lost benefit																								
Health & safety	0	1	1	2	2	2	3	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7	**95**
Network efficiency	6	11	16	21	26	30	34	38	42	46	49	52	55	58	61	63	66	68	70	72	74	75	77	**1109**
Environment	5	10	15	20	25	29	33	37	41	45	48	52	55	58	61	64	67	69	72	74	76	84	92	**1133**
Net cost savings																								
Net cost savings	**650**	**624**	**598**	**574**	**550**	**527**	**504**	**483**	**462**	**441**	**422**	**403**	**384**	**366**	**349**	**332**	**316**	**301**	**286**	**271**	**257**	**238**	**219**	9,554

Table E.5 : NPV of IMRP in its current form (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Costs																								
Cost savings	661	646	631	616	602	588	574	561	548	535	523	511	499	487	476	465	454	444	433	423	414	404	395	**11,891**
Lost benefit																								
Health & safety	0	1	1	2	2	2	3	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7	**95**
Network efficiency	6	11	17	24	30	37	45	53	61	69	78	88	97	108	118	130	141	154	166	180	194	207	222	**2235**
Environment	5	11	17	23	30	37	45	53	61	70	79	89	100	111	123	135	148	162	176	190	206	239	276	**2387**
Net benefit / (cost)																								
Net benefit / (cost)	**650**	**623**	**595**	**568**	**540**	**511**	**482**	**453**	**423**	**392**	**361**	**329**	**297**	**264**	**230**	**195**	**159**	**123**	**85**	**47**	**7**	**(50)**	**(110)**	**7,174**

Table E.6: NPV of IMRP in its current form (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Costs																								
Cost savings	661	646	631	616	602	588	574	561	548	535	523	511	499	487	476	465	454	444	433	423	414	404	395	**11,891**
Lost benefit																								
Health & safety	0	1	1	2	2	2	3	3	3	4	4	4	5	5	5	5	6	6	6	6	7	7	7	**95**
Network efficiency	6	11	18	26	36	46	58	71	86	103	122	143	166	193	222	255	291	331	376	425	480	538	603	**4605**
Environment	5	12	19	27	36	47	60	74	89	107	127	150	176	205	237	274	314	359	409	464	526	640	772	**5130**
Net benefit / (costs)																								
Net benefit / (costs)	**650**	**622**	**593**	**561**	**528**	**492**	**454**	**413**	**369**	**322**	**270**	**213**	**152**	**85**	**11**	**(69)**	**(156)**	**(252)**	**(357)**	**(472)**	**(599)**	**(781)**	**(987)**	**2061**

Table E.7: Counterfactual vs. Option A (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	Total
Costs																															
Cost savings	154	151	147	144	140	137	134	131	128	125	122	119	116	114	111	109	106	104	101	99	96	94	92	-296	-289	-282	-275	-269	-263	-257	**844**
Lost benefit																															
Health & safety	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.1	0.9	0.7	0.4	0.2	0.0	**27**
Network efficiency	1	3	4	5	6	7	8	9	10	11	11	12	13	14	14	15	15	16	16	17	17	18	18	15	12	9	7	4	2	0	**309**
Environment	1	2	4	5	6	7	8	9	10	10	11	12	13	14	14	15	16	16	17	17	18	20	22	19	17	14	11	7	4	0	**335**
Net benefit / (- costs)																															
Net benefit / (- costs)	152	146	140	134	128	123	118	113	108	103	98	94	90	85	81	78	74	70	67	63	60	55	51	-331	-318	-306	-294	-281	-269	-257	**174**

Table E.8 Counterfactual vs. Option A (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	Total
Costs																															
Cost saving	154	151	147	144	140	137	134	131	128	125	122	119	116	114	111	109	106	104	101	99	96	94	92	-296	-289	-282	-275	-269	-263	-257	**844**
Lost benefit																															
Health & safety	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.1	0.9	0.7	0.4	0.2	0.0	**27**
Network efficiency	1	3	4	6	7	9	10	12	14	16	18	20	23	25	28	30	33	36	39	42	45	48	52	45	39	32	24	17	8	0	**686**
Environment	1	3	4	5	7	9	10	12	14	16	19	21	23	26	29	32	35	38	41	44	48	56	64	60	55	47	38	28	15	0	**800**
Net benefit / (- costs)																															
Net benefit / (- costs)	152	145	139	132	126	119	112	106	99	92	84	77	69	62	54	45	37	29	20	11	2	-12	-26	-403	-383	-362	-339	-314	-286	-257	**-669**

Table E.9 Counterfactual vs. Option A (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	Total
Cost savings																															
Cost savings	154	151	147	144	140	137	134	131	128	125	122	119	116	114	111	109	106	104	101	99	96	94	92	-296	-289	-282	-275	-269	-263	-257	**844**
Lost benefit																															
Health & safety	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.4	1.1	0.9	0.7	0.4	0.2	0.0	**27**
Network efficiency	1	3	4	6	8	11	13	17	20	24	28	33	39	45	52	59	68	77	88	99	112	126	141	129	115	99	79	57	30	0	**1583**
Environment	1	3	4	6	9	11	14	17	21	25	30	35	41	48	55	64	73	84	95	108	123	149	180	177	168	153	130	97	55	0	**1976**
Net benefit / (- costs)																															
Net benefit / (- costs)	152	145	138	131	123	115	106	96	86	75	63	50	35	20	3	-16	-36	-59	-83	-110	-140	-182	-230	-603	-573	-534	-485	-423	-348	-257	**-2,742**

Table E.10: Counterfactual vs. Option B (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Increased costs																								
Increased costs	289	283	276	270	263	257	251	245	240	234	229	223	218	213	208	203	-454	-444	-433	-423	-414	-404	-395	**937**
Increased benefits																								
Health & safety	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	0	0	0	0	0	0	0	**22**
Network efficiency	2	5	7	9	11	13	15	17	18	20	21	23	24	25	27	28	0	0	0	0	0	0	0	**266**
Environment	2	5	7	9	11	13	14	16	18	20	21	23	24	25	27	28	0	0	0	0	0	0	0	**262**
Net cost / (benefit)																								
Net cost / (benefit)	284	273	262	251	240	230	221	211	202	193	185	176	168	160	153	145	-454	-444	-433	-423	-414	-404	-395	**388**

Table E.11: Counterfactual vs. Option B (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Increased costs																								
Costs	289	283	276	270	263	257	251	245	240	234	229	223	218	213	208	203	-454	-444	-433	-423	-414	-404	-395	**937**
Increased benefits																								
Health & safety	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	0	0	0	0	0	0	0	**22**
Network efficiency	2	5	8	10	13	16	20	23	27	30	34	38	43	47	52	57	0	0	0	0	0	0	0	**425**
Environment	2	5	7	10	13	16	20	23	27	31	35	39	44	49	54	59	0	0	0	0	0	0	0	**434**
Net cost / (benefit)																								
Net cost / (benefit)	284	272	260	248	236	224	211	198	185	172	158	144	130	115	100	85	-454	-444	-433	-423	-414	-404	-395	**57**

Table E.12: Counterfactual vs. Option B (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Increased costs																								
Costs	289	283	276	270	263	257	251	245	240	234	229	223	218	213	208	203	-454	-444	-433	-423	-414	-404	-395	**937**
Increased benefits																								
Health & safety	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	0	0	0	0	0	0	0	**22**
Network efficiency	2	5	8	12	16	20	25	31	38	45	53	62	73	84	97	111	0	0	0	0	0	0	0	**683**
Environment	2	5	8	12	16	21	26	32	39	47	56	66	77	90	104	120	0	0	0	0	0	0	0	**720**
Net cost / (benefit)																								
Net cost / (benefit)	284	272	259	246	231	215	199	181	162	141	118	93	66	37	5	-30	-454	-444	-433	-423	-414	-404	-395	**-488**

Table E.13: Counterfactual vs. Option C (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	264	258	252	246	240	235	229	224	219	214	209	204	199	195	190	186	181	177	173	169	165	161	158	**4,748**
Lost benefit																								
Health & safety	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**
Network efficiency	1	2	3	4	5	6	7	8	9	9	10	11	11	12	12	13	13	14	14	15	15	15	15	**225**
Environment	1	3	4	5	6	7	8	9	10	11	12	13	14	15	15	16	17	17	18	19	19	21	23	**286**
Net cost																								
Net costs/ (-) benefits	261	253	244	236	229	221	213	206	199	192	186	179	173	167	161	156	150	145	140	135	130	123	117	**4,218**

Table E.14: Counterfactual vs. Option C (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Cost savings																								
Costs	264	258	252	246	240	235	229	224	219	214	209	204	199	195	190	186	181	177	173	169	165	161	158	**4,748**
Lost benefit																								
Health & safety	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**
Network efficiency	1	2	4	5	6	8	9	11	12	14	16	18	20	22	24	26	29	31	34	36	39	42	45	**454**
Environment	1	3	4	6	8	9	11	13	15	18	20	23	25	28	31	34	37	41	44	48	52	60	69	**600**
Net cost																								
Net costs/ (-) benefits	261	253	244	235	226	217	208	199	190	181	172	163	153	144	134	124	114	104	94	84	73	58	42	**3676**

Table E.15: Counterfactual vs. Option C (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Cost savings																								
Costs	264	258	252	246	240	235	229	224	219	214	209	204	199	195	190	186	181	177	173	169	165	161	158	**4,748**
Lost benefit																								
Health & safety	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**
Network efficiency	1	2	4	5	7	9	12	14	18	21	25	29	34	39	45	52	59	67	76	87	98	109	122	**937**
Environment	1	3	5	7	9	12	15	18	22	27	32	38	44	51	60	69	79	90	102	116	132	160	193	**1,286**
Net cost																								
Net costs/ (-) benefits	261	252	243	234	224	213	202	190	178	165	151	136	120	103	84	64	42	19	-7	-35	-66	-110	-160	**2,506**

Table E.16: Counterfactual vs. Option D (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	**Total**
Cost savings																								
Costs	58	56	55	54	52	51	50	49	48	47	46	44	43	42	41	40	40	39	38	37	36	35	34	**1,035**
Lost benefit																								
Health & safety	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Network efficiency	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	**31**
Environment	0	0	1	1	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3	3	3	4	4	**49**
Net cost																								
Net costs/ (-) benefits	57	55	54	52	51	49	48	46	45	43	42	41	39	38	37	36	35	34	33	31	30	29	28	**952**

Table E.17: Counterfactual vs. Option D (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	58	56	55	54	52	51	50	49	48	47	46	44	43	42	41	40	40	39	38	37	36	35	34	**1,035**
Lost benefit																								
Health & safety	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Network efficiency	0	0	0	1	1	1	1	1	2	2	2	2	3	3	3	4	4	4	5	5	5	6	6	**64**
Environment	0	0	1	1	1	2	2	2	3	3	3	4	4	5	5	6	6	7	7	8	9	10	12	**102**
Net cost																								
Net costs/ (-) benefits	57	55	54	52	50	48	47	45	43	42	40	38	36	34	33	31	29	27	25	23	22	19	16	**867**

Table E.18: Counterfactual vs. Option D (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	58	56	55	54	52	51	50	49	48	47	46	44	43	42	41	40	40	39	38	37	36	35	34	**1,035**
Lost benefit																								
Health & safety	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Network efficiency	0	0	1	1	1	1	2	2	2	3	3	4	5	6	6	7	8	9	11	12	14	15	17	**132**
Environment	0	0	1	1	2	2	3	3	4	5	5	6	8	9	10	12	13	15	17	20	22	27	33	**218**
Net cost																								
Net costs/ (-) benefits	57	55	54	52	50	48	46	44	41	39	36	34	31	28	25	21	18	14	9	5	-0	-8	-16	**683**

Table E.19: Counterfactual vs. Option E (0% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	114	115	113	110	107	104	101	97	94	89	85	80	74	68	60	50	38	22	-1	-37	-100	-222	-369	**792**
Lost benefit																								
Health & safety	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	**0.2**
Network efficiency	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	**11**
Environment	1	2	2	3	4	4	4	5	5	5	6	6	6	6	6	6	6	5	5	4	4	3	2	**98**
Net cost																								
Net costs/ (-) benefits	113	114	110	107	103	100	96	92	88	84	79	74	68	61	54	44	32	16	-7	-42	-104	-226	-372	**683**

Table E.20: Counterfactual vs. Option E (5% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	114	115	113	110	107	104	101	97	94	89	85	80	74	68	60	50	38	22	-1	-37	-100	-222	-369	**792**
Lost benefit																								
Health & safety	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	**0.2**
Network efficiency	0	-0	-0	-0	-0	-0	-0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	4	**18**
Environment	1	2	3	3	4	5	6	7	8	8	9	10	11	11	12	12	12	12	12	11	10	9	5	**181**
Net cost																								
Net costs/ (-) benefits	113	114	111	107	103	99	95	90	86	81	75	70	63	56	48	37	25	8	-15	-50	-111	-233	-378	**593**

Table E.21: Counterfactual vs. Option E (10% deterioration rate) (£m 2009/10 prices)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	Total
Cost savings																								
Costs	114	115	113	110	107	104	101	97	94	89	85	80	74	68	60	50	38	22	-1	-37	-100	-222	-369	**792**
Lost benefit																								
Health & safety	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.11	**0.2**
Network efficiency	0	-1	-1	-1	-1	-1	-1	-0	-0	0	0	1	1	1	2	2	3	3	4	4	4	6	10	**35**
Environment	1	2	3	4	5	6	8	9	11	13	15	16	18	20	22	24	25	27	27	27	25	23	13	**346**
Net cost																								
Net costs/ (-) benefits	113	114	111	107	103	98	93	88	83	77	70	63	55	46	36	24	10	-8	-32	-68	-129	-251	-393	**411**

ANNEX F: AESL REPORT - HSE: 10 YEAR REVIEW OF THE IRON MAINS REPLACEMENT PROGRAMME FINAL TECHNICAL REPORT

HSE: 10 Year Review of the Iron Mains Replacement Programme

Final Technical Report

REPORT NUMBER RP3460

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APPROVED: -

EXECUTIVE SUMMARY

This study has considered the operational performance of all cast iron gas mains, using data provided by GDNs for the period 2003 to 2009. Fractures and associated GIBs continue to be dominated by small diameter pit and spun cast iron, both overall and when adjusted by km installed. Overall, when reported failures and GIBs for all mains are compared, there is no clear upward trend. However when adjusted to include events from the current mains population, rising trends are evident, mostly related to small pit and spun cast mains.

1) From incident data over the last 20 years, cast iron fractures represents the highest risk, sometimes influenced by corrosion. LP ductile iron incidents are corrosion related and pose less risk/km than pit and spun cast mains.
2) Comparison of the predicted risk of mains that have given rise to incidents shows the mains in question were often considered relatively unlikely to cause an incident. Comparison of later actual GIBs shows that high risk scores do correspond to a high number of GIBs from those mains. There is evidence that the MRPS Risk Modelling process is more reliable at predicting mains likely to causing GIBs than it is at predicting the likelihood of an incident.
3) Detailed study of sample data, for a rural and an urban area, of the relationship between ambient temperature and iron fracture suggests that, when adjusted for temperature, the fracture rate within the remaining iron mains population in rising. This relationship should be examined using a larger data set and over a longer time period, in order that any differences may be more reliably assessed and possible data issues eliminated.
4) Under current replacement criteria, not all highest risk mains are required to be replaced in the following year. However, in the following year, a disproportionate number of fractures and GIBs arise within the high risk mains not replaced. If the top 2% of high risk small cast iron mains were replaced each year, the rising trend in fractures and GIBs may be reduced.
5) There are strong economic advantages in replacing all mains within a given area at the same time and there needs to be scope to design such schemes which include lower risk mains.
6) Large diameter cast mains are deteriorating and are subject to occasional failure, and it may be considered that they need to be subject to a process of remediation or replacement. These mains are more difficult to replace than small diameters and are disproportionately more expensive. There is limited choice of suitable materials to replace the largest mains, especially 18” and above. Currently, large diameter lining repair methods with appropriate structural strength are not available, although improved systems are under development.
7) For larger diameter iron mains, especially 18 inch and above, consideration may be given to structural lining methods and their development. Until such systems are available, replacement of large diameter mains could be considered for deferment. This guidance may be reviewed should the repair systems prove unfeasible or uneconomic or the failure rates of these assets gives increased cause for concern.
8) Intermediate sizes of cast & ductile iron mains, from 8 to 18 inch, could have their risk score assessed and, if the risk is high, may be considered for replacement. If the risk is low, then a condition based remedial treatment may be considered more appropriate than replacement.
9) Steel distribution mains are not replaced under the 30:30 programme and there is evidence that failures and GIBs from steel mains assets are increasing. This degradation is considered likely to be corrosion related and to be progressive.
10) From 1990 to 2009, several incidents were related to steel services. The lack of data on services prevents identification of the services at most risk. The current service replacement level appears to be between 5% and 6% of the remaining stock, the quantity of which is itself uncertain. It has not been possible to confirm that the current replacement rate is keeping pace with their rate of degradation. Where GIBs arise from service failures, the age and condition of the service and details of its failure could be recorded.
11) Little data is available of the numbers or history of risers and laterals within medium and high rise buildings. A sample of these installations could be identified and assessed.
12) An assessment has been provided of the risks posed by LP gas holders, which concluded that most holders are above the ‘Broadly Acceptable’ level for societal risk. Estimated risks are greatly influenced by building proximity, with encroachment issues at some sites. Each holder could be treated as part of a system that included its mains supply network. Mains replacement schemes could then be put forward, where appropriate, including any associated holders existing adjacent to the location of the proposed replacement scheme.

CONTENTS

NOMENCLATURE

The following terms and names have been used throughout this report:

AESL - Advanced Engineering Solutions Limited
CEPA - Cambridge Economic Policy Associates
CI - Pit cast grey iron
DI - Ductile iron
Dia - Nominal diameter
GDN - Gas Distribution Network
GIB - A reportable Gas in Building event
IMRP - Iron Mains Replacement Programme
km - Kilometres
Large Diameter - Mains with nominal diameter > 12 inches
LP - Low Pressure (≤ 75 millibar)
MP - Medium Pressure (> 75 millibar & ≤ 2 bar)
NGG - National Grid Gas
NGN - Northern Gas Networks
PE - Polyethylene
SI - Spun cast grey iron
SGN - Scotia Gas Networks
Small Diameter - Mains with nominal diameter ≤ 12 inches
WWU - Wales and the West Utilities

1 INTRODUCTION

The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains and the consequent risk of injuries, fatalities and damage to buildings. The objective of the IMRP was to decommission all cast iron mains within 30 metres of property within 30 years - the IMRP is often termed the '30/30' programme. The IMRP accelerated the replacement of cast iron mains to a level estimated to be as *fast as practicable* at that time, given the potential risks to society and the resources required. The IMRP excluded steel mains/services from the replacement programme as potential risks from steel, at that time, were considered to be lower than risks from cast iron mains.

The Health & Safety Executive (HSE) and Office of Gas and Electricity Markets (Ofgem) have jointly commissioned an independent review to assess the progress of the IMRP to date, and evaluate potential options for the remaining 20 years of the original programme. Cambridge Economic Policy Associates (CEPA), in partnership with Advanced Engineering Solutions Ltd (AESL), has been contracted by the HSE and Ofgem to carry out this review.

Advanced Engineering Solutions Ltd has considered the overall performance of the IMRP since 2002, as evident from the assessment of operational data provided by all Gas Distribution Networks (GDNs). This technical report records the apparent performance of the IMRP, as inferred from the data study, and other perceived characteristics or observations arising from the assessment. This report is intended to inform and advise CEPA of technical issues relevant to their economic study and report "HSE/OFGEM: 10 Year Review of the Iron Mains Replacement Programme".

2 BACKGROUND TO CAST IRON PIPE IN UK

The following sections are intended to provide an introduction to the use of cast iron pipe for gas distribution mains, a basic understanding of the principal mechanisms contributing to the failure of cast iron gas mains in service and a summary of the limitations that are inherent in the use of cast iron pipes below ground in the UK.

2.1 Development of Cast Iron Pipe

Cast iron pipe was first manufactured in UK around 1660 and has been in continuous production ever since. The chemistry of grey cast iron was substantially improved by the early 19th Century and pipe was then cast in vertical sand moulds, typically within deep pits in the foundry floor - hence 'pit cast'. Thereafter, there was no major development in grey cast iron or commercial pipe casting until centrifugal casting was pioneered (USA 1914) and developed (Europe 1920's). Initially, centrifugal casting required a rotating (spinning) horizontal sand mould with an internal core and was faster and cheaper than pit casting. Within a decade, water cooled cylindrical metal moulds replaced sand moulds, giving major cost savings, faster production rates and better pipe quality. Centrifugally cast was termed 'spun cast' - hence 'spun' pipe. However, producing spun iron in metal moulds represented a major investment and many smaller manufacturers continued to produce pit cast grey iron pipe.

The next major development was spheroidal graphite iron, postulated in 1921 to replace coarse graphite flakes in grey iron with a fine graphite structure to improve its mechanical properties. However, no practical method of manufacture was found until 1943, when cast iron was developed as a wartime substitute for strategic metals then in short supply. Spheroidal graphite gave a stronger, tougher cast iron with much improved ductility. Spheroidal cast iron, soon known as 'ductile iron', was announced in USA in 1948, and first cast in UK in 1961, where the manufacture of spun iron in metal moulds had been delayed by post-war industrial issues. Many UK foundries produced pit cast grey iron pipe until they closed in the 1960's, unable to adopt both centrifugal casting and ductile iron in a shrinking market. By the mid 1960's when ductile iron became available commercially, few UK manufacturers were producing spun iron pipe (in metal moulds) in large diameter sizes.

Nominal dimensions of pit cast grey iron pipe were harmonised in the UK by the early 1900's and separate British Standards were developed for each of the main varieties of cast iron pipe. The standard wall thicknesses for pipe grades most frequently used within the UK gas industry are shown in Table 1 below.

TABLE 1 - CAST IRON PIPE - NOMINAL WALL THICKNESS

Pipe Material	Pipe Specification	Nominal Wall Thickness at Manufacture - mm			
		4 inch Pipe (100 mm)	12 inch Pipe (300 mm)	24 inch Pipe (600 mm)	48 inch Pipe (1,200 mm)
Grey Iron Pipe (Pit Cast - CI)	BS 78:1917 (imperial sizes)	14.5	20.3	28.7	40.6
Grey Iron Pipe (Spun Cast - SI)	BS 1211:1958 (imperial sizes)	10.9	15.2	21.6	N/A
	BS 4622:1971 (metric sizes)	9	13	19	N/A
Ductile Iron Pipe (Spun Cast - DI)	BS 4772:1971 (metric sizes)	6.1	7.2	9.9	15.3

From Table 1, ductile iron pipe is substantially thinner than pit or spun cast grey iron pipe of the same nominal size. The increased tensile strength of ductile iron, relative to grey iron, allowed the wall thickness to be reduced; for all varieties of cast iron, the nominal bending strength of the pipe is essentially similar for any pipe diameter.

2.2 Cast Iron Pipe Materials

2.2.1 Pit Cast Grey Iron Pipe

Pit cast grey iron is a characteristically brittle material - reasonable tensile strength but very limited elasticity; typical mechanical properties are shown in Table 2. Natural ground movement, from seasonal changes in soil temperature or moisture, can apply immense forces to a buried pipe, although the extent of overall movement is usually limited in all but landslide conditions. Typically, the ground movement will temporarily distort or deflect a section of the pipe by a few degrees from its original line, which will spring back when soil temperature/moisture returns to its earlier state. However, grey iron pipe will fracture at deflections beyond a few minutes of arc - less than 0.1 degree. Ground movement from heavy vehicles will have a similar effect on grey iron mains that are not well supported by the ground below the pipe; forces from wheel loads are less than from soil temperature/moisture change, but are repeated with each vehicle, gradually increasing the pipe deflection until it fractures.

Thus, ground movement and traffic loading are both capable of fracturing pit cast iron pipe in almost all diameters, even when newly laid. If the pipe is subject to surface or pitting corrosion in service, the wall thickness will gradually decrease, reducing the amount of ground movement or loading needed to fracture the pipe.

Vehicles have increased substantially in weight and number since grey iron pipe was introduced.

Vehicles have increased substantially in weight and number since grey iron pipe was introduced.

2.2.2 Spun Cast Grey Iron Pipe

Spun cast grey iron is essentially the same material as pit cast grey iron, only the method of casting differs; centrifugal casting gives a slightly refined microstructure - typical mechanical properties are shown in Table 2. Relative to pit cast iron pipe, spun iron pipe has a marginally higher tensile strength and slightly thinner wall, giving a similar overall strength and similarly limited elasticity. Both pit and spun cast grey iron pipe can fracture under ground movement and traffic loading, even where no significant reduction in wall thickness has occurred as a result of corrosion in service.

TABLE 2 - GREY AND DUCTILE CAST IRON - TYPICAL MECHANICAL PROPERTIES

PHYSICAL PROPERTY		GREY IRON	DUCTILE IRON
Ultimate Tensile Strength	MN/m^2	147-180	420
Yield Strength	MN/m^2	-	300
Typical Design Stress	MN/m^2	37 - 45	150
Elastic Modulus	GN/m^2	100 - 103	170
Fracture Toughness	$MNm^{-3/2}$	6 - 20	100 - 350
Density	Kg/m^3	7,200	7,050
Coefficient of Thermal Expansion	$K^{-1}x10^{-6}$	10	11.5

2.2.3 Spun Cast Ductile Iron Pipe

Ductile iron has much higher elasticity and tensile strength that any variety of grey iron - typical mechanical properties are shown in Table 2. Ductile iron is a relatively elastic material, able to withstand substantial deflections and resist all but the most extreme ground movement and surface traffic loads. Ductile iron is also a relatively strong material, with a higher tensile strength than low grades of plain carbon steel. However, the ultimate strength of ductile iron pipe is limited by its wall thickness, which is substantially less than pit or spun cast iron pipe. From Table 1, relative to ductile iron pipe, small pit cast iron pipe is more than twice as thick, increasing to almost three times thicker in larger sizes; small spun iron pipe is around 60% thicker, increasing to around twice as thick in larger sizes.

Ductile iron is still a cast iron material and its overall corrosion rate within any specific soil type is broadly similar to that of pit or spun cast iron. When buried within aggressive soils, all cast irons, including ductile iron, will corrode at an extremely rapid rate. However, the thinner wall of ductile iron pipe will ensure that, in any soil, it will suffer through wall corrosion earlier than any grey iron pipe of the same size.

2.3 Corrosion in Service Below Ground

When ferrous pipes (iron or steel) are buried within soil, various reactions are likely to occur at the interface between the pipe surface and the soil; most reactions are essentially oxidative and electrochemical in nature and the overall effect of these reactions is collectively termed ‘corrosion’ or ‘rusting’.

In general, the rate of any corrosive reaction will depend principally on the following:

1) Soil temperature
2) Amount of oxygen available
3) Inherent corrosivity of the specific soil type
4) Inherent reactivity of the specific pipe material

Overall, a wide range of complex reactions are possible.

During the 1940's/50's, extensive studies of buried pipe corrosion were undertaken in USA and UK to establish data on general corrosion rates within buried iron and steel pipes in service. From various reports of this work in USA[47] and UK[48], key findings from these studies can be summarised as:

a) Buried ferrous materials corrode, with widely varying rates of corrosion.
b) Corrosion rate is more dependent on the soil type than the pipe material.
c) Long-term corrosion rates could possibly reduce with time. Corrosion processes cause surface oxidation and form an external layer of cohesive corrosion product that could tend to inhibit further corrosion at the pipe surface, below the corrosion product. However, in general, this is less likely to occur in more corrosive soils.

Two main types of corrosion were reported by these studies;

i) General corrosion: attack occurs as surface corrosion over much of the pipe - severity is normally represented by the rate of gross weight loss/year.
ii) Pitting corrosion: attack occurs as localised outbreaks of corrosion pits at the surface - severity is normally represented by the rate of growth of the largest pits.

Best practice changed as a result of the findings of this work, with the development of modified pipe coating processes and a general recognition of the need and value of cathodic protection systems for steel pipelines.

2.3.1 Corrosion Protection

Since 1917, at the least, all cast iron pipes for service below ground had some form of external coating applied during manufacture. Early coatings were tar-based, changing to bitumen solutions during the 1940s/50's which usually gave a thinner, more brittle coating. Historically, the UK gas industry has used galvanised iron pipe at some above ground application but seldom for any buried pipeline.

In general, for older steel mains, protective coatings applied during manufacture were usually similar to those applied to cast iron pipes, although tar/bitumen coatings were typically thicker and often hessian reinforced. Galvanised pipe was seldom used in any mains applications. A thin PE sleeve applied over a bitumen coating became the minimum standard for all small diameter steel mains from the 1970's; other coatings may have used for larger steel mains, especially if cathodic protection was applied.

Typically, older steel services were often bare or finished in paint/primer only, with tar-based and bitumen coatings coming into use from around the 1950s, largely as

[47] The Corrosion Handbook edited by H H Uhlig: John Wiley & Sons

[48] Corrosion of Buried Metals Special Report No. 45 British Iron & Steel Research Association

above for steel mains. Galvanised steel services were used occasionally in some areas. A thin PE sleeve over a bitumen coating became standard for all steel services during 1970's.

In general, tar/bitumen-based coatings are likely to provide only a limited degree of corrosion protection and are known to be prone to damage during transport/storage and, especially, during pipe laying and trench reinstatement. However, where coatings have been damaged or failed in service, the small size of the coating defect often results in a more concentrated corrosive attack; the depth of corrosion pits has often been reported to exceed that measured on comparable samples of uncoated pipe. Recent PE coatings may be expected to give improved corrosion protection, although no data is available to support this theory; deep corrosion attack has been found under all PE coatings that have been subject to small areas of damage.

2.3.2 Graphitic Corrosion of Cast Iron Pipe

Corrosion of buried cast iron pipe, often termed graphitic corrosion or graphitisation, results in much of the iron effectively dissolving into the groundwater (electrolyte) around the pipe, leaving a corrosion product based on the residual graphite structure of cast iron. In grey irons, the corrosion product, termed graphitised iron, is invariably a consistent cohesive mass that adheres to the pipe surface; its consistency has been likened to hard chocolate. Samples of small diameter grey iron water mains that were fully graphitised (through wall corrosion around entire pipe diameter) have been recovered, tested and found to be leak tight at internal pressures up to several bar. In the absence of ground movement or external loading, fully graphitised iron mains, well supported by surrounding soils, have continued to provide leak-free service for long periods of time.

Ductile iron corrodes in a similar manner to grey iron, and the corrosion product is usually very similar to graphitised grey iron. However, this does not necessarily occur in every case; some weaker variants of ductile iron corrosion product have occasionally been reported.

Graphitic corrosion usually begins at a point where the pipe coating is damaged or the local environment is most highly corrosive, and then develops as a hemispherical shaped pit, gradually growing in size until it becomes through wall when the pit diameter reaches approx twice the wall thickness. Typically, several adjacent pits will form simultaneously and grow together into a single large pit of irregular shape/size.

2.3.3 Corrosion of Steel Mains

Steel pipe corrodes at broadly similar rates to cast iron pipe and protective coatings applied to steel pipe are similarly prone to damage, usually during transport, storage and pipe laying. However, steel pipe is usually substantially thinner than cast iron pipe of similar diameter, and through wall corrosion will usually occur earlier.

Steel corrosion product is significantly different to graphitised iron, the main corrosion product of corroded cast iron pipe. Steel corrosion product is not a cohesive material and it does not adhere to the pipe surface; it cannot form a protective layer around the corroded area and therefore cannot tend to prevent or minimise the extent of leakage when the corrosion becomes through wall.

2.3.4 Corrosion of Joint Bolts

In general, cast iron mains are jointed using various rigid spigot/socket joints or any of a wide range of flexible mechanical joints and couplings, occasionally by simple flanges. Some rigid, most flexible and all flanged joints contain a sealing gasket that is maintained in compression by a series of bolts/nuts around the joint circumference; bolting (bolts and/or nuts) is usually cast iron, typically of a similar grade to the pipe.

Joint bolting corrodes, usually at a similar or faster rate than the pipe itself; corrosion protection for bolting is rare. Typically, corrosion of bolting reduces the compression of the sealing gasket, most types of joint will develop some degree of leakage and the overall leakage rate is likely to increase slowly with time. However, bolting will continue to corrode and many bolts ultimately fracture, often with a rapid increase in the rate of leakage from the joint. In total, for all cast iron pipes, the number of joint leaks arising from causes other than bolt corrosion is more than twice the number of leaks arising from fractures and corrosion of the pipe barrel; the number of joint leaks arising from bolt corrosion is quite small, by comparison.

In general, LP and MP steel mains are mostly screw jointed, although various mechanical joints, couplings and simple flanges are also relatively common; welded joints are relatively rare. Most mechanical joints, couplings and flanges used to joint steel mains are as likely to corrode as their cast iron counterparts and the effects of bolt corrosion/fracture and subsequent joint leakage are broadly similar.

2.3.5 Influence of Soil Type

In theory, for any specific geographical area, reference soil data could give typical rates of general and pitting corrosion for whatever soil types are native to that area. However, most UK towns/cities grew in a series of developments where land was levelled using imported fill, typically waste materials from industrial sources. In most urban areas, consistent soil types are uncommon and entirely non-corrosive conditions are relatively rare. Traditional pipe laying practices further increased the variety of soil types in contact with pipes and altered drainage patterns below ground. Water run-off from roads, etc also often adversely affects the soil chemistry.

In UK urban areas, estimated corrosion rates for ferrous gas mains are rarely reliable, even for general surface corrosion. When pitting corrosion occurs, pit depths are likely to fit an extreme values distribution, where pit depth plotted against frequency shows many shallow pits, with an extended tail of fewer deeper pits.

2.4 Failure of Cast Iron Pipe

All pipe below ground will be subject to some combination of external loading from natural ground movement, vehicle traffic etc. Natural ground movement will vary substantially with seasonal weather conditions; vehicle loading will vary significantly, especially HGV traffic. The resulting stress/strain induced within the pipe wall can exceed the ultimate limit for cast iron pipe by a very large margin.

All pipes below ground will also be subject to some degree of corrosion, from the oxidative action of adjacent soils, and the overall pipe strength will deteriorate with time as it corrodes in service. The overall rate of corrosion for well protected pipe within benign soils may be almost zero; for poorly protected pipe within highly corrosive soils, the overall rate of corrosion will be extremely rapid.

Most pipes below ground will fail in a characteristic manner, depending on the dominant weaknesses of the pipe material. Inevitably, the combination of external loading and corrosion will result in a finite service life and eventual failure of the pipe.

2.4.1 Pit and Spun Cast Grey Iron Mains

Grey iron is not an elastic material; grey iron mains will fracture when subject to ground movement arising from normal changes in soil temperature/moisture and/or routine vehicle traffic at the surface. Pipe sizes below 10 to 12 inch diameter fracture readily; larger pipes are more likely to fracture if changes in soil temperature/moisture occur rapidly or when surface loading includes HGV traffic, or when weakened by graphitic corrosion.

For small grey iron mains (less than 10 to 12 inch diameter), the dominant failure mode is likely to be circumferential fracture in bending - the pipe essentially snaps when displaced. For larger grey iron mains, the dominant failure mode is likely to be longitudinal fracture in crushing - the circular cross-section of the pipe becomes oval and the pipe essentially collapses. In general, grey iron mains of 18 to 48 inch diameter are likely to fracture only under extremes of ground movement or surface loading unless the pipe bed has been disturbed and cannot provide adequate support or, more likely, the pipe has been substantially weakened by corrosion. In practice, large diameter grey iron mains rarely fracture in service.

Grey iron mains below ground will corrode and gradually lose strength; most mains will eventually suffer circumferential or longitudinal fracture, depending on the pipe diameter. Mains that are not subject to significant external loading from ground movement or vehicle traffic will continue to corrode; through wall corrosion will eventually occur at some point around the circumference - ultimately, through wall corrosion will develop around the full circumference. Such mains may randomly fracture or collapse at any time; however, some are known to have continued to provide leak-free service for many further years.

The following instances represent the extremes of iron pipe corrosion within the Authors' personal experience within the UK:

1) Fastest Corrosion Rate - a 10 or 12 inch diameter spun grey iron main, laid in ground contaminated with carbonaceous material (particles of coal/coke) is known to have corroded to the through wall condition within 12 months of laying.
2) Slowest Corrosion Rate - many pit and spun cast grey iron mains laid in benign (non-corrosive) ground have survived at least 150 years in service and still remain in good condition; the oldest is thought to have been laid around 1825.

2.4.2 Ductile Iron Mains

Ductile iron is a relatively elastic material; ductile iron mains are likely to have adequate flexibility to tolerate all but the most extreme ground movement and will rarely fracture in service. For all sizes of ductile iron main, the dominant failure mode is likely to be through wall corrosion - the pipe essentially suffers local fragmentation and a discrete area of the pipe wall detaches or falls away, leaving an irregular hole.

Ductile iron mains below ground will corrode and gradually lose strength; most mains will eventually suffer loss of integrity by some form of perforation. Inevitably, substantially corroded ductile pipe can fracture if subject to significant external loading or ground movement, and such failures do occasionally occur. However, these failures are essentially corrosion assisted, rather than characteristic fractures.

In general, ductile iron mains of 18 to 48 inch diameter are likely to fail only when the pipe has been substantially weakened by corrosion. In practice, large diameter ductile iron mains rarely fail in service unless buried in corrosive soils.

2.4.3 All Cast Iron Mains

From the above, pit and spun cast grey iron mains are predominantly susceptible to external loading, usually aggravated by external corrosion. Ductile iron mains are predominantly susceptible to external corrosion, often aggravated external loading. Under unusual permutations of corrosive action and external loading, both grey and ductile iron mains will occasionally fail in a non-characteristic manner.

Typically, cast iron mains below ground fail as a result of several factors combining, usually temporarily, to increase the external loading over some section of main until the pipe fails at a point where the resulting stress or strain is greatest. However, the eventual point of failure will not necessarily be where the external loading is highest or where the pipe is weakest or most corroded. In many cases, external loading and corrosion will both have been subject to a number of separate influencing factors and the location of the final failure is essentially random.

In general, the specific cause of any cast iron pipe failure will often be difficult to identify. In practice, current data records for many cast iron failures, whether fracture or corrosion, may not be adequately accurate or reliable.

2.5 Inherent Limitations of Pipe Materials

2.5.1 Grey Iron Mains

Grey iron pipe below ground is subject to ground movement, mostly from seasonal variations in soil temperature/moisture, and external loading from vehicle traffic and the natural deadweight of ground materials. However, the physical properties of grey cast iron, the parent material of all pit and spun iron pipe, are not compatible with this movement and loading, especially in small pipe sizes. Grey iron pipe below ground is also prone to corrosion, depending on the aggressive nature of the adjacent soil.

Pipe sizes below 10 to 12 inch diameter may fracture as a result of relatively minor changes in soil temperature or moisture. Pipe sizes above 10 to 12 inch diameter are likely fracture only when subject to the effects of external corrosion. Pipe sizes above around 18 inch diameter are unlikely to fail in service under all but the most extreme conditions.

2.5.2 Ductile Iron Mains

Ductile iron pipe below ground is capable of resisting most ground movement, from variations in soil temperature/moisture etc, and most traffic loading. However, the physical properties of ductile iron pipe are broadly compatible with this movement and external loading. Ductile iron pipe below ground is also prone to corrosion, depending on the aggressive nature of the adjacent soil.

Pipe sizes below around 18 inch diameter may fail when weakened by external corrosion. Larger pipe sizes are unlikely to fail in service unless subject to substantial external corrosion.

2.5.3 Overall - All Cast Iron Mains

All pit, spun and ductile iron pipe below ground will deteriorate with time as corrosion occurs. In general, the main influence on the rate of deterioration is likely to be the corrosivity of the soil around the pipe and the prevailing weather conditions.

Pit, spun and ductile cast iron pipe are legacy materials that cannot provide the same level of performance or reliability in service as current pipeline materials and cannot satisfy all detailed requirements of the Pipeline Safety Regulations:1996.

2.5.4 Steel Mains

Steel pipe below ground is capable of resisting all but the most extreme ground movement and external loading; the pipe is also prone to corrosion, depending on the aggressive nature of the adjacent soil. In general, steel pipe of all sizes is unlikely to fail in service unless subject to external corrosion. In practice, the protective coatings applied to LP and MP steel mains are prone to damage and corrosion failure in service is not uncommon.

In general, many types of joint used for steel pipe are essentially similar to those used for cast iron mains and joint leaks do occur. However, a substantial majority of small diameter steel mains are screw jointed; overall, steel pipe of all sizes are less likely to leak than cast iron mains.

2.5.5 Reference - PE Mains

PE pipe below ground is unaffected by all but the most extreme ground movement and external loading; PE is also non-corrosive and isn't affected by aggressive soils. However, PE can be subject to degradation by chemical attack; PE gas mains within land contaminated with industrial pollutants do occasionally suffer chemical attack in service, but such occurrences are thought to be quite rare.

In general, PE gas mains of all sizes/pressures are expected to provide a service life of 50 years or more. PE pipe is prone only to interference damage, usually when struck during excavation by third parties undertaking street works or other civil engineering works adjacent to the PE pipe. In practice, PE is generally considered to be the most durable pipe material, capable of satisfying all detailed requirements of the Pipeline Safety Regulations:1996 and likely to provide a long service life unaffected by the limitations of any cast iron pipe.

2.6 Replacement of Cast Iron Pipe

From 1974, the replacement of cast iron gas mains in the UK has been undertaken in accordance with a series of replacement programmes, culminating in the current 30:30 Iron Mains Replacement Programme. From 1977, following the King Inquiry 'Report of the Inquiry into Serious Gas Explosions', several successive replacement programmes concentrated on specific types of gas main and many small diameter iron mains and MP iron mains were replaced under these programmes. Later replacement programmes reassessed the remaining population of iron mains and focussed on what were considered to be the most vulnerable categories of main, representing the highest risks to society, as perceived at that time.

Today, some of the cast iron pipe categories previously considered to be the most likely to fail have been largely replaced and more data is now available from failures within the remaining mains networks. As a result, the reducing amount of cast iron mains still in service now represents a more varied range of potential risk. Evaluation of the remaining cast iron pipe categories, recognition of the most vulnerable pipes and identification of the highest likely risks to society are all now substantially more complex that at the time of earlier replacement programmes.

Other developments have also occurred during this period that may have affected some aspects relevant to the assessment and identification of the likely risk.

2.6.1 Reporting of Gas Escapes

The Gas Safety (Management) Regulations:1996 require GDNs to provide a national gas emergency telephone service (Freephone 0800 111999). Calls are assessed to identify the potential nature of the emergency and appropriate persons are instructed to attend the site. This procedure has evolved into a mature gas emergency service that is thought to process around 2 million calls/year. Over 50% of calls are deemed to represent a potential gas emergency, most of which result in emergency response to a suspected leak within or affecting a building.; attendance at the site is required within a '1 hour' response time.

The assessment of emergency telephone calls is inherently difficult and procedures must be fail-safe, to some degree. The reporting and recording of GIBs are now standardised procedures and it is very likely that all GIBs, and suspected GIBs, are reliably recorded. However, it is likely that many GIBs represent a very small quantity of gas within a building; at some suspected gas leak locations, no gas is found.

2.6.2 Incidents and Gas in Buildings

The terms incident and Gas in Building event (GIB) are both somewhat imprecise:

1) GIBs are defined as being where the concentration of a gas:air mixture within a building approaches or exceeds the explosive limits - 5 to 15% gas in air. The actual volume of gas:air mixture is seldom known and will often be too small to allow any explosion that could realistically exceed minor damage. However, volume is not the main factor - lean mixtures (~5%) have substantially greater explosive potential than rich mixtures (~15%).
2) Incidents are defined as being where the severity of injury and/or property damage exceeds defined limits. However, limits are necessarily arbitrary and are open to interpretation; some costs will be inflated for compensation and insurance claims

Most or many GIBs will have the potential to ignite, and the resulting explosion or fire may have the potential to cause injury or property damage, which will occasionally be severe. However, the blast severity will depend on the gas:air mixture concentration and volume, and the extent to which its combustion is confined i.e. strength/stiffness of building structure, size of openings (doors/windows), whether doors/windows are open/curtained etc. The gas:air concentration will depend on temperature, ventilation and draughts within the building, whether doors/windows are open etc. Ignition will depend on the transient concentration of any gas:air mixture moving near to any source of sparks or a very hot object within the building.

Overall, incidents are truly unpredictable events with many controlling factors, and should not form the basis for any risk assessment process. Taken as a whole, GIBs appear more likely to represent a realistic measure of the range of potential factors that can, in combination, result in a gas explosion or fire.

2.6.3 District Pressure

From the 1970's, the control of district gas pressures has gradually developed into sophisticated systems to reduce the real-time operating pressure to a level that is no greater than is required to maintain supply. The complex mechanical regulators and clocks of the 1970's have now been replaced with electronic units, but the main control features are unchanged. The main benefits are essentially environmental and economic, from reductions in the amount of gas lost by leakage, rather than health and safety.

In general, if the operating pressure of a gas main is higher, gas will escape at a greater rate, which could result in gas entering a building slightly earlier or at a fractionally faster rate. However, there is no clear evidence to show that MP gas mains represent a higher risk than LP mains, and minor variations in transient district pressure are therefore unlikely to be of any overall significance.

2.6.4 MRPS - Mains Risk Prioritisation System

The MRPS predicts the likelihood of failure of each individual cast iron mains unit, using a linked set of three independent models, as follows:

1) Cast Iron Mains ≤12 inch Diameter - forecasts likely fracture of pipe barrel
2) Cast Iron Mains > 12 inch Diameter - forecasts likely fracture of pipe barrel
3) Ductile Iron Mains - forecasts likely corrosion of pipe barrel in all diameters

Note: None of the above models appear to consider gas leakage from any source other than failure, by fracture or corrosion, of the pipe barrel.

3 DESCRIPTION OF DATA SUPPLIED, BY CATEGORY

In the event of any gas main failure, there are essentially three potential levels of broad consequence:

i) A release of gas requiring a mains repair only
ii) Entry of escaping gas into a building without ignition i.e. a GIB
iii) Ignition of escaping gas that has entered a building i.e. an incident

GDNs maintain extensive records for all mains failures and resulting repair activity within their network, as well as all consequential events, GIBs, incidents, etc. Much of this data is recorded in database sets maintained principally for the purposes of the IMRP and its procedures to predict potential risk levels for cast iron mains units.
Historically, in the UK, the most frequent cause of gas incidents has been fracture of small diameter pit and spun cast iron mains, primarily because fractures can release a large volume of gas and are likely to occur suddenly. Typical corrosion failures of pit/spun grey iron pipe tend to release a smaller volume of gas with a slower onset and, on a historical basis, are less likely to cause incidents. Ductile iron mains suffer various forms of corrosion failure that can, especially for MP mains, release a large volume of gas and can occur suddenly, occasionally resulting in an incident.

GIBs may occur as a result of fracture, corrosion or other, mostly joint related failures of cast iron mains. Joint failures on cast iron gave rise to one incident in the period

1990-2009 according to HSE report[49], on a 30" MP main, as a result of corroded bolts. The frequency of these "other failures" is of a similar level to the frequency of fracture; both are more frequent than corrosion, as illustrated below:

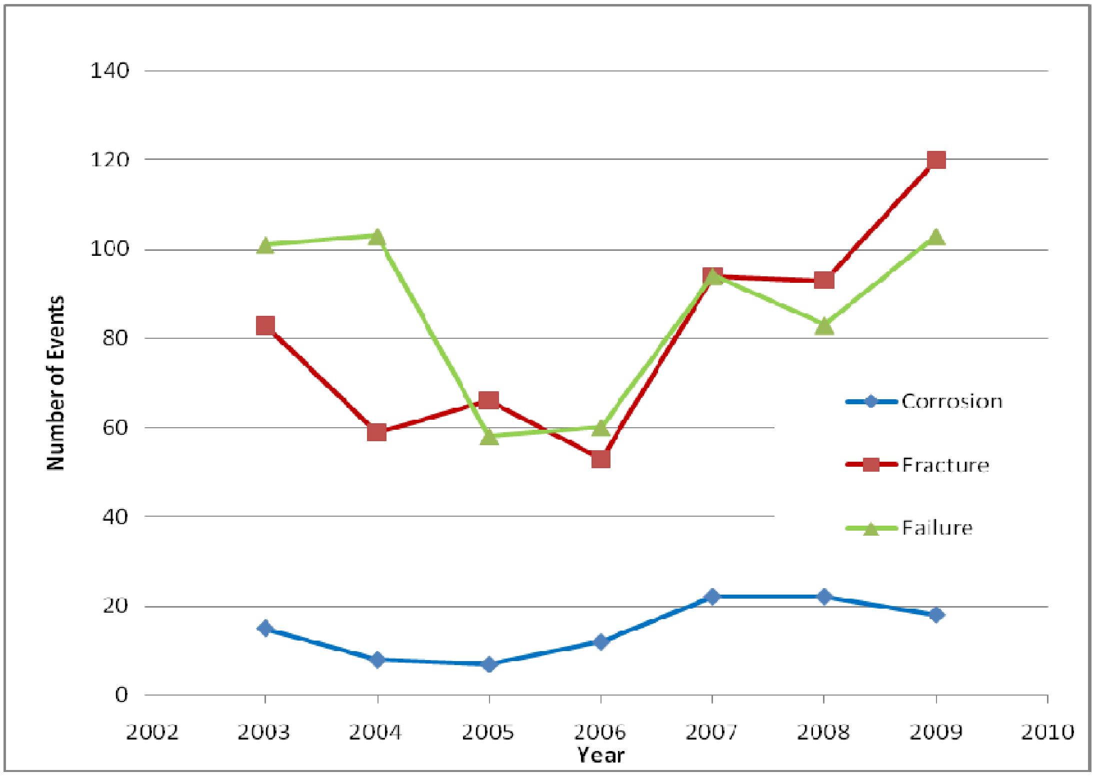

FIGURE 1 - GIBS FOR CAST IRON FROM ALL FAILURE MODES (WWU)

Failure modes that give rise to incidents are primarily concerned with fracture failures in pit and spun cast iron and corrosion failures in ductile iron; this is also evident from the HSE Summary Report[50]

Data was provided for the entire period of the analysis, in different formats and in different levels of completeness. Consequently, some analysis was possible for some groups and not for others. The maximum amount of data and most complete data sets were used wherever possible. Some data requested was stated to be unavailable and some data arrived after the completion of the analysis.

3.1 Averages of Incidents, GIBs & Failure Events - 2003-2009

In the data presented below, fracture failures for cast iron and corrosion failures for ductile iron are reported, as described in the previous section. This is because these are the mains failure events that are known, historically, to be most likely to have given rise to incidents and GIBs.

[49] HID Gas and Pipelines Unit Summary of UK Gas Distribution Mains and Service Related Incidents (1990 to present)
[50] HID Gas & Pipelines Unit Major Hazard SafetyPerformance Indicators in GB's Onshore Gas & Pipelines Industry Annual Report 2009/10

Note: Fracture failures for cast iron and corrosion failures for ductile iron are the events that form the basis for the risk prediction processes within the current Mains Replacement Prioritisation System.

3.1.1 Failure Events

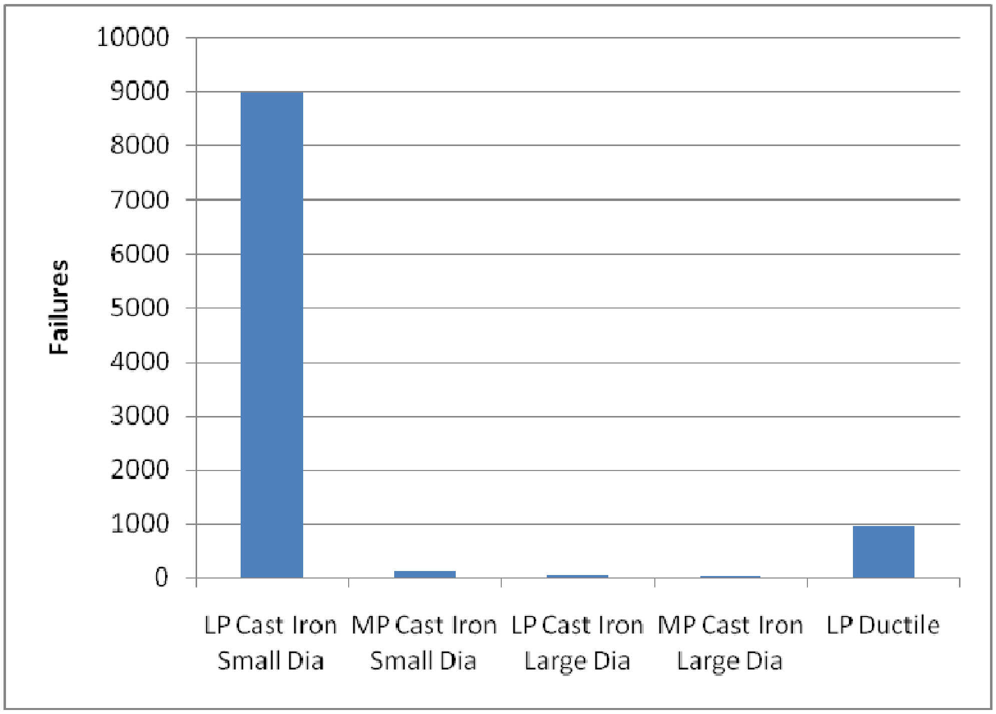

FIGURE 2 - AVERAGE ANNUAL FAILURES 2003-2009

From Figure 2, the most frequent failure events, by far, are small diameter LP cast iron fractures.

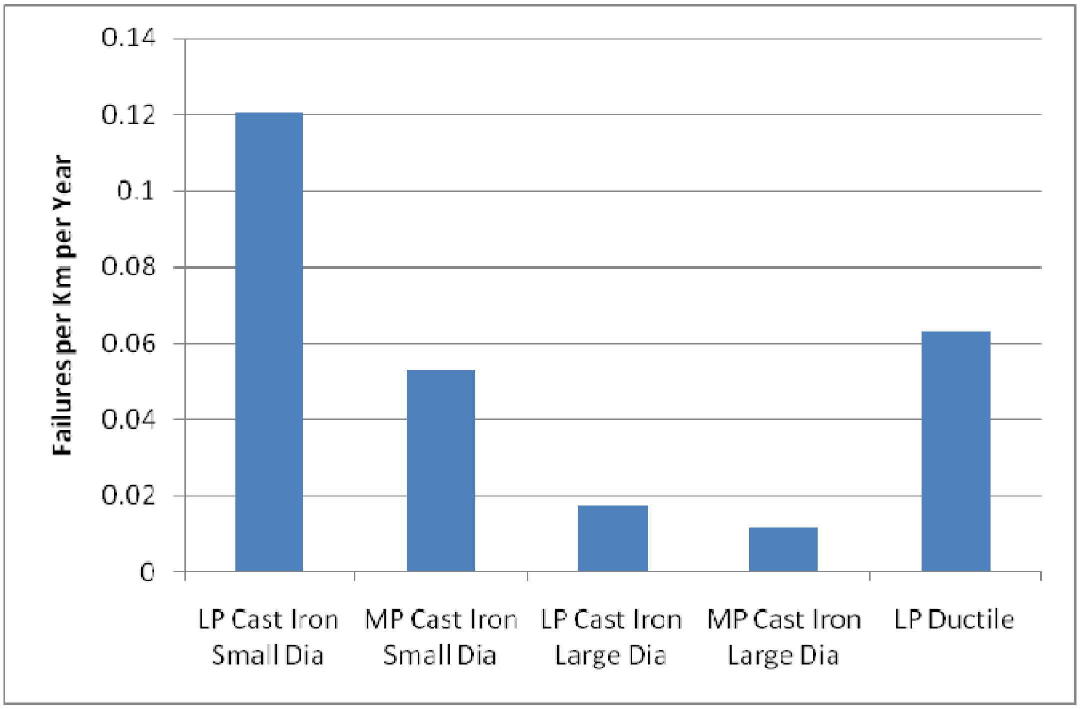

FIGURE 3 - AVERAGE FAILURE EVENT/KM/YEAR

The above data indicates that when corrected for the installed lengths LP small diameter cast iron fractures are the most frequent event.

3.1.2 Gas in Building Events

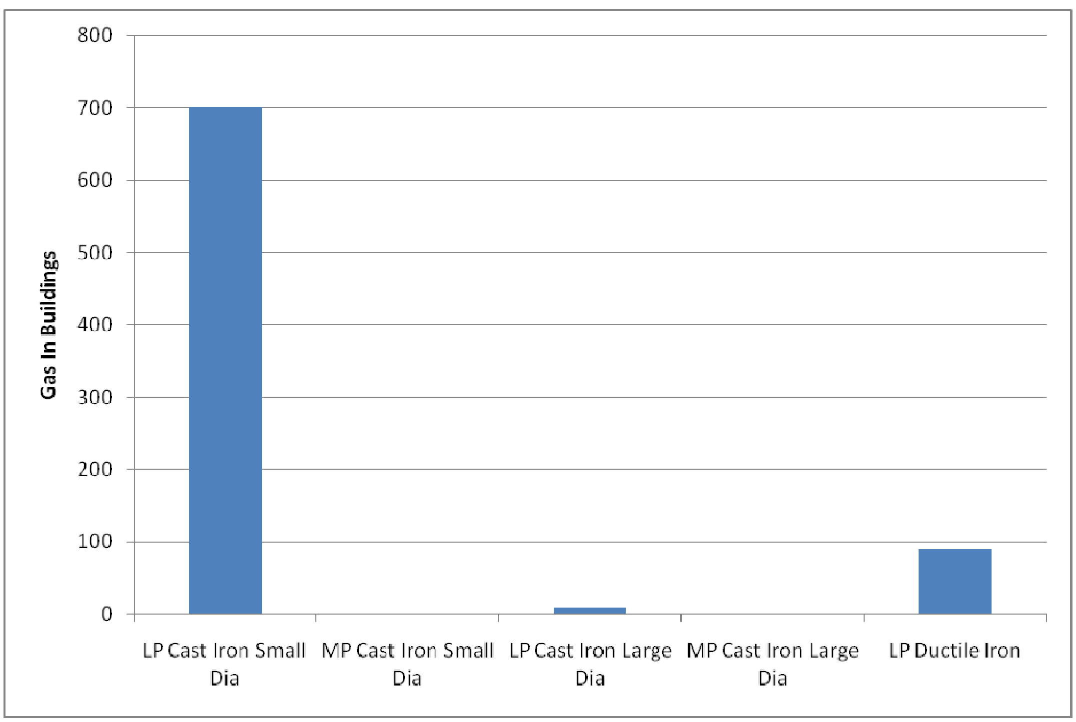

FIGURE 4 - AVERAGE ANNUAL GIBS 2003-2009

Small diameter LP cast iron and LP ductile iron give rise to most GIBs.

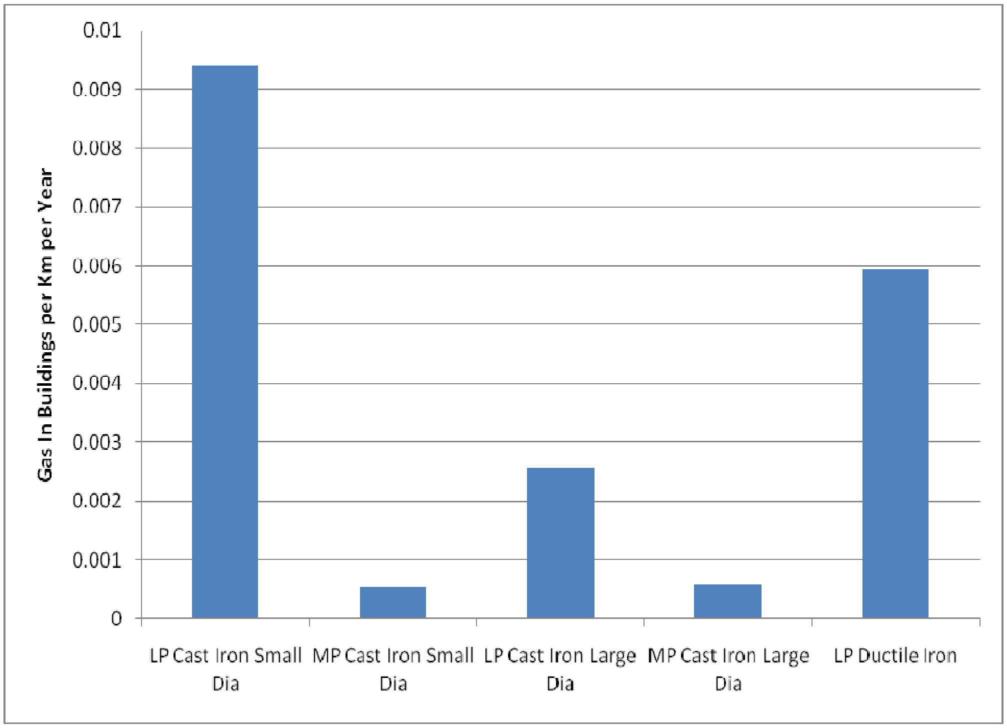

FIGURE 5 - AVERAGE GIBS/KM/YEAR

When adjusted for the installed length, LP small diameter cast iron, followed by LP ductile iron give rise to highest frequency of GIBs.

3.1.3 Incidents by Pipe Category

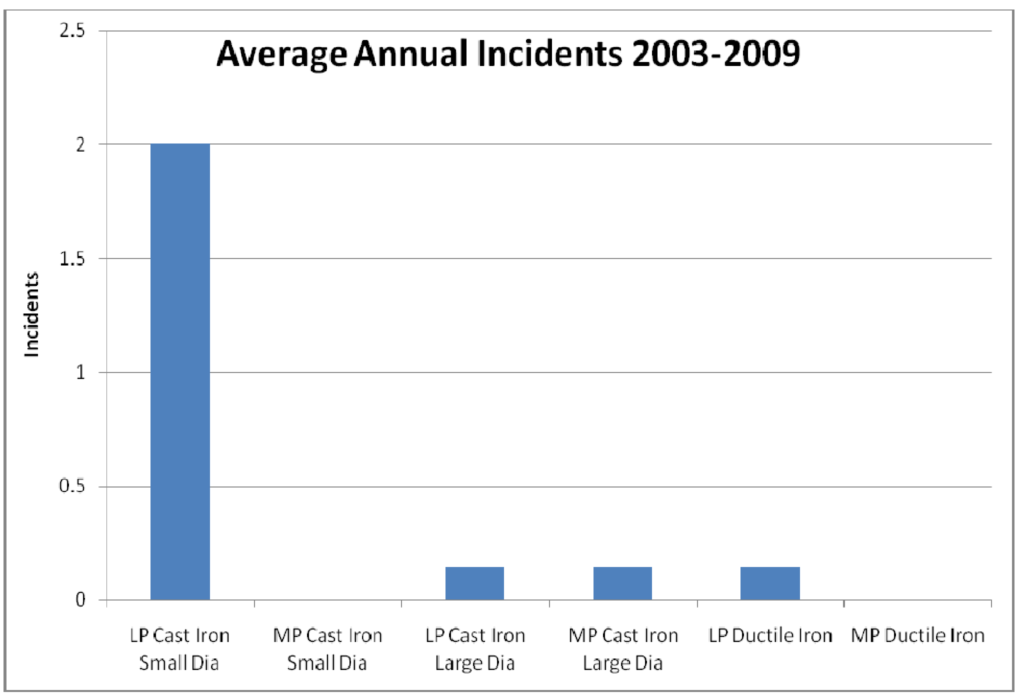

FIGURE 6 - AVERAGE ANNUAL INCIDENTS 2003-2009

Small diameter cast iron gives rise to the largest numbers of incidents over the period under consideration. This reflects in part at least the larger volume of these assets.

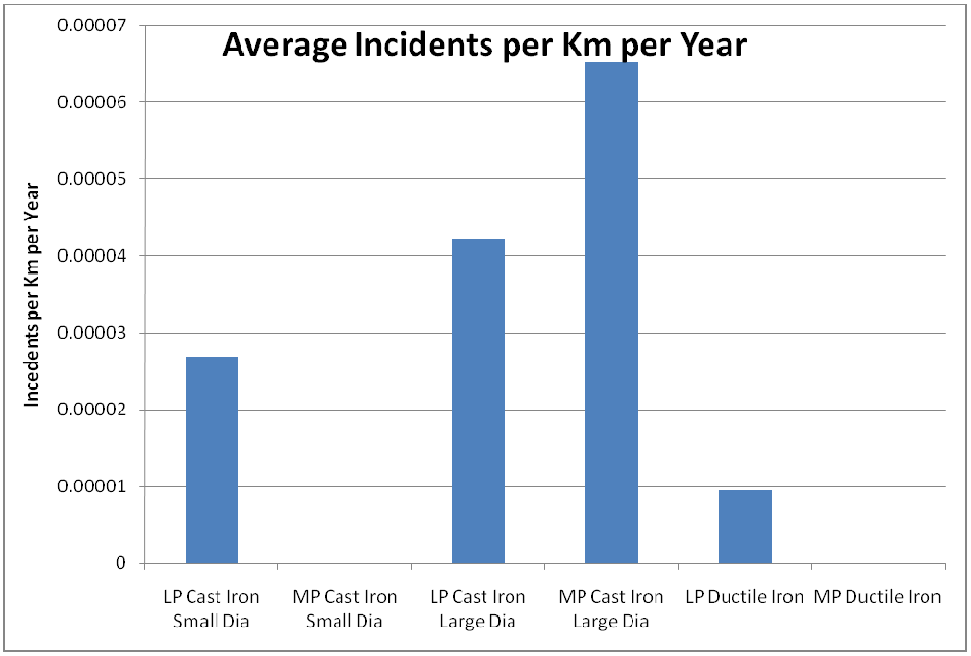

FIGURE 7 - AVERAGE INCIDENTS/KM/YEAR

When adjusted by installed lengths, large diameter cast iron, both LP and MP give highest incident frequency/km, impacted by the small volume of these assets. Both these large diameter failure events were single events. The MP cast iron event was caused by bolt corrosion, not fracture.

3.1.4 Average Incident Frequency - 1990 to 2009

For purposes of comparison those incidents that have occurred over the 20 year period for which data is available have been grouped. The average yearly frequency of incidents by category has been estimated. These values are approximate, because the installed lengths are not known precisely over this longer period.

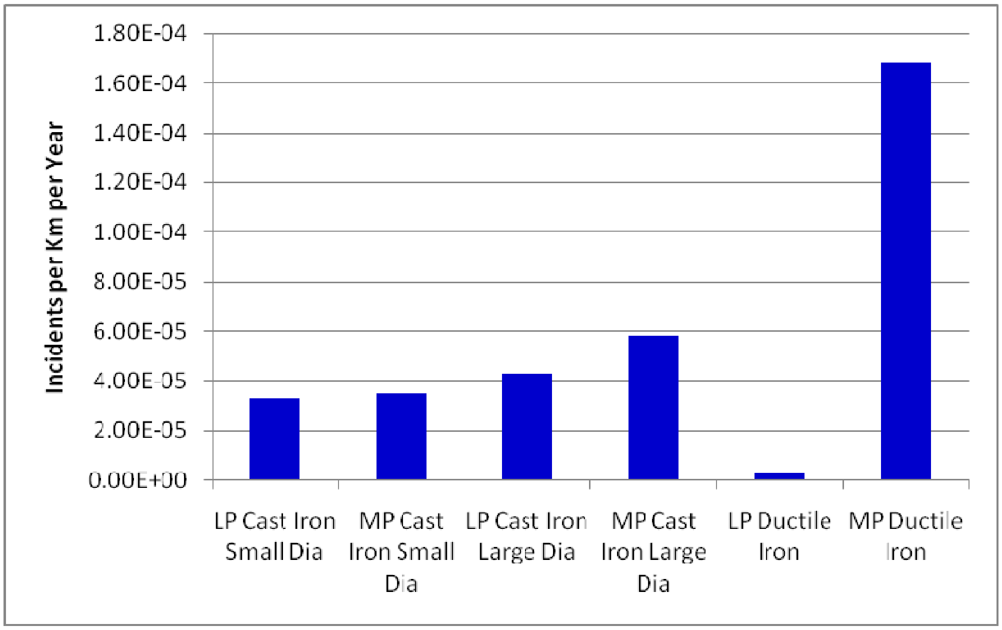

FIGURE 8 - AVERAGE INCIDENTS/KM/YEAR

MP ductile iron is now substantially removed. Large diameter cast iron show an incident frequency/km up to double that compared to small diameter cast, although based on few events

3.1.5 Comparison of Average Frequencies of Failures, GIBs & Incidents

The average frequency of failures, GIBs and incidents have been grouped by mains category. Within the data below, for cast iron mains, fracture failures and associated GIBs are presented; for ductile iron, corrosion failures and associated GIBs are presented.

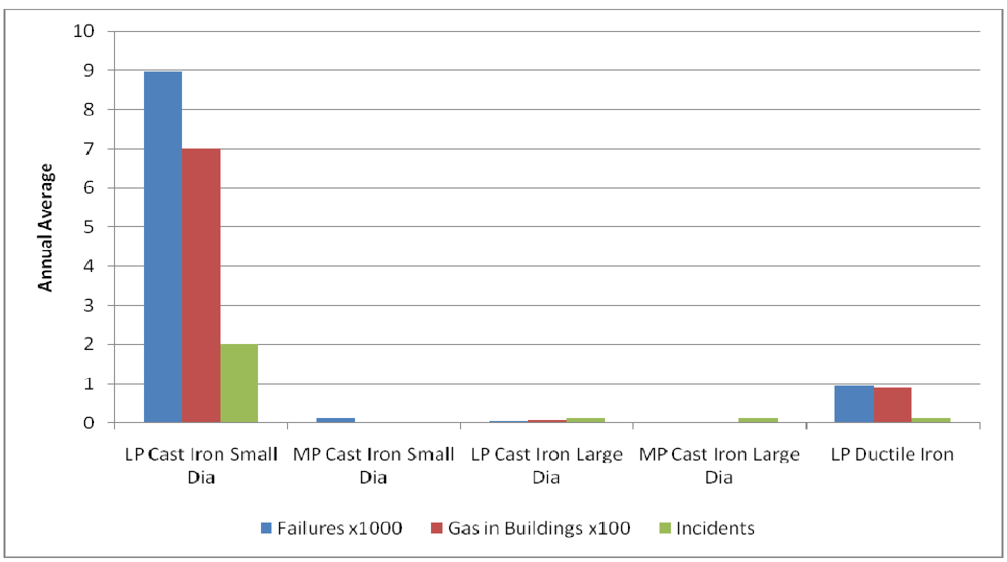

FIGURE 9 - ANNUAL AVERAGE FREQUENCIES 2003-2009

Note the relatively few fracture failures on large diameter cast iron

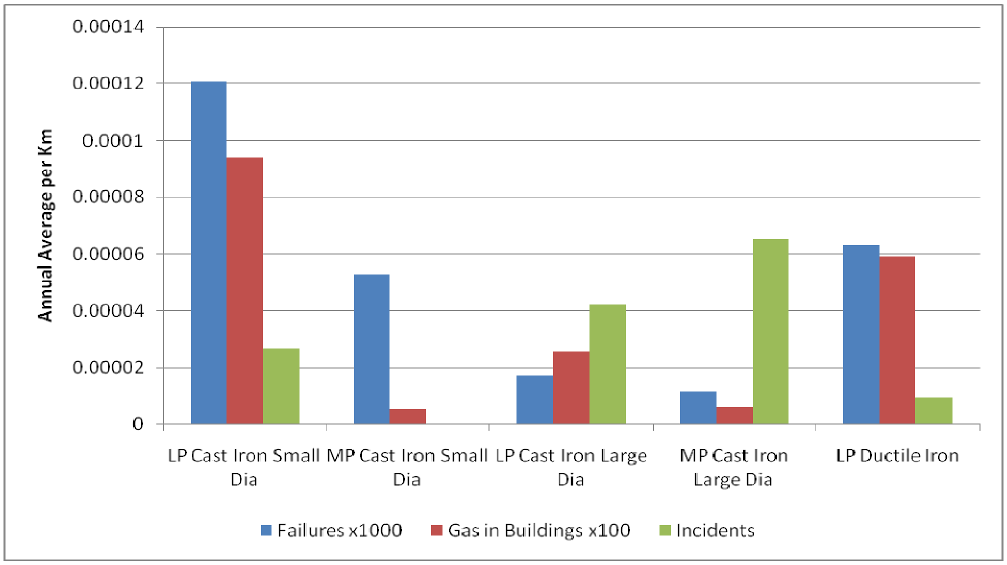

FIGURE 10 - ANNUAL AVERAGE FREQUENCIES/KM 2003-2009

When adjusted for installed length, the highest risk of incidents is large diameter cast iron, but only one incident in each pressure range case, and combined with relatively few failures and GIBs. One of these incidents was related to the corrosion of bolts.

Ductile iron corrosion failures give rise to proportionately more GIBs, but a lower incident frequency, when compared to cast iron fracture failures.

3.2 Mains Trend - All Population Reported (Inc. Those Replaced)

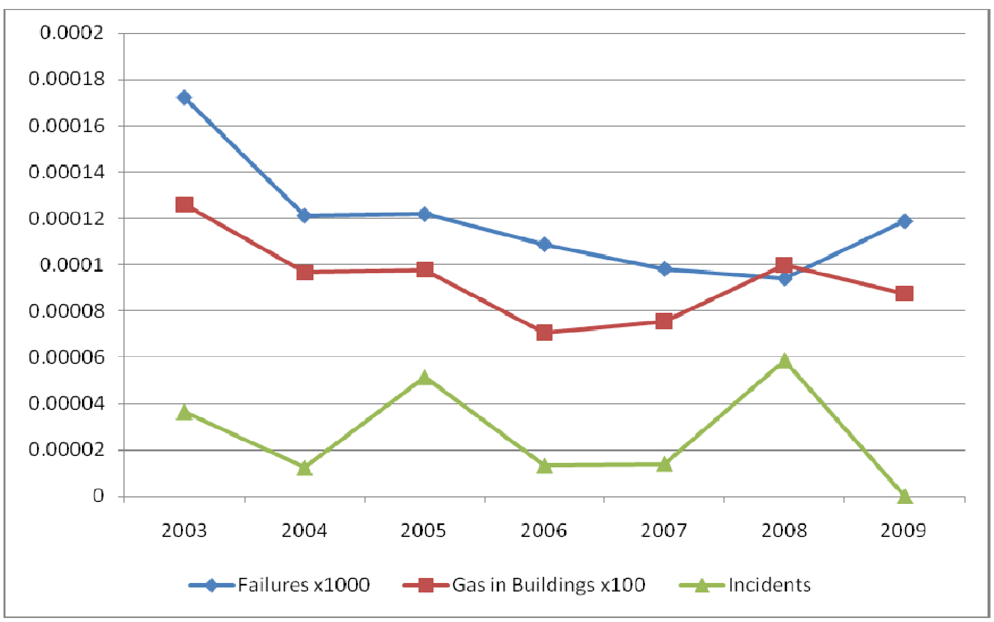

FIGURE 11 - EVENTS/KM - SMALL DIAMETER LP CAST IRON

There is a reduction in fracture failure rate, but little corresponding drop in GIBs or incidents evident for this asset class. The fracture data is strongly influenced by the first data point.

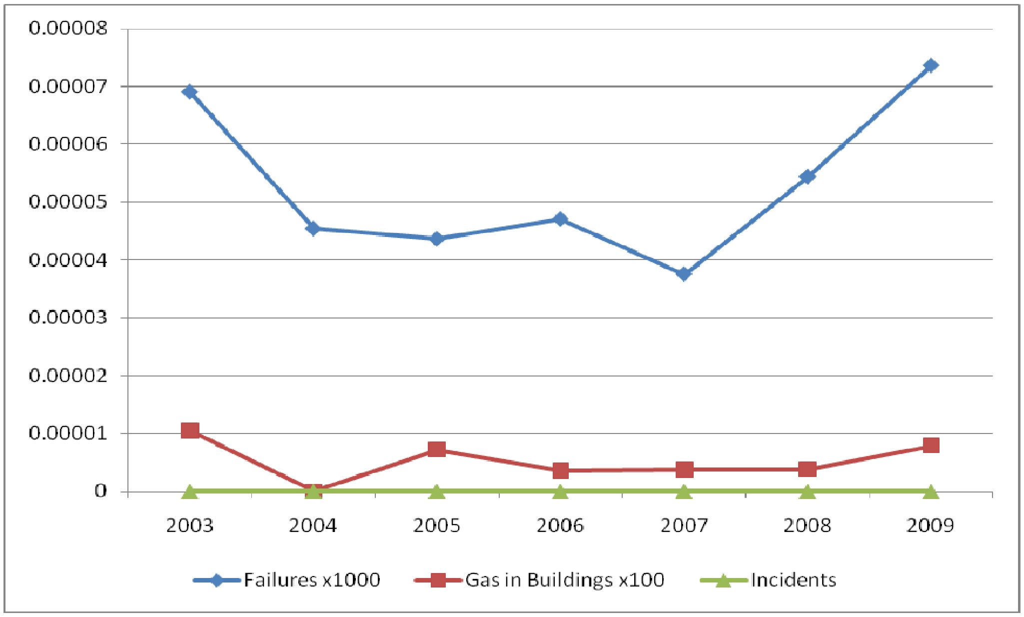

FIGURE 12 - EVENTS/KM - SMALL DIAMETER MP CAST IRON

There are relatively fewer GIBs in relation to frequency of fracture, when compared to data for LP mains (Fig 11), perhaps influenced by increased proximity for much of the remaining MP population. From 1980's, MP mains must be at least 3 metres from any building; LP mains must be at least 1 metre. However, given that there is no clear evidence to show that MP mains represent a higher risk than LP mains, this minor variation in proximity is unlikely to be of any real significance.

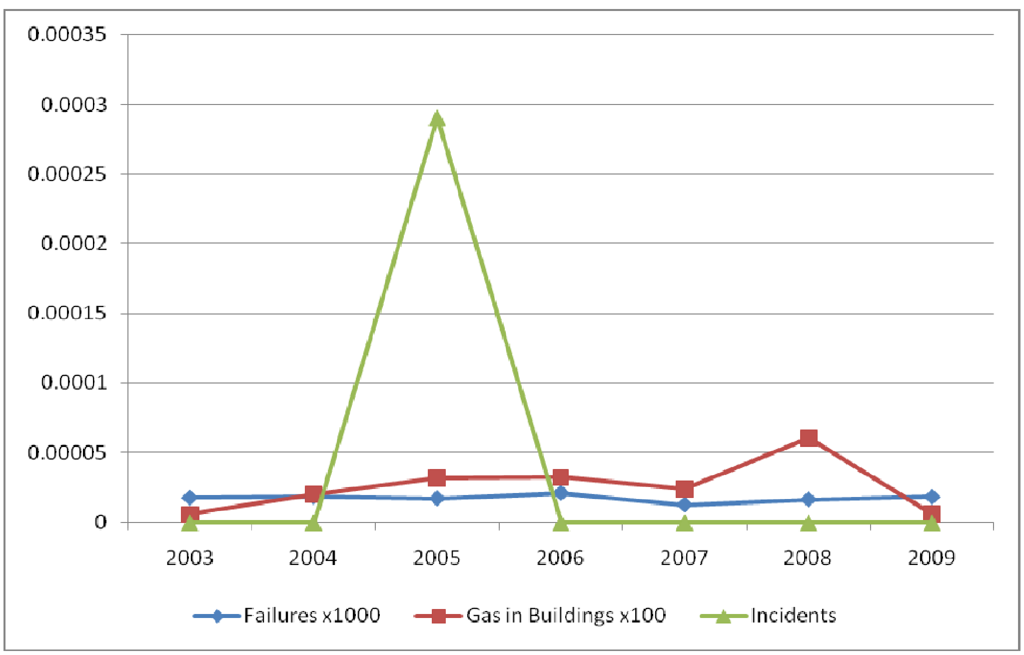

FIGURE 13 - LARGE DIAMETER LP CAST IRON/KM

There is a relatively higher frequency of GIBs associated with fracture when compared to small diameter cast iron fracture events shown in Fig 11. The Incident peak is a single event.

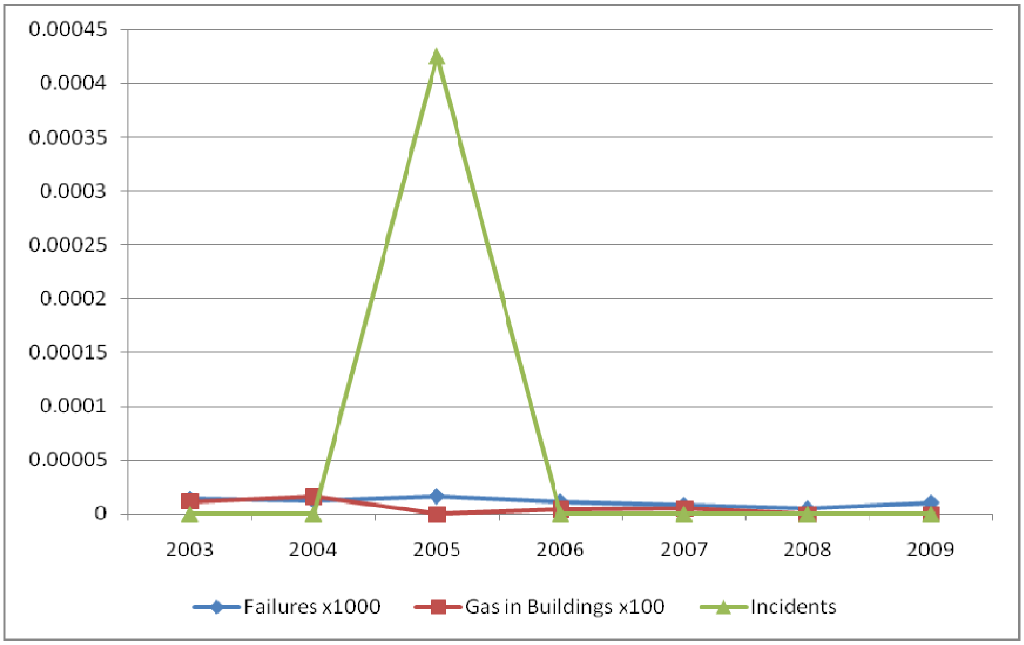

FIGURE 14 - LARGE DIAMETER MP CAST IRON/KM

There is a relatively high frequency of GIBs associated with fracture, although small numbers are involved. The Incident peak is a single event, and understood to be a corrosion failure.

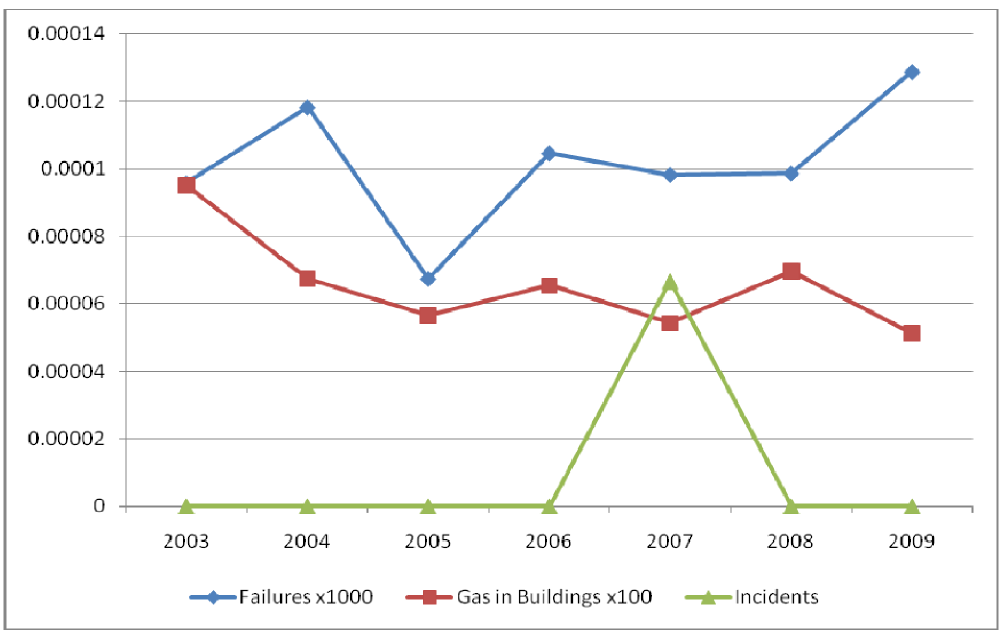

FIGURE 15 - LP DUCTILE IRON/KM

There is a slightly lower frequency of GIBs associated with failure, when compared to LP cast iron fracture rates.

It should be noted that the graphs displaying the trends of gross annual values for failure, GIBs and incidents display very similar trends as Figures 11-15 and are therefore not included in this section.

3.3 Yearly Trends Compared by Mains Category

3.3.1 Failure Events Compared by Mains Category

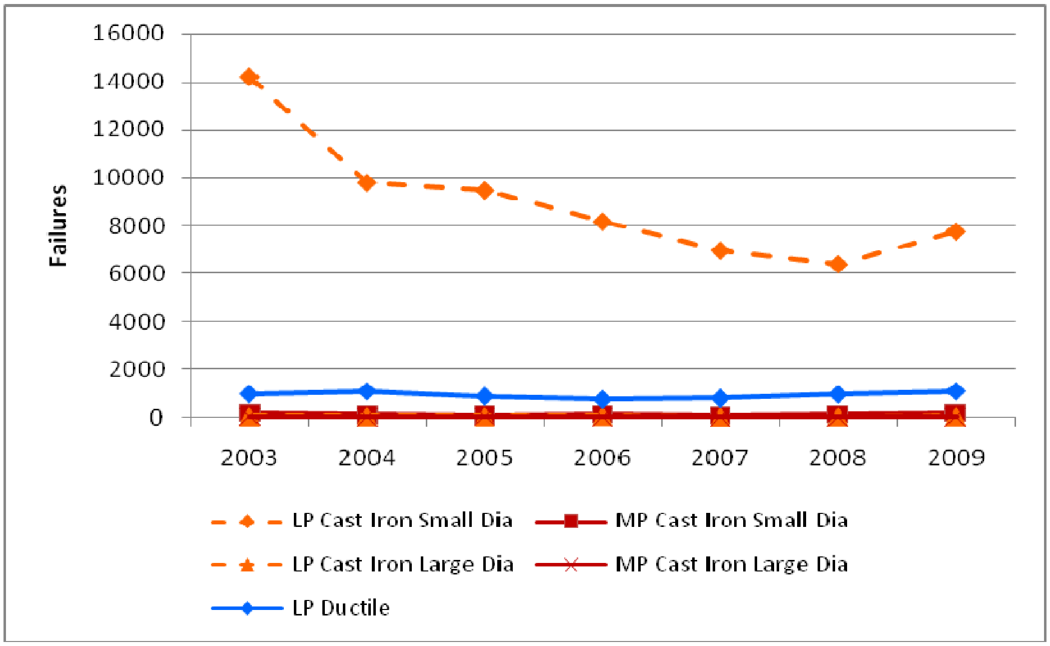

FIGURE 16 - TOTAL FAILURES

Cast iron fracture shows year on year reduction except 2008 to 2009 period.

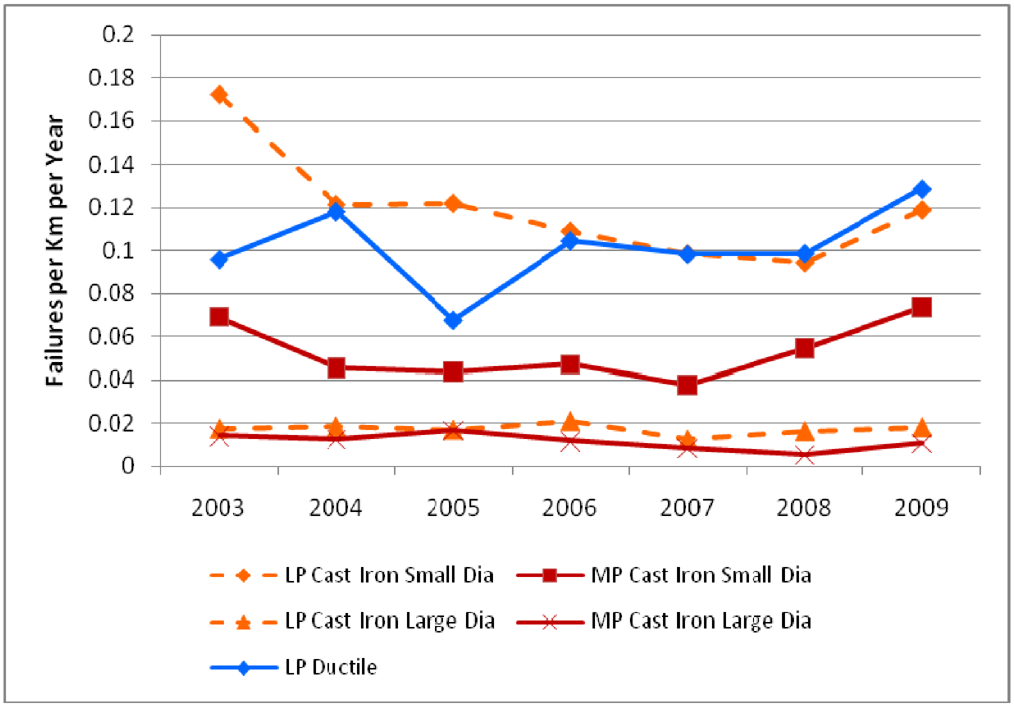

FIGURE 17 - TOTAL FAILURES/KM/YEAR

When corrected by length fractures of LP small diameter cast iron and corrosion failures on LP ductile iron are the largest sources of failure.

3.3.2 GIBs Compared by Mains Category

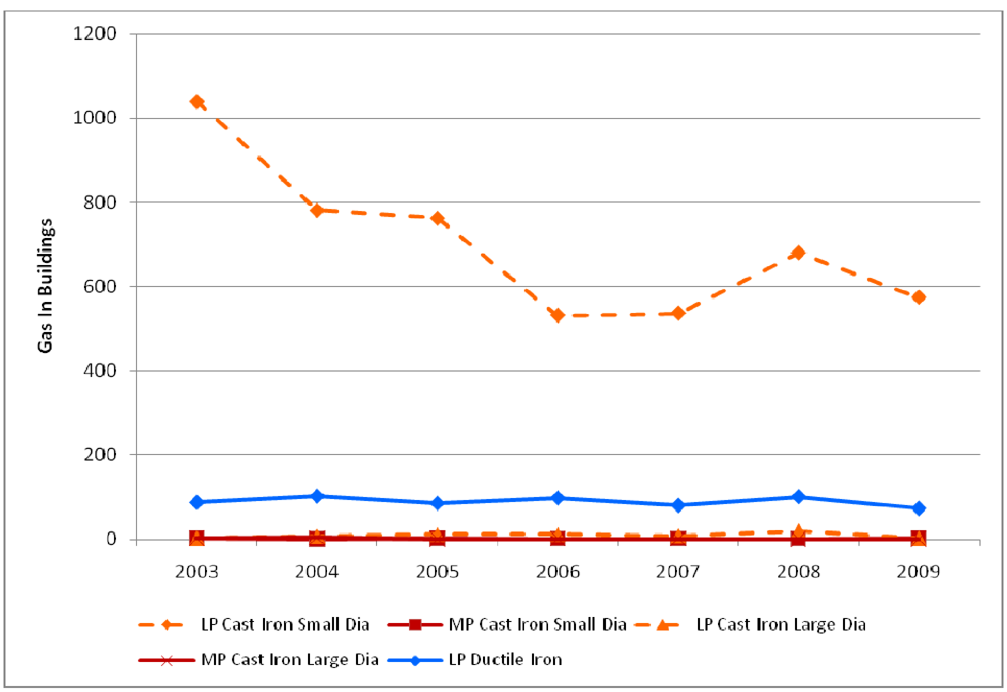

FIGURE 18 - TOTAL GAS IN BUILDINGS

For most categories, there is little evidence of trend in GIBs data; small diameter LP cast is the largest overall source of GIBs. For these assets, 2008 & 2009 show higher GIBs than 2006 & 2007, although all are lower than the period 2003 to 2005.

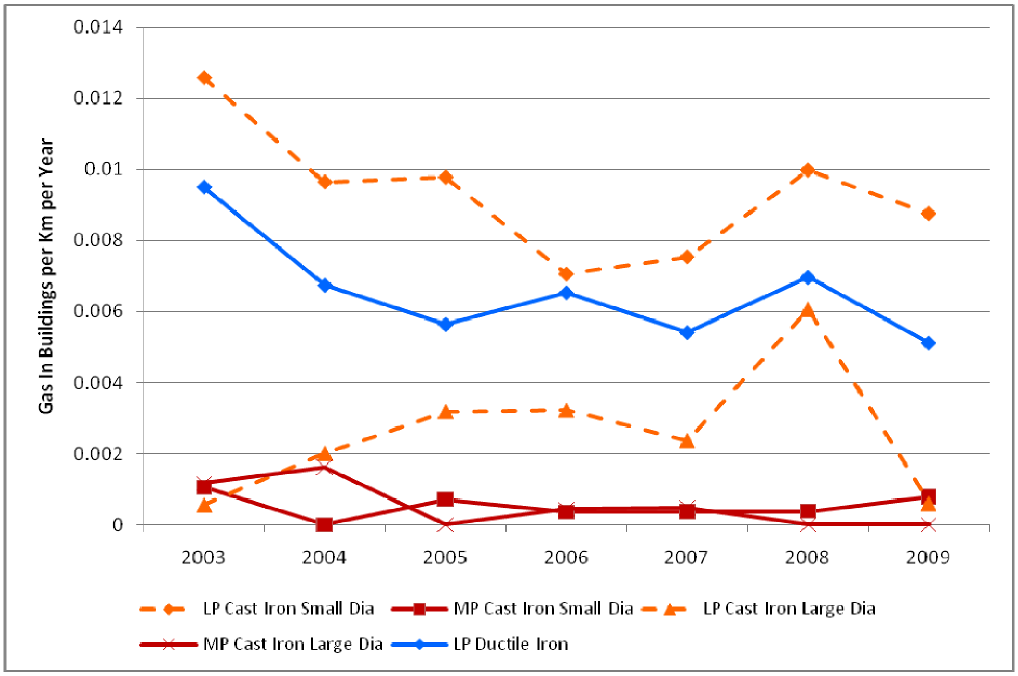

FIGURE 19 - TOTAL GIBS/KM/YEAR

When corrected for installed length, Small diameter LP cast iron remains largest source of GIBs. LP ductile iron also has a large contribution.

3.4 Mains Failures in Service 2009 V Performance in Earlier Years

For the purposes of comparison, failure trends have been derived for those mains in continuous service 2003 to 2009. This data included all GDNs except NGN, whose information arrived too late for processing. The influence of replaced mains has been removed. This data gives fracture failure events for Cast iron and corrosion failure events for ductile iron.

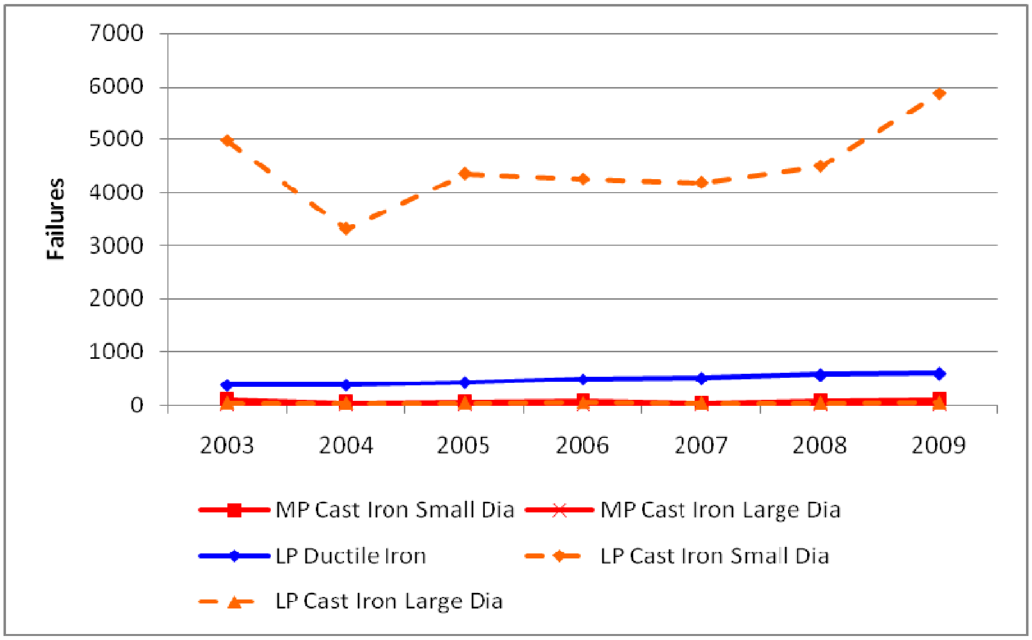

FIGURE 20 - ANNUAL FAILURES OF MAINS IN SERVICE THROUGHOUT 2003-2009

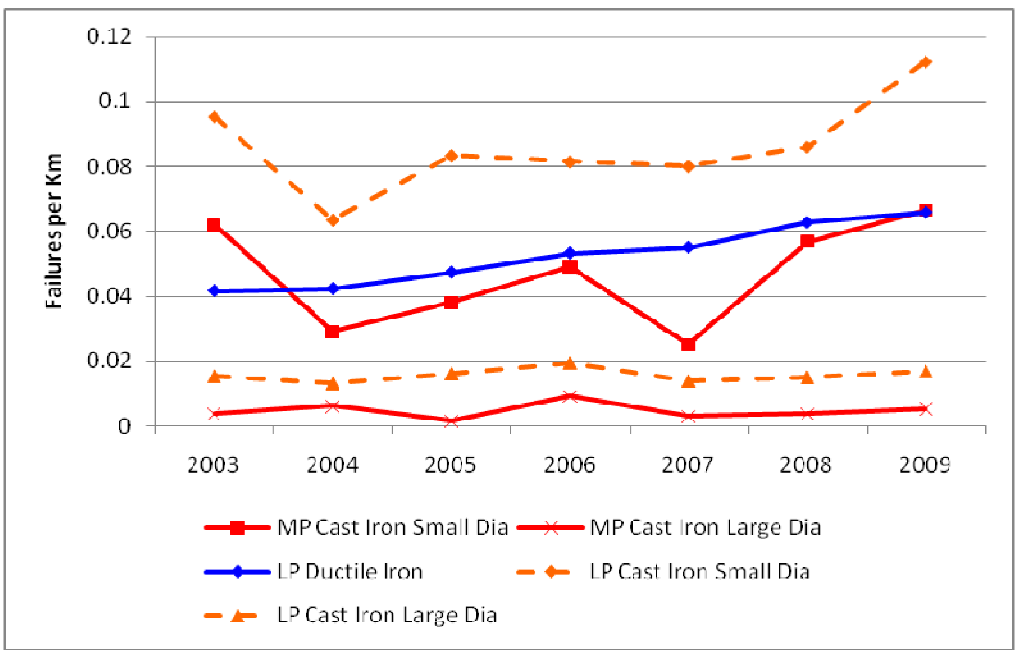

FIGURE 21 -FAILURE EVENTS/KM/YEAR - MAINS IN SERVICE 2003-2009

3.5 Fractures for Mains in Service 2003-2009 (NGG & SGN)

For NGG and SGN, sufficient detail was provided of both failure events and GIBs, with the mains unit ID, to allow the determination of the performance of those mains that were in service in 2009 and throughout the period 2003-2009.

3.5.1 Fractures for Mains in Service 2003-2009 (NGG & SGN)

The failure data is given below

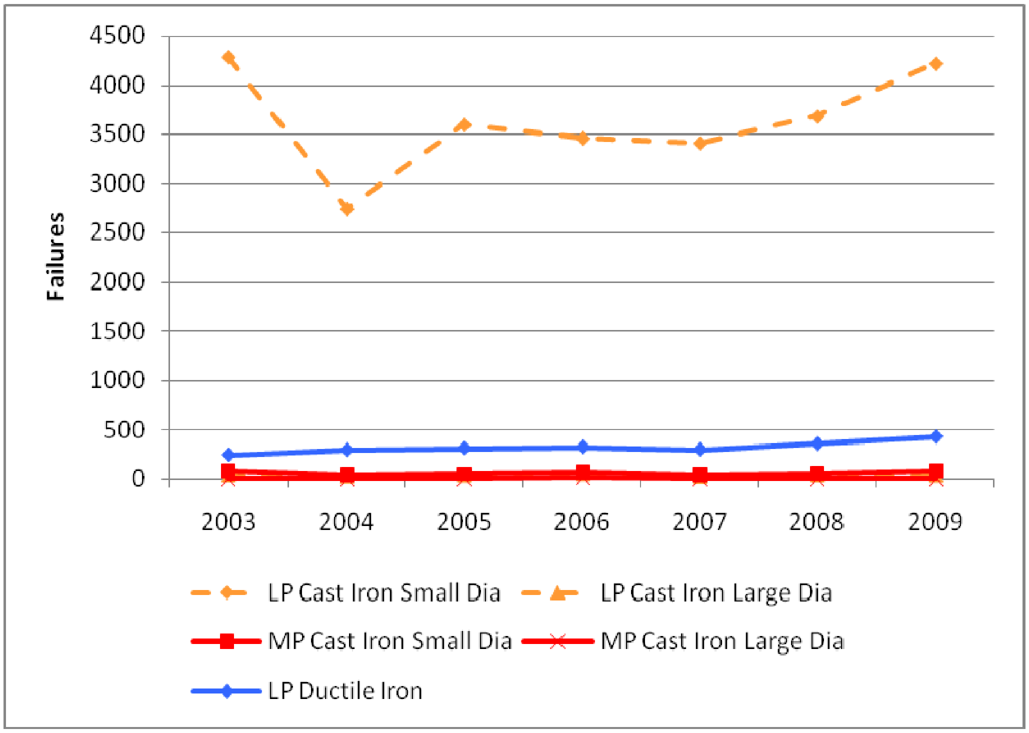

FIGURE 22 - TOTAL FAILURES (NGG & SGN)

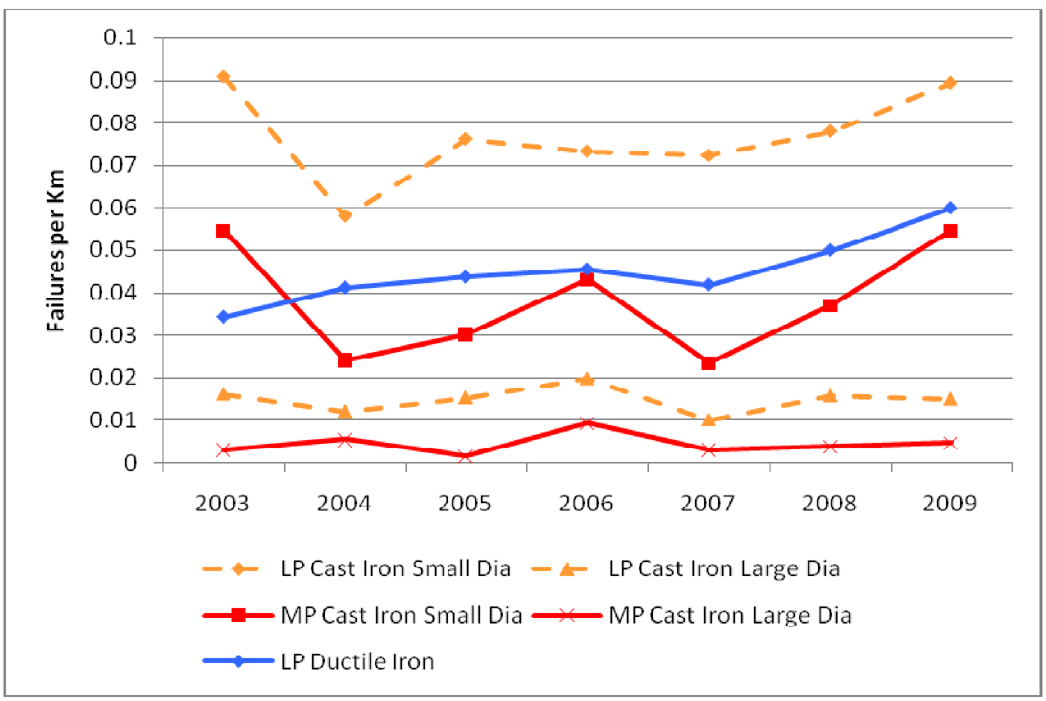

FIGURE 23 - TOTAL FAILURES/KM/YEAR (NGG & SGN)

For LP cast iron there is a sharp drop in recorded failures from 2003 to 2004.

3.6 GIBs for Mains in Service 2003-2009 (NGG & SGN)

For NGG and SGN, sufficient detail was provided to allow the determination of the performance of those mains that were in service in 2009 and throughout the period 2003-2009. The GIBs data is given below

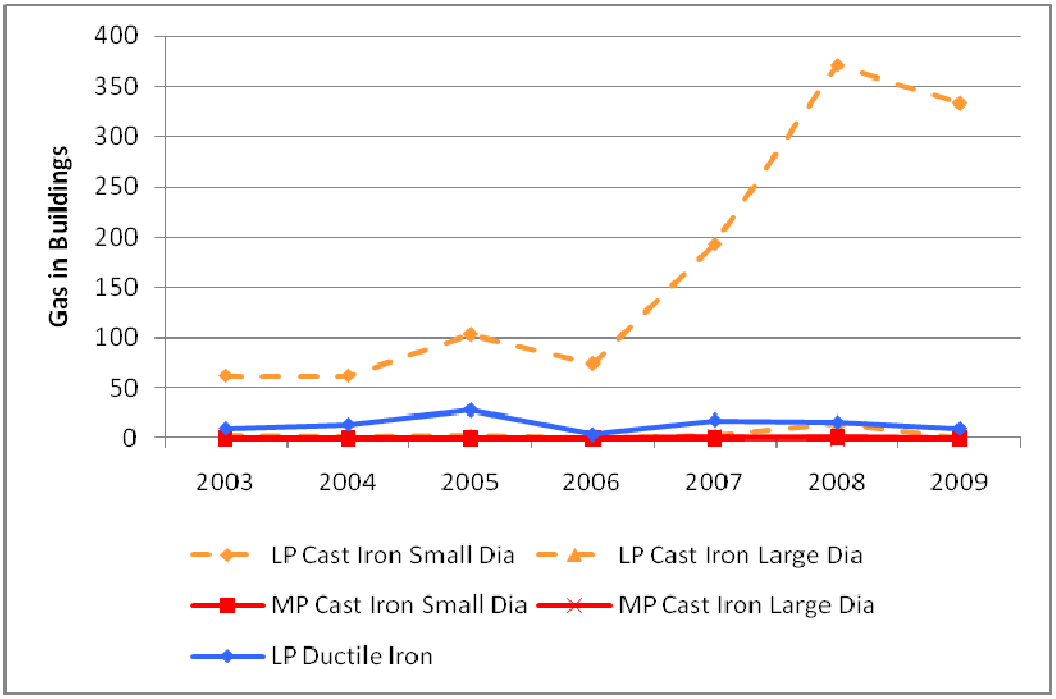

FIGURE 24 - TOTAL GAS IN BUILDINGS (NGG & SGN)

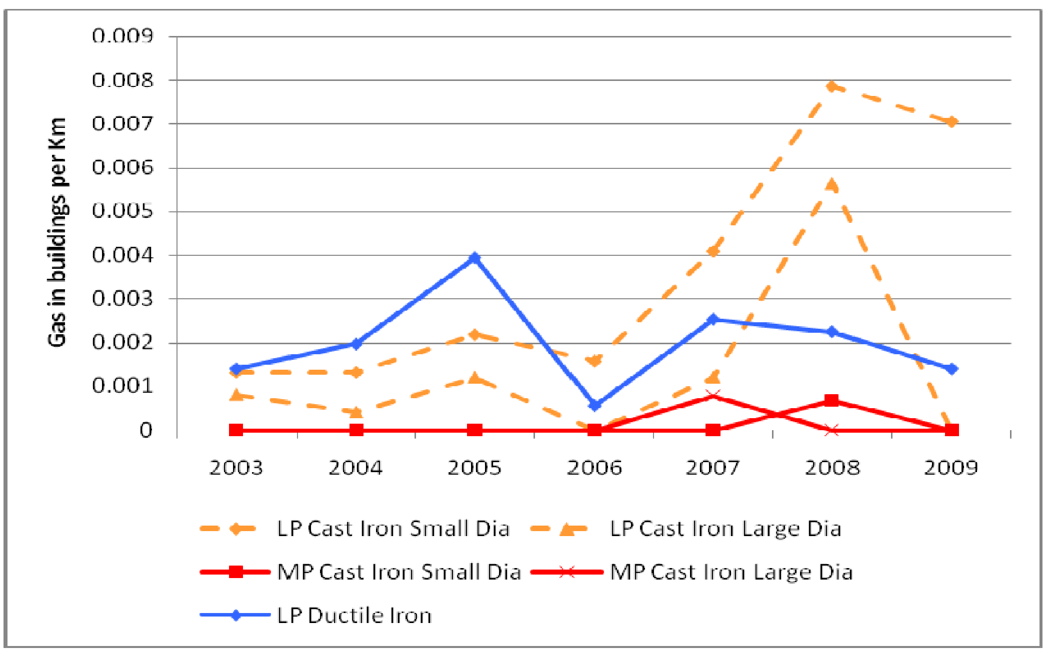

FIGURE 25 - TOTAL GIBS/KM/YEAR (NGG & SGN)

There is a strong rising trend in GIBs from the small diameter cast group of mains.

4 COMPARATIVE RISK BY MAINS CATEGORY

Based on the observed events during the last 20 years the HSE HID Report[51] provides a summary of incidents including details of material and pressure.

TABLE 3 - ACTUAL INCIDENTS 1990 TO PRESENT (HSE DATA)					
Material	Diameter	Actual Number of Incidents		Approx Incidents/km/year over period (based on 2003 lengths) $x10^{-6}$	
		LP	MP	LP	MP
Cast Iron	Small (≤ 12 inch)	55	2	**33.3**	**35.2**
Cast Iron	Large (>12 inch)	3	3 (but one corrosion)	**43.2**	**58.4**
Ductile Iron		1	3	**3.3**	**168**
Steel mains		1	0	**4**	**-**
Steel Services (assumed 7,000,000 at 10 m length - 2003)		10	Not known	**7.1**	**-**

The above table represents the approximate average of the whole population over 20 years. Incidents from Steel mains and Steel services are included for comparison.

The only LP ductile iron incident was described as caused by fracture, but is believed to be probably corrosion related. The 3 MP ductile iron incidents are believed to be related to corrosion failures.

The cast iron failure events are described as caused by fracture, sometimes with corrosion also reported as a contributing factor. One of the large diameter cast iron failures was caused by bolt corrosion.

4.1 Average MRPS Risk Model Output by Mains Category

The output of the MRPS Risk Model has been averaged/km for the period under consideration. The data is illustrated below.

[51] Summary of UK Gas Distribution Mains and Service Related Incidents (1990 to Present)

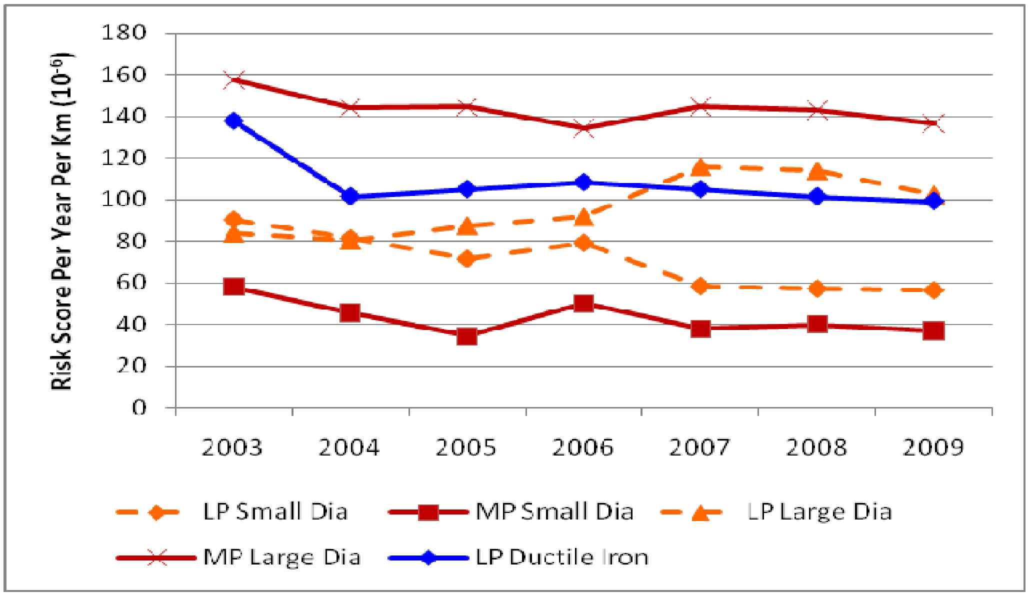

FIGURE 26 - GROSS AVERAGE ESTIMATED INCIDENTS/KM

The model predicts large diameter mains, on average, to represent more risk than small diameter mains, by a factor of around 2 (LP) or 3 (MP).

The MRPS Risk Model is predicting that LP ductile iron mains now represent a higher average risk than small diameter cast iron mains.

These differences may reflect the historic replacement practice, although they have mostly been present throughout the period under consideration.

The differences in the derived average risk values may be influenced by events that took place before the period under consideration.

4.2 Comparison of Model Risk, by Length with Actual Incidents

During the period under consideration there were 12 incidents which involved small diameter LP cast iron; risk scores/km were included in HSE incident reports and further details have been supplied by GDNs. To investigate whether these incidents occurred on mains units predicted by the MRPS Risk Model to be of high risk, the following process was carried out:

For each year, data for all small diameter LP cast iron pipes for all GDNs was collated and the total length of these mains units was then calculated. The list of mains units was then sorted by their risk score, in descending order and separated into 100 groups where the total length of all mains units within each group was equal. The list was then sorted, starting with the mains unit with the highest risk score/km, followed by the remaining groups in order of descending risk.

From the above, group 1 is the top 1% of the installed length of small diameter LP cast iron in the UK with the highest risk, according to the MRPS Risk Model output for the relevant year of the study. For each of these 1% groups, the maximum and minimum risk scores/km were calculated to identify the range of risk scores represented by each 1% interval. The total risk for the mains units within each group was also calculated to see what proportion of the total risk each 1% represented. Each 1% group has the same total pipe length.

If the MRPS Risk Model predictive powers were strong, one might expect incidents to be clustered at the top of the list. Conversely, If the MRPS Risk Model had weak predictive powers, incidents would be more scattered down the list.

This process was repeated for each of the 12 incidents arising from small diameter LP cast iron main where the risk score/km for the individual mains unit was known. The results of this analysis are shown in Table 2 below.

TABLE 4 - INCIDENT RISK SCORES - SMALL DIAMETER LP CAST IRON MAINS

Year	Diameter	Risk Score (incidents/km 10^{-6})	Group
2003	4 Inch	337	1
2004	4 Inch	180.4	3
2004	4 Inch	72.7	23
2005	6 Inch	49.8	30
2005	4 Inch	20.3	59
2005	10 Inch	11.5	75
2006	8 Inch	19.6	72
2007	8 Inch	11.2	79
2008	4 Inch	64.9	14
2008	4 Inch	41.5	28
2008	8 Inch	25.9	43
2008	6 Inch	18.2	61

For illustration, the total risk that the MRPS Risk Model estimates for one year, split into 1% risk groups of equal total length as described above, is shown below.

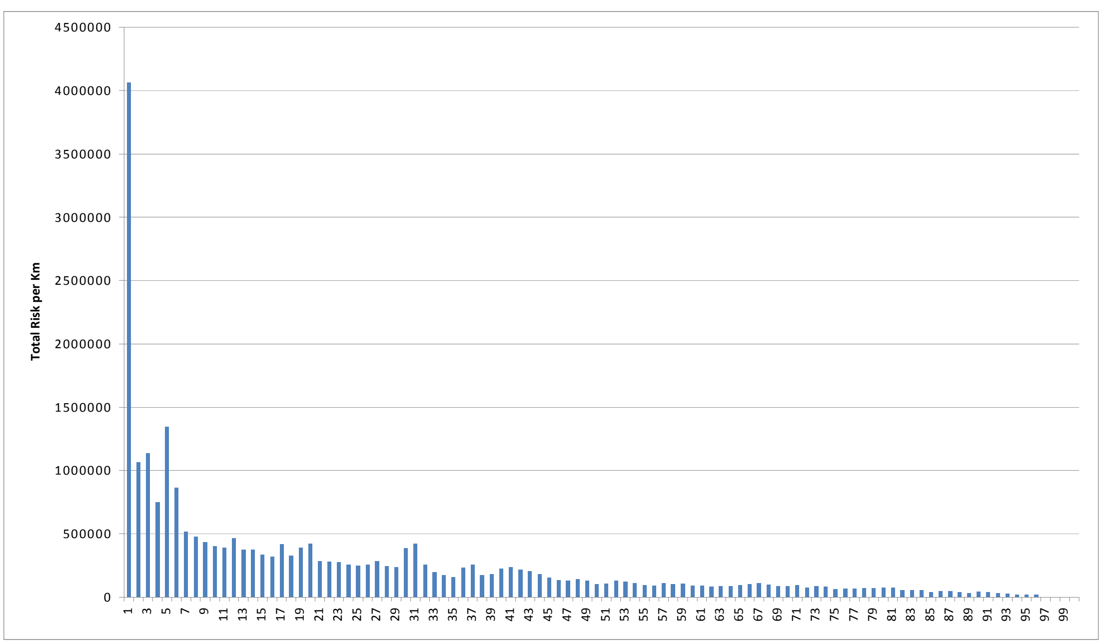

FIGURE 27 - TOTAL RISK SCORE - 1% INTERVALS OF TOTAL MAINS LENGTH (2008)

4.2.1 Small Diameter Cast Mains - Predicted Risk v Later Actual GIBs

GIBs in 2008 have been compared against the 1% groups (risk in 2007).

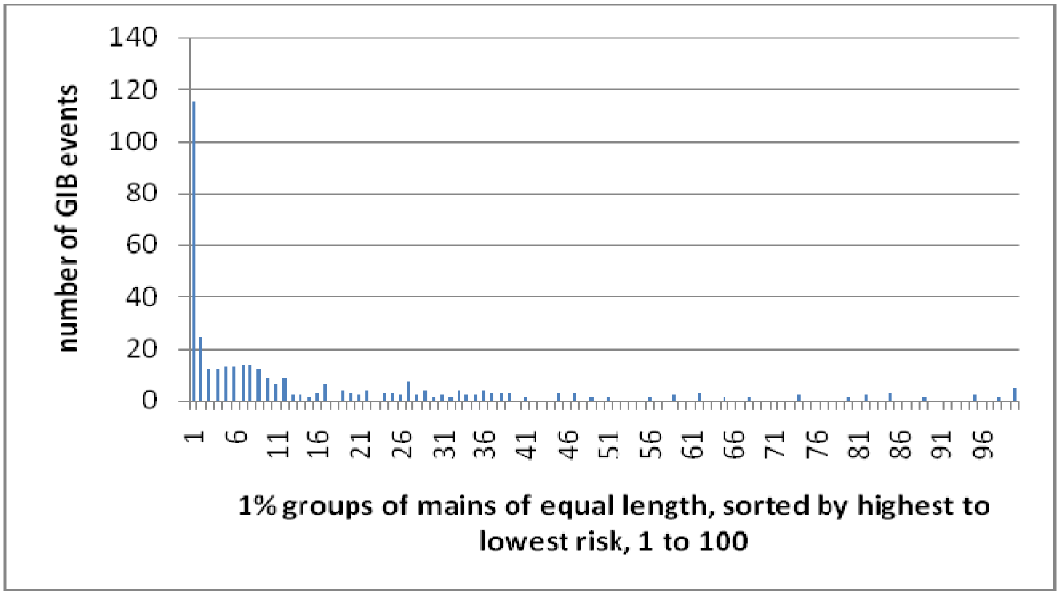

FIGURE 28 - ACTUAL GIBS 2008 V PREDICTED RISK 2007, SMALL DIA CAST IRON (NGG)

Fig 29 shows that a relatively large proportion of GIBs arise in the top 1% risk group.

4.3 Large Diameter Cast Iron Fracture MRPS Risk Model

There were six incidents recorded in the previous 20 years for this category of mains, one was bolt corrosion related, the other believed to be from fracture. The other risks scores of these mains have not been provided so comparison cannot be made.

4.3.1 Large Diameter Cast Mains - Predicted Risk v Later Actual GIBs

There have been relatively few large diameter mains fracture incidents during the period under consideration. To provide evidence to validate the large diameter MRPS Risk Model, GIBs have been compared to the pattern of predicted risk.

Note that the MRPS Risk Model output predicting GIB likelihood was not available.

For some limited data on 8 GIB events that took place on one network's large diameter cast iron mains, 6 of the events occurred on mains in the top 1% of risk. This is given in the table below:

TABLE 5 - INCIDENT RISK SCORES - LARGE DIAMETER LP CAST IRON MAINS			
Diameter (inch)	**Length**	**Risk Score**	**Group**
20	44	6776	Top 1%
15	118	3312	Top 1%
18	85	2641	Top 1%

TABLE 5 - INCIDENT RISK SCORES - LARGE DIAMETER LP CAST IRON MAINS			
18	166	2043	Top 1%
18	335	1074	Top 1%
18	1110	1041	Top 1%
15	222	454	Top 4%
15	85	120	Top 17%

GIBs (2008) are compared against 1% groups (2007 risk) for large cast iron mains.

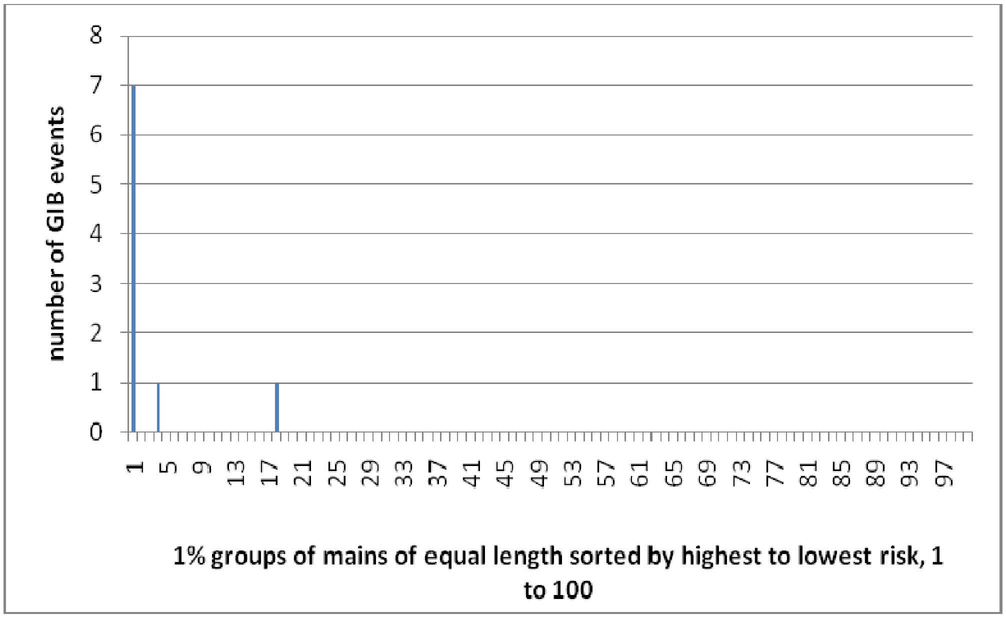

FIGURE 29 - GIBS IN 2008 V PREDICTED RISK GROUPS 2007, LARGE DIA CAST (NGG)

4.4 Ductile Iron Corrosion MRPS Risk Model

The only incident recorded in the last 20 years relating to LP ductile iron corrosion had a predicted risk score of 16.5, putting it into the 14th risk group for that year.

4.4.1 Predicted High Risk Ductile Iron Mains v Later Actual GIBs

From NGG data, the MRPS predicted risks for ductile iron mains in 2007 have been compared to actual GIBs in 2008.

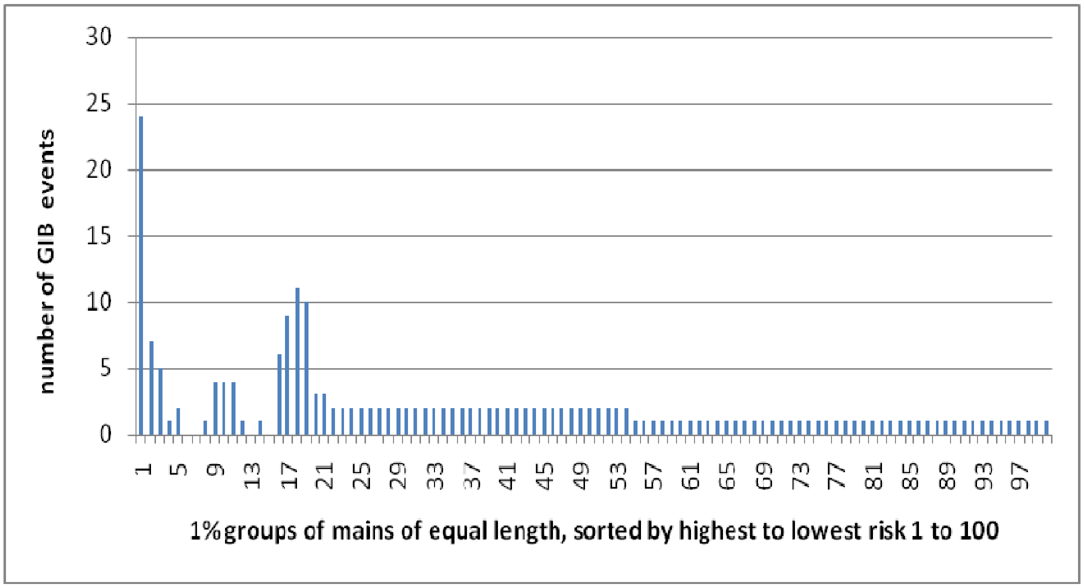

FIGURE 30 - ACTUAL GIBS 2008 BY PREDICTED RISK GROUPS 2007 DUCTILE IRON (NGG)

GIBs related to ductile iron failures are distributed throughout the risk ranking, although the top 1% group does include the largest number of events.

5 Evidence Of Deterioration Of Iron Pipe System

5.1 Overall Fracture and Corrosion Trends in Entire Network

The amount of fracture for cast iron and corrosion failure events for ductile iron has been examined over the period in question. Data has been prepared for those mains recorded as being present throughout the period. Gross totals are presented below:

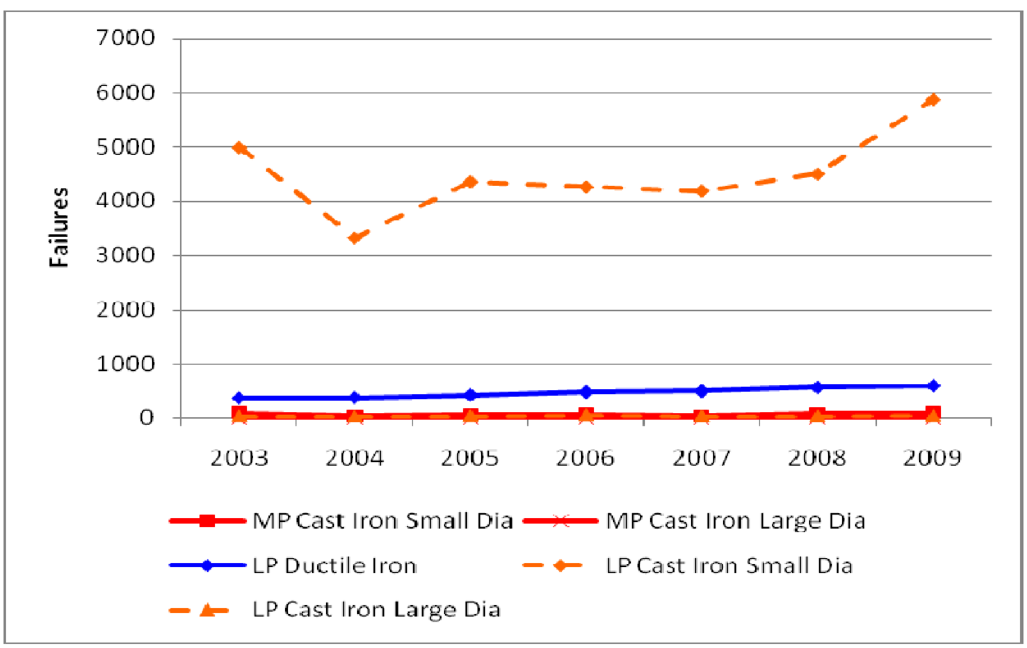

FIGURE 31 - CAST FRACTURE & DUCTILE CORROSION - MAINS IN SERVICE 2003 - 2009

The data is given below, adjusted per km of total mains length installed.

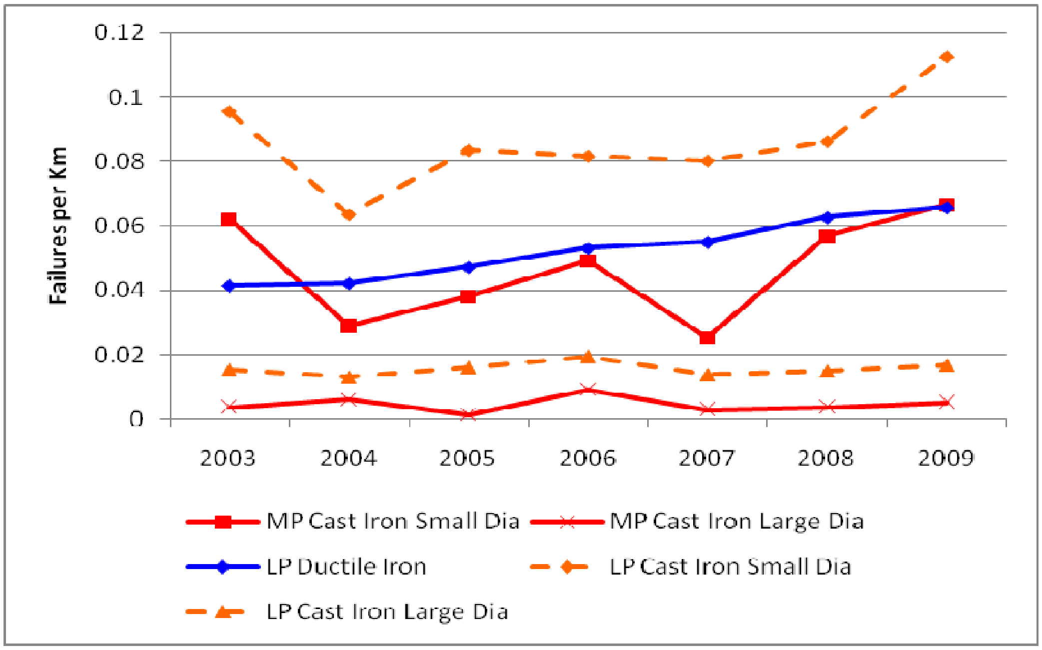

FIGURE 32 - TOTAL FAILURES/KM FOR MAINS IN SERVICE 2003 - 2009

Trend lines have been fitted to cast & ductile iron data and results are shown below:

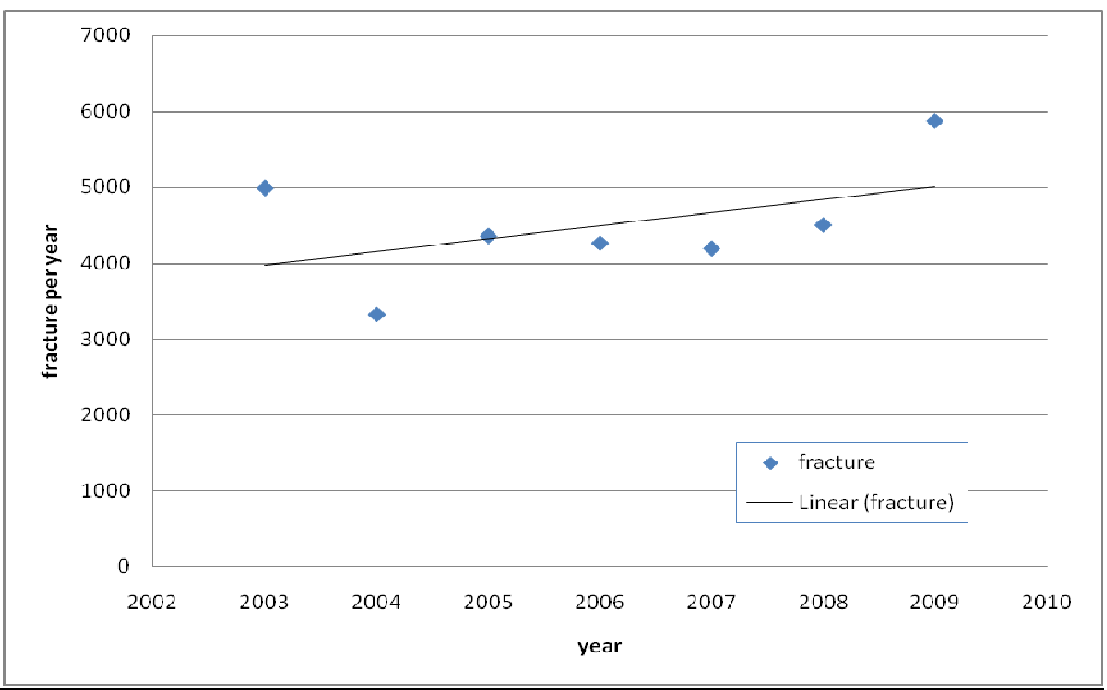

FIGURE 33 - FRACTURE - SMALL DIAMETER LP CAST - 2009 & 2003 (NGG, SGN & WWU)

For cast iron mains units in ground in UK in 2009, and present in 2003, for the networks for which data was available (SGN, NGG & WWU) suggests an overall underlying increase in fracture, from those cast iron mains units only, of between 3 and 4 %/year. There are difficulties with this plot because it is strongly influenced by the first and last points, and the last point is a cold winter, so the apparent slope may be the result of a temperature effect

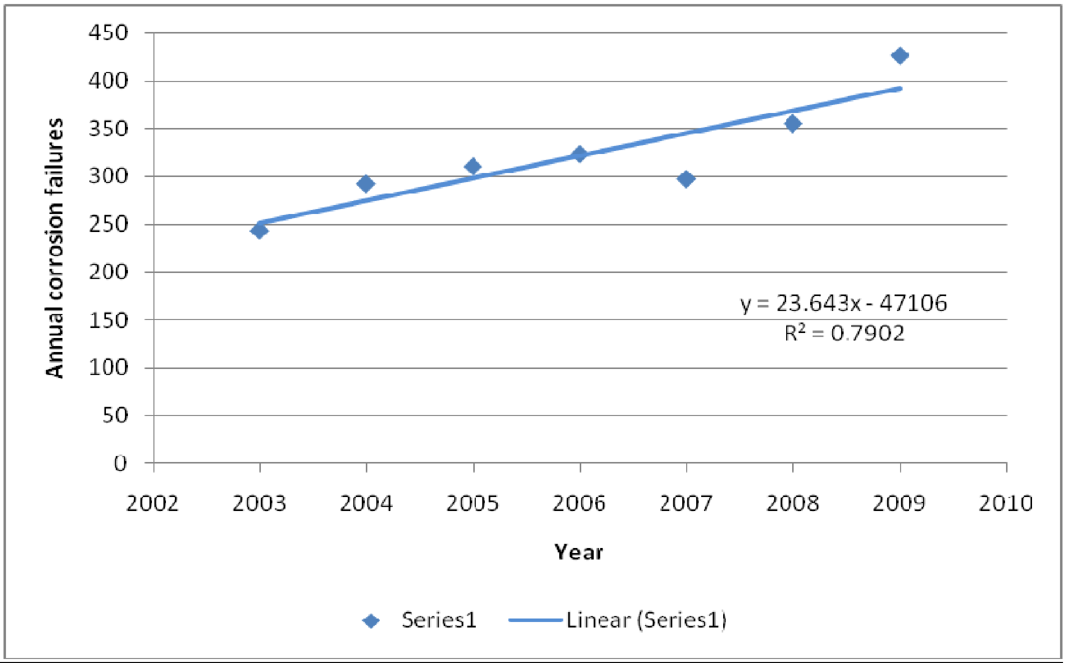

FIGURE 34 - LP DUCTILE CORROSION FAILURE - 2009 & 2003 (NGG, SGN & WWU)

For equivalent populations of ductile iron mains units, data suggests an underlying increase in overall corrosion failure, in ductile mains units only, of around 8 %/year. However, neither of the above data sets has been adjusted for temperature effects, which are known to influence the fracture rate of iron. Therefore a more detailed analysis has been applied to some data provided by NGG. This is presented below

Mains are not selected for replacement randomly. The use of a risk score, one element of which involves likelihood of fracture, introduces the possibility that mains that contribute a disproportionate amount of fracture are being selectively replaced

5.2 Temperature Effect on Fracture - NGG (EA & NL)

Fracture data from NGG (East Anglia & North London networks) has been examined for evidence of any trend related to ambient temperature. Fracture behaviour of all cast iron mains in service in 2009 has been examined in earlier years, to exclude the influence of mains replaced during the period. Initially, for 2005 and 2009, weekly average fracture rates were plotted v weekly average ambient temperature, using daily temperature data for Luton (East Anglia) and Hampstead (North London). From these plots, fractures showed a relationship with ambient temperature, although there was considerable scatter from other influencing factors and randomness. The 2005 & 2009 data was regressed and differences between the annual fitted lines were found to correspond to an average increase in fracture rate of between 10% and 15%/year. Regressions of both East Anglia and North London data were verified to confirm that both the slope and intercept for 2005 & 2009 were significantly different. These tests of difference required correction for the autocorrelation of residuals.

Following the initial data examination for 2005 and 2009, data for intermediate years 2006 to 2008 were also plotted. Figure 35 shows the final weekly average fracture rates v weekly average ambient temperature; Fig 35A shows East Anglia (Luton temperature data), Fig 35B shows North London (Hampstead temperature data).

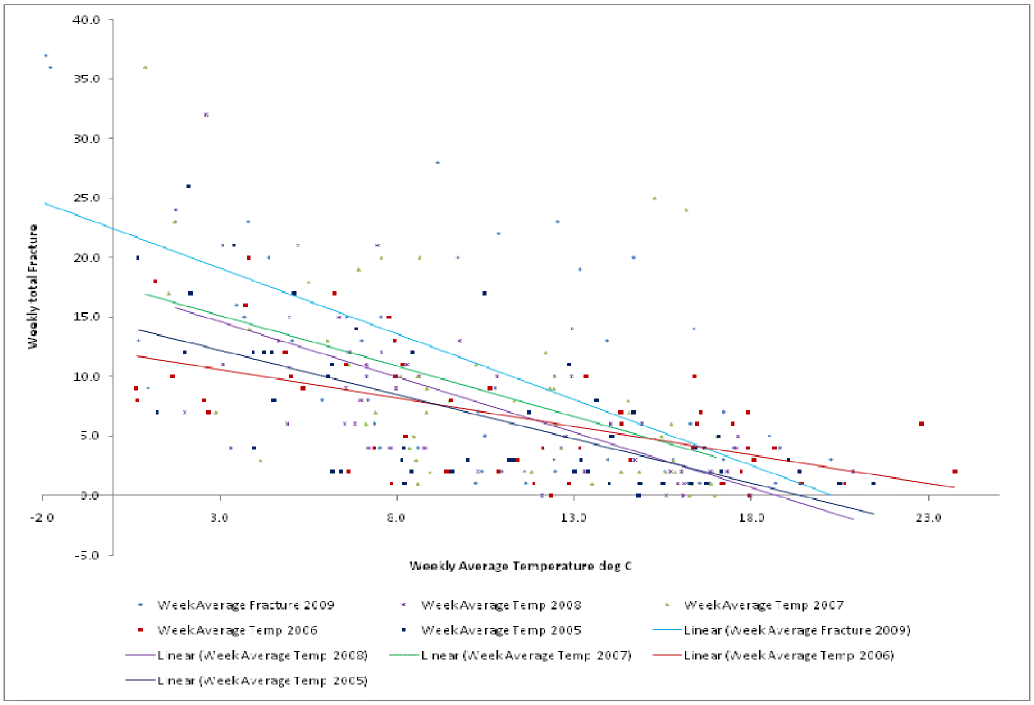

FIGURE 35A - WEEKLY FRACTURES v WEEKLY AVERAGE TEMP (NGG EA)

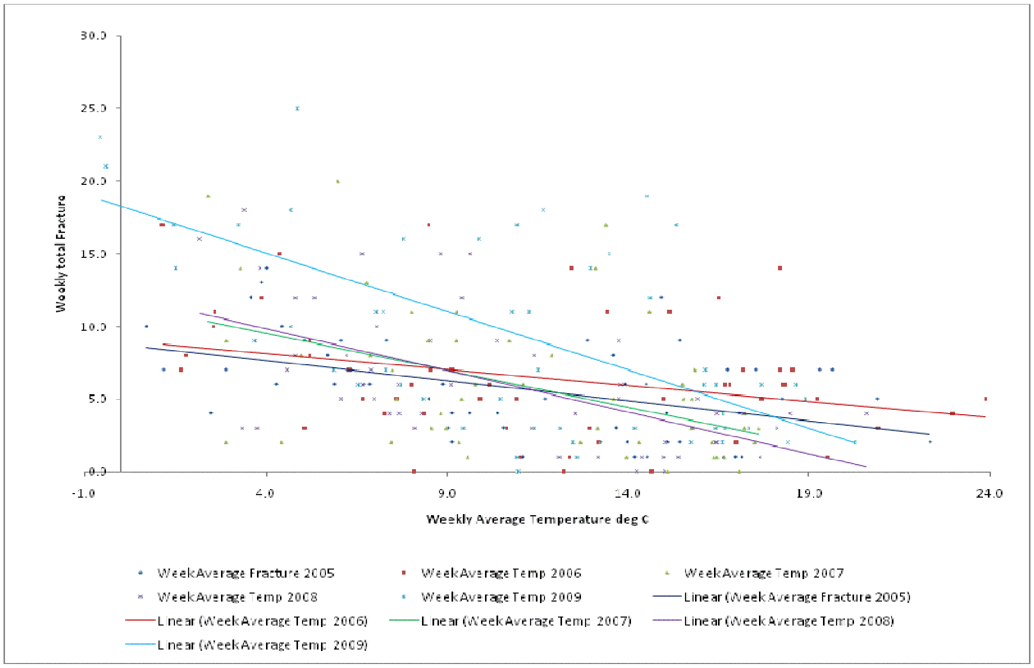

FIGURE 36 - WEEKLY FRACTURES v WEEKLY AVERAGE TEMP 2005 & 2009 (NGG NL)

Figure 35 shows average fracture rate v average ambient temperature, but does not give any indication of seasonal ambient temperature. Data from Fig 35A (years 2006 & 2009 only) has been re-plotted as total fractures v week number, see Figure 36.

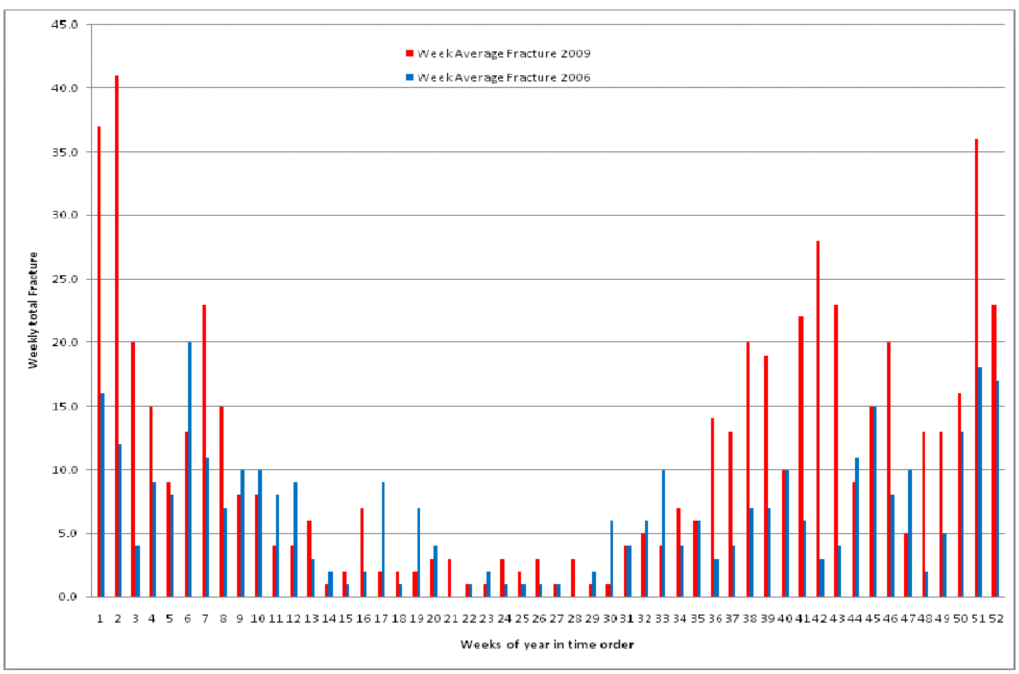

FIGURE 37 - WEEKLY TOTAL FRACTURE v WEEKLY AVERAGE TEMP 2005 & 2009 (NGG NL)

Figure 36 shows the strong seasonality of mains fractures, which occur mostly in winter, when ground temperatures are low and change relatively quickly, typically resulting in significant ground movement. However, fractures also often occur in autumn, when changes in soil moisture may also be relatively rapid and may also result in substantial ground movement.

Overall, the trend shown in Fig 35 may represent an underlying level of deterioration of all cast iron mains. The majority of cast iron mains fractures clearly occur during winter (December to January in 2005 to 2009) and Fig 35 shows the effect of this variable. However, the majority of all remaining cast iron mains fractures occur during autumn (October to November in 2005 to 2009), possibly as a result of soil moisture changes, but Fig 35 cannot adequately reflect the effect of this variable.

Note: Autocorrelation of residuals is the correlation coefficient between residuals at time t and residuals at time (t-1). If the autocorrelation of residuals (R) of the line fitted to the data is greater than $2/\sqrt{N}$, then this suggests that the residuals are not truly independent of one another but have some significant positive autocorrelation. When this data is put in time order, because the average temperature of any week will tend to be related to the temperature of adjacent week in the time series, the residuals were auto-correlated. The tabulated critical t value for testing of differences between the slopes and intercepts will be higher, making it more difficult for there to be a clear and significant result. To correct for this effect, the variance estimate is increased and the Degrees of Freedom (DF) term is adjusted.

6 HISTORICAL REPLACEMENT OF MAINS - 2003 V 2009

Replacement rates for the group of small diameter cast iron mains that contribute most of the fracture related GIBs have been examined in more detail.
Over the period under consideration there has been a small reduction in the amount of the highest risk small diameter cast iron mains being replaced, in 2004, 264 km of the highest 1% predicted risk were replaced, falling to only 229 km of highest 1% risk replaced in 2008. 1% represented 836 km in 2004 and 707 km in 2008. So in both years around 1/3 (32%) of the top 1% was replaced in the following year.

6.1 Highest Risk Mains and Subsequent Fracture & GIBs

The same basis of 100 groups of 1% risk, as earlier, has been used to study the overall risk predicted in 2007 and the corresponding small diameter cast iron mains that were replaced in 2007 and 2008.

The table below shows the amount of each of the three top 1% risk groups that were predicted in 2007, and the subsequent performance in 2008 of the remainder of these groups i.e. the pipe that was not replaced in 2008.

If the 1st 1% group, representing the 1% of small diameter cast iron mains with the highest risk (as predicted for 2007), had been entirely replaced during 2008, the total amount of fracture that subsequently occurred in 2008 may have been reduced by around 5.5%.

However, only around 1/3 of this top 1% group (35%) was actually replaced in 2008 and the remaining 2/3 (65%) that was not replaced, but left in the ground, suffered a total of 276 fractures during 2008.

If the 1st and 2nd top 1% risk groups in 2007 had been replaced during 2008, fractures in 2008 would have been reduced by around 8.0% and GIBs would have reduced by around 14%.

The 3rd top 1% risk group is not so strongly predictive of risk than the first and second. Had the top 2% been replaced, perhaps 8% less fracture may have occurred in the later year.

TABLE 6 - SMALL DIAMETER LP CAST IRON MAINS - PERFORMANCE OF TOP 1%, 2% & 3% RISK (PREDICTED 2007) V ACTUAL PERFORMANCE IN 2008

Risk in 2007 (predicted by MRPS Risk Model)	% not replaced 2007 (left in ground 2008)	No. of Fractures in 2008 (from % left in ground)	% of all fractures in 2008 (from % left in ground)	No. GIBs in 2008 (from % left in ground)	% of all GIBs in 2008 (from % left in ground)
1st 1% Group (Top risk)	**0.65% left (i.e. 0.35% removed)**	**276**	**5.5%**	**47**	**10%**
2nd 1% Group (Second risk)	**0.79% left (i.e. 0.21% removed)**	**119**	**2.4%**	**20**	**4.3%**
3rd 1% Group (Third risk)	**0.84% left (i.e. 0.16% removed)**	**105**	**2.1%**	**7**	**1.5%**
Totals	**Total risk removed 0.72% of top 3%**	**Total Fracture 4966**		**Total GIBs 467**	

7 REPLACEMENT STRATEGIES

If there is a need to improve the targeting of mains for replacement, to reduce the rate of increase in fractures and GIBs in subsequent years, then the following approaches could be considered.

7.1 Small Diameter Mains - ≤8 inch Diameter - MP & LP Cast

Figure 37 shows, for small diameter cast mains, the fracture of mains 8” diameter and below continues to dominate GIBs. There is evidence that the MRPS Risk Modelling process is able to more reliably identify mains most likely to give rise to GIBs than actual incidents and a higher proportion of replacement effort could be focused on these smaller mains with high prediction of GIBs. If at least the top 2% of high risk small diameter cast iron mains are replaced each year; this would represent about 1,200 km/year. Over the last 3 years, ‘at risk’ mains have been replaced at a rate of approx 3,500 km/year, although only a relatively small proportion of this amount appears to have been from the highest risk groups. If effort was focused on the highest risk groups, then, assuming replacement rates do not fall significantly below 3,500 km/year, at least 1,200 km of mains could be selected from the top 2% of risk. The balance of around 2,300 km could be selected from other categories, to give reasonable freedom in optimising replacement to avoid excessive units cost.

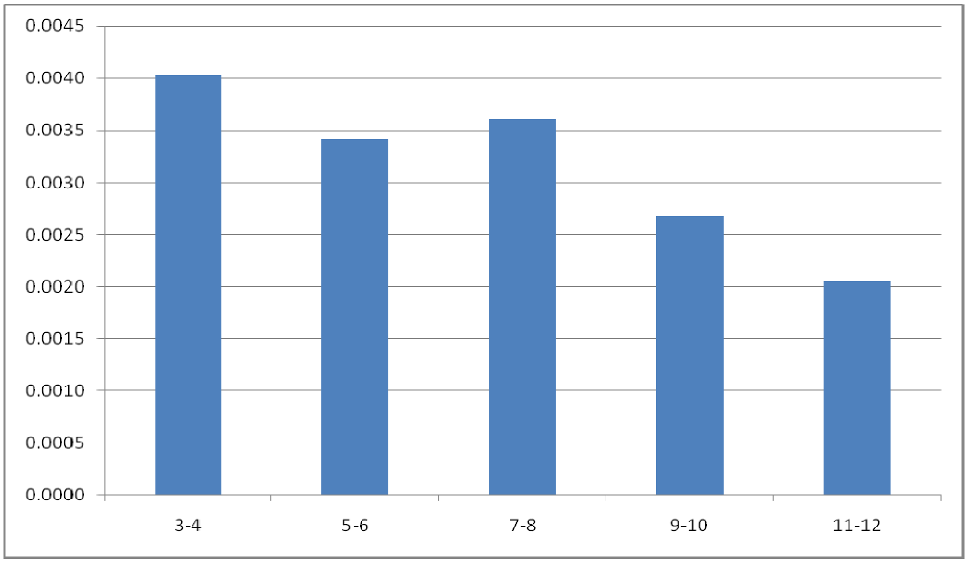

FIGURE 38 - AVERAGE GIB/KM/YEAR v DIAMETER- LP CAST IRON FRACTURE (NGG & SGN)

7.2 Large Diameter Cast ≥12 inch Diameter - MP & LP

Large diameter cast iron mains are subject to failure and are also subject to much the same corrosion drivers and similar loading regimes as smaller mains, although they have a considerably thicker wall. It may be that large diameter cast iron mains need to be subject to a process of remediation or replacement.

Large diameter mains will usually be integral to the operation of a local network and are consequently more difficult to replace and involve more complex operations. Large diameter mains also incur higher excavation/reinstatement and traffic management costs and are disproportionately more expensive to replace than small diameters.

For the largest mains diameters, only steel pipe will be available as replacement, unless operating pressures can be increased to allow smaller diameter PE pipe to be used. Sensibly, any new steel mains would have to be protected from corrosion. Maintenance of corrosion protection systems on buried steel mains in urban areas often poses serious difficulties, where coating integrity cannot be relied upon because of interference damage by other parties. Impressed current systems are often adversely affected by external coating damage and are prone to grounding/earth faults.

It is recognised that suitable lining repair methods for larger diameter cast mains are not currently available but this is an area where development is taking place within the pipeline industries.

Larger diameter iron mains consideration may be given to the development of structural lining methods where there is evidence that the condition of the main warrants. Until such methods are available, replacement of these large diameter mains may be considered for deferment.

It may be appropriate that those mains that have diameter above 8” and below 18” could have their risk score assessed and if high be considered for replacement. If their risk score is low then the main may be considered for deferment to condition based remedial treatment.

8 OTHER NETWORK RISKS

There has been consideration of evidence provided of risks posed by other network assets, not in the replacement programme, that may be subject to degradation

All GDNs report lengths of ductile iron mains, still in operation at MP, some 880 km. It is unclear if these records are in error or if previously miss recorded mains are coming to light. Because the decision has already been enforced to remove this material, its performance has not been considered in this review."

8.1 Steel Mains

Part of the LP & MP network is made up of steel mains where corrosion is likely to be the principal degradation process. Generally, steel mains would have been laid with some corrosion protection, including coatings and perhaps sacrificial anodes. Some parts of the steel system will have impressed current systems providing some measure of corrosion protection. However as time passes, especially in congested urban areas, the efficacy of these protection measures is expected to decline.

There was some 10,400 km of steel distribution main in 2009.

8.1.1 Steel Main Risk

Over period 1990 to 2009 there was 1 incident and 1 fatality related to steel mains. This average of 0.05 fatalities/year, with approximately 40 million people exposed corresponds to a mean individual risk of 1.25×10^{-9} individual risk/year from steel mains. Over that same period, iron mains caused 17 fatalities with an average of 0.85 fatalities/year, corresponding to approximately 21×10^{-9} individual risk/year from iron mains. Information provided by NGG[52] gives estimates of individual risk posed by different classes of distribution mains. For steel mains they estimate an individual risk of 100×10^{-9} based on estimates derived from the MRPS Risk Model.

8.1.2 Steel Mains - Failures and GIBs

Steel mains give rise to failures, mainly corrosion and joint related, and some of these events give rise to GIBs. The graph below illustrates the relative frequency by km of these events for SGN and WWU data for different materials.

[52] GL Report 7451

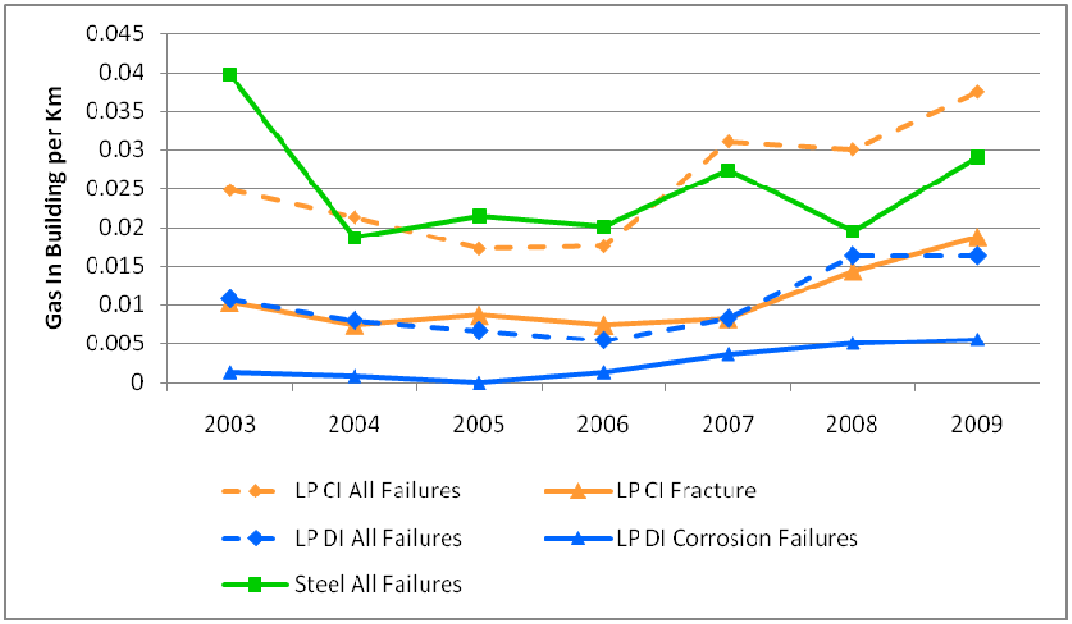

FIGURE 39 - COMPARISON OF GIBS RELATED TO LP CAST, LP DUCTILE AND STEEL (WWU)

From Figure 36 It can be seen that in relation to the frequency of GIBs arising from Steel mains relatively few incidents occur. This is thought to reflect the usual slow onset and relatively small volume of gas released associated with these failures. There is an apparent rising trend in GIBs arising from steel mains failure.

8.2 PE Mains Risk - Non-Interference Damage

The individual risk posed by different classes of gas distribution mains has been estimated. PE mains, based on NGG data[53] and considered to be representative of the UK as a whole, give rise to a calculated individual risk of 1.7×10^{-9} (values derived from actual numbers of failures and associated GIBs. Because of the lack of data, the likelihood of a GIB causing an incident is assumed to be the same for PE and metallic mains.

8.3 Steel Services

8.3.1 Steel Service - Population

Wales and the West estimate 460,000 steel or part steel services and, NGG estimate 1.94×10^6 steel services in use in 2010. That suggests that somewhere between 5×10^6 and 6×10^6 steel or part steel services may be currently in service. Based on WWU data, about 8.0% of total steel services may be connected to steel mains

8.3.2 Steel Services - Rate of Replacement

WWU report an average replacement of 22,700/year, with a total steel population of 460,000. This suggests a replacement rate of about 4.9%. NGG report an estimated 1,942,000 steel services and average replacement rates of 114,000/year, equivalent to 5.9%.

[53] GL Report 7451

It is understood that steel services are not repaired and any fault found gives rise to replacement with PE.

8.3.3 Steel Services - Estimation of Risk

Services are not held on an asset register. The location, material, diameter and age of any individual service is there not known. This means that the opportunity to design and develop a system to predict the relative risk posed by an individual service is very limited. It is understood that GDNs do not attempt to predict risk arising from individual services.

The age of metallic services remaining may be estimated in many cases from the date of the original housing development. Where service failures begin to occur in clusters then this may be expected to be identifiable. At some stage block replacement of all remaining services in an area is desirable to avoid isolated metallic services remaining.

Service failure may be expected to primarily relate to the progression of corrosion. It has already been described that the nature and rate of corrosion combines many factors that are difficult to quantify or estimate. The relatively thin wall thickness, especially near threaded joints and the potential for coating damage on metallic services makes them vulnerable. Localised corrosion at points of coating failure may be expected to advance more rapidly than on completely bare pipe.

The nature of the soil chemistry influences corrosion rates, and this also is a factor that is difficult to reliably assess.

It is likely that the cost of replacement of a service would be less than a process of survey and risk estimation, and a more reliable means of reducing risk.

8.3.4 Steel Services - Incidents

Over period 1990 to 2009 there were 10 incidents and 3 fatalities related to services. One of these was a PE service failure caused by rodents, the other services were steel.

This average of 0.15 fatalities/year, with approximately 40 million people exposed corresponds to a mean individual risk of 3.8×10^{-9} individual risk/year from steel services.

Over that same period, iron mains caused 17 fatalities with an average of 0.85 fatalities/year, corresponding to approximately 2.1×10^{-8} individual risk/year from iron mains.

8.3.5 Steel Services - GIBs

We have limited data on the frequency of GIBs arising from failures on metallic services but WWU have presented some data. WWU alone are reporting between 800 and 1,000 GIBs/year from services. These are made up of corrosion and other failures, believed to be predominantly related to joints.

During the same period WWU were reporting about 6000 failures/year on steel or metallic (probably part steel) services. For the UK as a whole, were it similar to WWU, perhaps 5000 or so GIBs from services/year may be taking place.

It can be seen therefore that relatively few GIBs from service failure give rise to incidents, when compared to, for example, cast iron mains fractures.

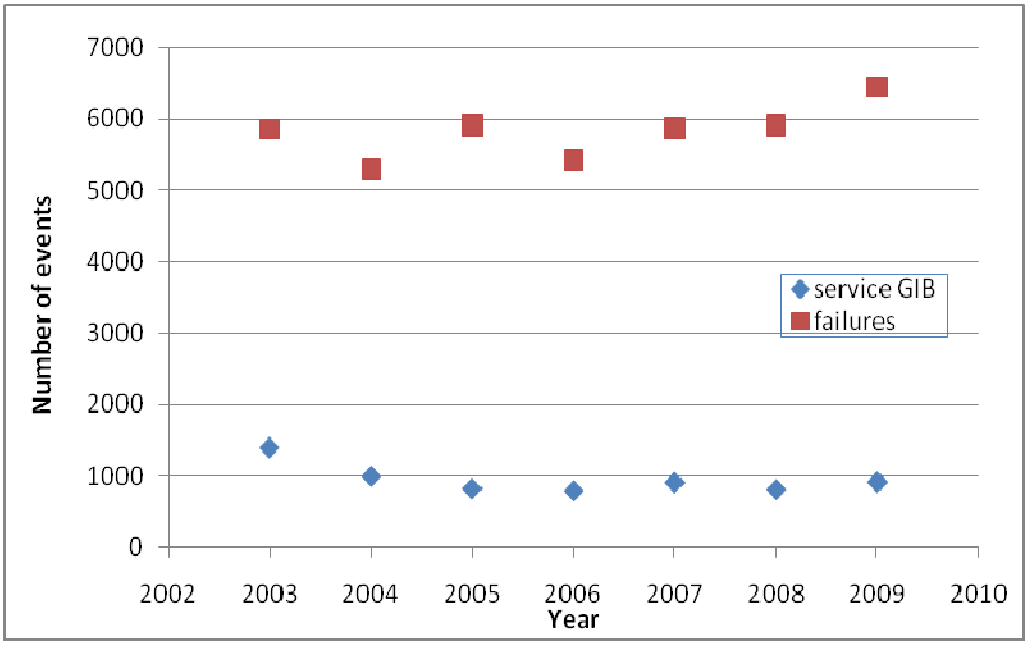

FIGURE 40 - STEEL SERVICE FAILURES & GIBS BY YEAR (WWU)

The above data includes all reports and does not correct for the replacement of steel services during the period. Given that services are always replaced on failure and not repaired, the above plots indicate a rising trend in failure and GIBs from services.

8.3.6 Steel Services - Rate of Replacement v Rate of Deterioration

The quality of information available of services is incomplete. It is not possible to make a reliable estimate of the rate at which steel services are deteriorating. The current level of replacement appears to be between 5% and 6% of the remaining stock, the quantity of which is itself a matter of some uncertainty.

A process of recording service failures and GIBs arising from service failures could be applied. Where GIBs have arisen, the age, and details of the failure and condition of the service involved could be determined and recorded.

8.4 Comparison of Mains and Services (NGG Data)

Table 7 compares the estimated and derived risks created by distribution mains provided by NGG[54]. Several assumptions were necessary in the derivation of the estimates below. The values are somewhat higher than may be derived directly from observed incident frequency.

The difference in risk in the table below between cast iron mains above and below 12” diameter is greater than the apparent difference in risk based on the observed incidents in the last 20 years[55] This data suggests that the average level of risk posed by PE mains, for non-interference damage events, is at least 10 or 20 times less than the metallic mains they are replacing.

[54] GL Report 7451

[55] HID Summary of UK Gas Distribution Mains and Service Related Incidents (1990 to present)

TABLE 7 - COMPARISON OF MAINS & SERVICES - AVERAGE ANNUAL ESTIMATED RISK		
Mains Material	Service Material	Average estimated risk/year to public (non-interference damage x 10^{-9})
Cast Iron ≤12”		52
Cast Iron >12”		320
Ductile Iron		21
Steel, believed unprotected from corrosion		100
PE		2.4
	Metallic	70
	PE	18
	High Rise	71

8.5 Risers in Multi-Dwelling Buildings

Little evidence has been provided on the numbers or age of gas installations in medium or high rise property. No data appears to be available of the frequency of failure or GIBs associated with risers/laterals within medium and high rise buildings.
It is understood that most of these installations are engineered in steel, and that the pipework, although within buildings, may often be subject to localised corrosion.
The number, age and property type could be identified and a sample could have their condition assessed. This may assist in a more meaningful view of the risks posed.
No evidence has been provided of any incidents caused by these installations.

8.6 Gas Holders

No incidents have been reported related to gas holders. No GIB reports have been provided caused by escapes from gas holders.

NGG have provided a detailed assessment of risk posed by holders. This report concluded that one site was close to ‘Unacceptable’ and most sites lay above the ‘broadly acceptable’ level for societal risk.

Risks created by gas holders are greatly influenced by the proximity of occupied buildings. In some locations it is understood that there are continuing issues with encroachment.

Gas holders are necessarily closely associated with the local mains network. The removal of a holder may involve re-engineering of the associated mains network in order that peak gas supplies may be maintained. Also, supply mains to holders will often be large diameter, perhaps relatively long & often MP; district supply mains from holders are similarly likely to be large diameter, but perhaps not as long before reducing to smaller diameters, and probably mostly LP.

Removal or remediation of iron mains in the location of a holder is likely to facilitate the removal of the holder itself and the proportion of large diameter or MP mains within the overall removal or remediation scheme is perhaps less likely to dominate the scheme logistics.

Each gas holder could be treated as part of an engineering system that includes the nearby associated mains network. For this purpose, schemes could be prepared for the removal of relevant holders and appropriate replacement of their nearby mains network, with the overall risk reduction benefits being identified and assessed.

In the selection of schemes for mains replacement and their submission for approval, it is suggested that mains schemes be put forward in combination, where appropriate, with any associated holders existing adjacent to the scheme location.

9 DISCUSSION

Data has been provided that describes the numbers of fractures and corrosion failures on metallic mains during the period 2003 to 2009. These metallic mains are grouped by LP and MP (≤0.75 millibar, >0.75 millibar and ≤2 bar), small and large (≤12 Inch, >12 Inch) diameter cast iron (Pit and Spun) and LP ductile iron.

This data shows that fracture on LP iron mains is the most frequent failure event on these assets both overall and by km installed. GIBs are most frequent for this class of assets also, both overall and by km installed. Small diameter LP cast iron also gives to the greatest number of incidents, although when adjusted by the lengths installed, large diameter cast iron gives rise to a higher frequency.

When incident frequencies are considered over a longer time period, large diameter cast iron gives rise to a slightly higher frequency of incident than small, although based on relatively few events.

When mains categories failures and GIBs are compared on a year by year basis there is either a reduction or no clear trend evident. This applies to the data that includes events on mains that have been replaced during the period.

When the performance of only those mains present in 2009 versus their failure events in earlier years, there is indication of a rising trend in failure and GIBs for small diameter LP cast mains. The increase in GIBs is unusual in that it exceeds the increase in recorded fracture events in corresponding years (reference Figures 21 & 23). This is difficult to explain but may relate to under recording of GIBs in earlier years. This is based on a subset of NGG and SGN data.

There has been a comparison of the risks of the different categories of main based on the observed incidents in the previous 20 years. This suggests that cast iron mains, all sizes and pressures represents most risk, generally caused by fracture, although sometimes reported as accompanied by corrosion. LP ductile iron incidents are corrosion related and pose less risk/km than cast materials.

For those mains, mostly small diameter LP cast, that have caused incidents their predicted risk has been compared to the population of their mains category as a whole. This shows that for 12 mains for which the risk score is known, most often the main had been assigned a relatively low likelihood of causing an incident.

Actual GIBs that took place in 2008 have been compared with the previously assigned risk. This detailed process suggests that the MRPS Risk Model is capable of identifying the top few % of mains that are most likely to give rise to GIBs. This capacity is most well developed for cast iron mains, both small and large diameter, but less strongly expressed for ductile iron.

It appears therefore that the MRPS Risk Modelling process is more reliable at predicting those mains with a high likelihood of causing GIBs than it is at predicting incident likelihood.

There has been more detailed examination of the changes in fracture rates year on year. It is known that iron fracture is influence by temperature, and that therefore changes in fracture rates year on year may be related to changes in weather conditions. For two NGG networks (East Anglia & North London), detailed comparison has been made between the weekly pattern of fracture regressed against the weekly average local temperatures. This has been applied for the years 2005 and 2009 in both areas. In both cases, when adjusted for temperature more fracture events occur in 2009, these events being spread through the year. The yearly regression fits have been tested statistically and the differences are significant and therefore unlikely to arise by chance.

Should this difference be a result of deterioration then it corresponds to an annual increase in fracture rate of between 10% and 15%.

There may be another cause of the difference in fracture rate, perhaps as a result of changes in data gathering and recording. However the observed increase in fracture between 2005 and 2009 is gradual and progressive, year by year, and in both geographic areas. The increase in fracture is also distributed throughout the year on individual days. A data gathering or recording source of the changes might be expected to be more sudden in onset.

This process could be assessed more reliably if it were applied separately for each GDN, and using established temperature series appropriate to the locality and over a longer time period.

There has been comparison of those mains identified as high risk in earlier years, versus how much was replaced in later years. This is for the small diameter LP group of mains. However under the current replacement rationale not all these high risk mains are required to be replaced in the following year, indeed only about 0.35% is replaced of the highest 1%. The remnant 0.65% generates some 5% of fracture and 10% of GIBs for the following year.

Small diameter cast iron mains create the highest proportion of GIBs, by the most dangerous cause, fracture. There has been an increase in recorded GIBs related to fracture, generally driven by the largest class of assets, the small diameter cast.

The risk model is currently used to predict incident likelihood, which it cannot be shown to do reliably for these cast mains. But the risk model can be demonstrated to be capable of identifying the top few % of mains that give rise to the highest likelihood of fractures and GIBs.

If, to reduce the rising trend in fracture and related GIBs, there were to be an increased focus on the replacement of the small diameter mains with the highest likelihood of GIBs, then the top 2% of predicted high risk small diameter cast iron mains could be replaced each year. This would represent some 1200 km/year. In the last 3 years mains at risk are being replaced overall at about 3500 km/year.

It is recognised that there are strong economic advantages is replacing geographically close groups of mains simultaneously and that there needs to be some operational freedom to prepare such schemes by including lower risk mains.

Large diameter cast iron mains, 18” and above, are subject to ongoing corrosion and occasional failure and do need to be subject to a process of remediation or replacement. Incidents on large diameter mains during the last 20 years suggest they represent up to twice as much risk of incident compared to small diameter mains, although based on isolated events. The risk scores for large diameter mains that caused incidents have not been provided, so it has not been possible to evaluate the reliability of the predictive model.

Large diameter mains are more difficult to replace and are disproportionately more expensive to replace than small diameters. For the largest mains diameters, only steel pipe may be suitable as replacement, but this creates difficulties to adequately protect from corrosion in built up areas.

Suitable lining repair methods are not available for larger diameter cast mains although the structural lining processes are subject to development within the pipeline industries. For the larger diameter iron mains, consideration could therefore be given to the development of structural lining methods where there is evidence that the condition of the main warrants. Until such methods are available, replacement of these large diameter mains could be considered for deferment.

For other groups of mains currently included in the replacement programme, intermediate sizes of cast iron and ductile iron could have their risk score assessed. If the risk score is high they may be considered for replacement. If their risk score is low then they may be considered for condition based remedial treatment.

Part of the distribution network is made up of steel mains, and these mains are subject to an uncertain quality of corrosion protection. There is some evidence that failures and GIBs are increasing for this group of assets. This degradation is likely to be corrosion related and to be progressive. The GIBs caused by steel failures give rise to too few incidents for their relative seriousness to be assessed.

Steel mains are failing and causing GIBs and are likely to do so at an increased frequency in the future. From 1990 to 2009, several incidents and fatalities were related to steel services. Information on the location, material, diameter and age of any individual service is not held. This effectively prevents a process of identifying those specific services most at risk. The clustering of failures may allow local problem areas to be identified, but isolated metallic services may not be identified by this process.

There is no information on which to make a reliable estimate of the rate at which steel services may be deteriorating. The current level of replacement appears to be between 5% and 6% of the remaining stock, the quantity of which is itself a matter of some uncertainty. It is not possible to determine if the current rate of replacement is keeping pace with the rate of degradation.

Were service failures and GIBs arising from service failures to be recorded, this may facilitate more detailed considerations. Where GIBs have arisen, the age, and details of the failure and condition of the service involved could be determined and recorded. This may assist in any future investigation into the adequacy of the replacement rate.

There is little information available of the numbers or operational history relating to risers and laterals within medium and high rise buildings, although there is no evidence of any incidents caused by these installations. It is understood that most of these installations are engineered in steel, and may be expected to be subject to localised corrosion. These installations could be identified and a sample could be assessed.

A detailed assessment has been provided of the risks posed by LP gas holders. This concluded that most sites lay above the 'broadly acceptable' level for societal risk. These estimated risks created are greatly influenced by the proximity of occupied buildings to the holder and in some locations there are continuing issues with encroachment.

Each holder could be treated as part of an engineering system that included nearby associated mains. In the selection of schemes for mains replacement approval, it is suggested that the mains could be put forward, where appropriate, with any associated holders existing adjacent to the scheme location.

10 CONCLUSIONS

This study has considered the operational performance of all cast iron gas mains, using data provided by GDNs for the period 2003 to 2009. Fractures and associated GIBs continue to be dominated by small diameter pit and spun cast iron, both overall and when adjusted by km installed. Overall, when reported failures and GIBs for all mains are compared, there is no clear upward trend. However when adjusted to include events from the current mains population, rising trends are evident, mostly related to small pit and spun cast mains.

1) - From incident data over the last 20 years, cast iron fractures represent the highest risk, sometimes influenced by corrosion. LP ductile iron incidents are corrosion related and pose less risk/km than pit and spun cast mains.

2) - Comparison of the predicted risk of mains that have given rise to incidents shows that the mains in question had often been assigned a relatively low likelihood of causing an incident. Comparison of later actual GIBs to the mains risk score shows that a high risk score does correspond to a predominant quantity of GIB reports from those mains. There is evidence that the MRPS Risk Modelling process is more reliable at predicting mains with a high likelihood of causing GIBs than it is at predicting the likelihood of an incident.

3) - Detailed examination of sample data, for both a rural and an urban area, of the relationship between ambient temperature and iron fracture suggests that, when adjusted for temperature, the fracture rate within the remaining iron mains population in rising. This relationship should be examined using a larger data set and over a longer time period, in order that any differences may be more reliably assessed and possible data issues eliminated.

4) - Under current replacement criteria, not all of the highest predicted risk mains are required to be replaced in the following year. However, in the following year, a disproportionate number of fractures and GIBs arise within those high risk mains not replaced. If the top 2% of predicted high risk small cast iron mains were replaced each year, the rising trend in fractures and GIBs may be reduced.

5) - There are strong economic advantages in replacing all groups of mains within a given area at the same time and there needs to be operational scope to design such schemes which include lower risk mains.

6) - Large diameter cast iron mains are deteriorating and are subject to occasional failure, and it may be considered that they need to be subject to a process of remediation or replacement. These mains are more difficult to replace than small diameters and are disproportionately more expensive. There is limited

choice of suitable materials for the replacement of the largest mains, especially 18” and above. Currently, large diameter lining repair methods with appropriate structural strength are not available, although improved liner systems are under development.

7) - For larger diameter iron mains, especially 18 inch and above, consideration may be given to structural lining methods and their development. Until such systems are available, replacement of large diameter mains could be considered for deferment. This guidance may be reviewed should the repair systems prove unfeasible or uneconomic or the failure rates of these assets gives increased cause for concern.

8) - Intermediate sizes of cast and ductile iron mains, from 8 inch to 18 inch, could have their risk score assessed and, if the risk is high, may be considered for replacement. If the risk is low, then a condition based remedial treatment may be considered more appropriate than replacement.

9) - Steel distribution mains are not replaced under 30:30 programme and there is evidence that failures and GIBs from steel mains assets are increasing. This degradation is considered likely to be corrosion related and to be progressive.

10) From 1990 to 2009, several incidents were related to steel services. The lack of data on individual services prevents the identification of specific services at most risk. The current level of service replacement appears to be between 5% and 6% of the remaining stock, the quantity of which is itself a matter of some uncertainty. It has not been possible to confirm that the current replacement rate is keeping pace with their rate of degradation. Where GIBs arise from service failures, the age and condition of the service and details of its failure could be recorded.

11) Little data is available of the numbers or operational history of risers and laterals within medium and high rise buildings. A sample of these installations could be identified and assessed.

12) A detailed assessment has been provided by GDNs of the risks posed by LP gas holders, which concluded that most holder sites lay above the ‘Broadly Acceptable’ level for societal risk. These estimated risks are greatly influenced by the proximity of occupied buildings to the holder and there are continuing issues with encroachment at some holder sites. Each holder could be treated as part of an engineering system that included the associated mains supply network nearby. Mains replacement schemes could then be put forward, where appropriate, including any associated holders existing adjacent to the location of the proposed replacement scheme.

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HSE/Ofgem: 10 year review of the Iron Mains Replacement Programme

The Iron Mains Replacement Programme (IMRP) was introduced in 2002 to address 'societal concern' regarding the potential for failure of cast iron gas mains and the consequent risk of injuries, fatalities and damage to buildings (defined as incidents). The objective of the IMRP was to decommission all cast iron mains within 30 metres of property in 30 years - the IMRP is often referred to as the '30/30' programme. The IMRP accelerated the replacement of cast iron mains to a level that was estimated to be as fast as practicable at that time, given the potential risks faced by society and the resources required. The IMRP excluded steel mains and services from the replacement programme as potential risks from steel, at that time, were considered to be at a lower level than risks from cast iron mains.

The Health & Safety Executive (HSE) and Office of Gas and Electricity Markets (Ofgem) have commissioned jointly an independent review to assess the progress of the IMRP to date, and evaluate potential options for the remaining 20 years of the original programme. Cambridge Economic Policy Associates (CEPA), working in partnership with Advanced Engineering Solutions Ltd (AESL), has been contracted by the HSE and Ofgem to conduct this review.

Advanced Engineering Solutions Ltd has considered the overall performance of the IMRP since 2002, as evident from assessment of operational data provided by all Gas Distribution Networks (GDNs). This technical report records the apparent performance of the IMRP, as evident from the data study, and any perceived characteristics or other observations arising from the study. The AESL analysis is intended to inform and advise CEPA of technical issues relevant to this report "HSE/OFGEM: 10 Year Review of the Iron Mains Replacement Programme".

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