21ST CENTURY DRAINAGE PROGRAMME

CAPACITY ASSESSMENT FRAMEWORK PROJECT REPORT

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Project Management	**John Spence, on behalf of WaterUK**
Contractor	**HR Wallingford**
Sub-Contractor	**None**
Author of Report	**Gorton, Elizabeth** **Kellagher, Richard** **Udale-Clarke, Helen**
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Co-chairs	**Ed Bramley, Yorkshire Water** **Phil Hulme, Environment Agency**

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21ST CENTURY DRAINAGE PROGRAMME - CAPACITY ASSESSMENT FRAMEWORK: PROJECT REPORT

Summary

The vision of the 21st Century Drainage Programme is to enable the UK water industry, in partnership with the UK's governments and regulators, to make plans now that will ensure the sustainability of our drainage infrastructure in the future.

The Programme recognises the need to move away from the short-term delivery of levels of service towards planning for long-term resilience. This requires measurement of the current and future performance of all of our drainage systems at a national scale. This will provide the foundation for making decisions for achieving a defined future level of resilience and to identify the interventions necessary to achieve this level now and in the future.

Part of this Programme is to understand the available capacity in the UK's drainage systems to accommodate the flows expected in the future. This project has developed a consistent, transparent and high-level approach to assessing available capacity, which has been called *The 21st Century Drainage Programme Capacity Assessment Framework*.

This document provides details of the research and testing carried out to develop the Framework. A separate document is also available that provides the guidance on how to apply the Framework to foul and combined drainage systems.

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Acronyms

AMP	Asset Management Period or Plan
CSO	Combined Sewer Overflow
DAP	Drainage Area Plan
DSF	Drainage Strategy Framework
DWF	Dry Weather Flow
EDM	Event Duration Monitoring
EO	Emergency Overflow
FEH	Flood Estimation Handbook
FME	Feature Manipulation Engine
FSR	Flood Studies Report
LDP	Local Development Plan
LoS	Level of Service
P50	Probability of occurrence of 50% for any modelled climate scenario
PR19	Price Review 2019
PSG	Project Steering Group
Q95	Flow rate that is equalled or exceeded 95% of the time
RAG	Red Amber Green
RP	Return Period
SAAR	Standard Average Annual Rainfall
SQL	Structured Query Language
SuDS	Sustainable Drainage System
TSR	Time Series Rainfall
UKCP09	UK Climate Projections 2009
UKCP18	UK Climate Projections 2018
UKWIR	UK Water Industry Research Ltd

WaSC	Water and Sewerage Company
WRMP	Water Resources Management Plan
WwTW	Wastewater Treatment Works

1 Introduction

1.1 The Programme

The vision of the 21st Century Drainage Programme is to enable the UK water industry, in partnership with the UK's governments and regulators, to make plans now that will ensure the sustainability of our drainage infrastructure in the future.

The Programme recognises the need to move away from the short-term delivery of levels of service towards planning for long-term resilience. This requires measurement of the current and future performance of all of our drainage systems at a national scale. This will provide the foundation for making decisions for achieving a defined future level of resilience and to identify the interventions necessary to achieve this level now and in the future.

1.2 This project

This project has developed a consistent, transparent and high-level approach to assessing the available capacity in the UK's drainage systems to accommodate the flows expected in the future - *The 21st Century Drainage Programme Capacity Assessment Framework*.

The project started in October 2016. The first key milestone for the project was a knowledge gathering workshop, which took place on 15th December 2016. A record of the workshop and the conclusions drawn by the project team were provided to participants in the Workshop Report, which was issued on 17th January 2017.

The technical work to develop the Framework and to test it on four pilot catchments was completed by the end of March 2017.

This report forms one of three final documents, the others being the Executive Summary and the Guidance Document. This report provides a detailed account of the work completed and supporting information for the Guidance Document. Information provided in the Guidance Document is generally not repeated in this report. Therefore, reference should be made to the Guidance Document whilst reading this report.

A further deliverable was a dissemination seminar that was held on 27th April 2017 to an invited audience.

This project was given a tight timetable, so that sewerage undertakers would be able to apply the Framework to their analysis work for PR19 and other equivalent regulatory regimes. Therefore, this project looked at foul and combined sewerage systems only, but with consideration of how any recommendations and methods might also be suitable for application to surface water systems.

1.3 The significance of drainage capacity

When quantifying the performance of our drainage systems, we usually express this as outcomes for stakeholders in terms of:

- Enabling new development
- Preventing network escapes
- Preventing adverse environmental impacts (including amenity use).

Pressures on systems arise due to:

- Loss of available capacity
- Deterioration of the fabric of the network
- Operational reasons, such as sewer misuse.

The focus of this project was on the first of these pressures - loss of available capacity - whilst recognising the interdependence between all three.

Loss of capacity can occur for a number of reasons, including (but not limited to):

- Changes in rainfall due to climate change
- Increases in population
- Increases in impermeable area, due to urban creep, infill development and development growth
- Increases in infiltration.

The overall objective of the project was to better understand the linkage between present-day and future pressures on hydraulic capacity and outcomes, and also available interventions. In other words, we need to know:

- When will drainage systems have insufficient capacity and the risk of failing too often becomes unacceptable?
- What do we need to do to prevent this happening?
- When will we need to do it?

We want to be able to do this in a consistent way across the industry, taking advantage of the metrics and methods already in use, but improving on these where necessary. This includes ensuring that existing management frameworks can be updated or supplemented based on the recommendations and guidance from of this project. Thus providing part of the toolkit required by sewerage undertakers to move to long-term wastewater planning.

2 The 21st Century Drainage Programme Capacity Assessment Framework

2.1 Purpose

The overall aim was to provide part of the toolkit required to enable sewerage undertakers to move towards and embed long-term planning. The intention was also to enable dialogue to take place between sewerage undertakers and government agencies and other stakeholders regarding risks associated with the diminishing available capacity and investment requirements in the longer term.

Hence, the requirements of the Framework were:

- To provide information on the impact of present-day and future pressures on sewerage systems, specifically to show the change in available capacity over time and the likely type of investment required to address any loss in available capacity;
- To take into account uncertainties;
- To be in keeping with best practice and latest research;
- To be suitable for assessing surface water systems (although this project is only looking at foul and combined sewerage systems);
- To dovetail with other planning activities by sewerage undertakers, without creating contradictions on investment planning produced by more detailed assessments and frameworks already in place (see Section 2.3);
- To enable selection of either a simple assessment approach where drainage models do not already exist (Initial Method) or a more detailed assessment approach where there are existing drainage models (Enhanced Method);
- To be sufficiently straightforward that it does not create a significant additional burden on sewerage undertakers (i.e. the choice of performance metrics needs to be such that analysis can be carried out as rapidly and simply as possible whichever method is used);
- To provide outputs that are suitable for informing all stakeholders, not just sewerage undertakers.

Additional aspirations of the Framework included:

- To be sufficiently flexible, so that guidance/methods can be updated in the future based on latest research (e.g. better understanding of infill development) and changes in future projections (e.g. the migration from UKCP09 to UKCP18) without undermining the concepts behind the Framework;
- To be sufficiently flexible so that it could include other types of drainage performance assessment, such as pipe deterioration;

- To encourage all sewerage undertakers to reach an “agreed minimum standard” with their network data and modelling methods.

Detailed procedures are already in place for determining investment requirements on a 5-year cycle, which tend to focus on key “local” problem areas in networks. The Framework described in this report complements the current methods of drainage planning by providing an approach that enables long-term planning.

The Drainage Strategy Framework (DSF) is the prime approach currently used by UK sewerage undertakers in carrying out drainage planning. The Framework described in this report is different from the DSF in three distinct ways:

1. This Framework is primarily for high-level (i.e. regional and national) long-term planning, whilst the DSF is for much more detailed planning determined by “local” circumstances.

2. This Framework proposes a common set of metrics for use by all sewerage undertakers.

3. This Framework operates at a different time scale from the DSF.

The high-level assessment of system capacity does not conflict with existing procedures, as reporting is at a catchment scale using a few simple but relevant metrics.

There is limited scope for interventions to be analysed at the high-level, as this is done in an automated, catchment-wide way and, therefore, has implications for investment accuracy. Detailed intervention analysis, where it is considered appropriate, can be accommodated within the Framework to provide a more accurate assessment. However, at the national reporting level a distinction is not made between catchments that have had detailed intervention analysis and those that have not.

2.2 Framework development

In order to develop the Framework, four fundamental questions were considered:

1. What information/data was to be provided by the Framework?

2. How would this information/data be generated?

3. Who was this information/data for?

4. What decisions would be made with this information/data?

Subsidiary questions included:

a) What information/data already exists?

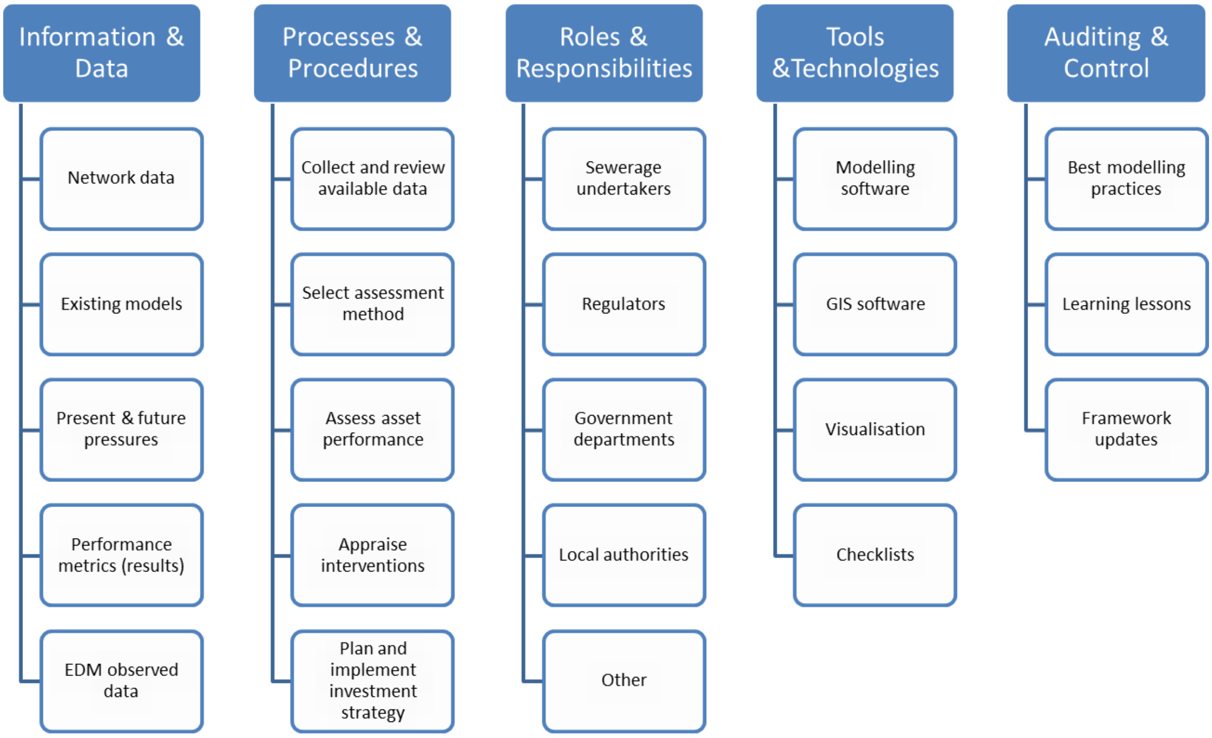
b) How accurate is the information/data (both incoming and outgoing)?

c) How can information/data (both incoming and outgoing) be updated in the future?

d) How can the Framework be updated in the future?

The content of the Framework was be grouped into five categories as shown in Figure 1.[1]

Figure 1 The content of the Framework



The five steps under "Processes & Procedures" are shown again in Figure 2. These form the main structure for the Framework, mirroring many risk assessment and decision-making frameworks that have gone before. These five steps have been broken down further in Figure 3.

[1] This is based on the "Business Elements Method" developed by Bernard Dyer at the London School of Economics, in conjuncture with HR Wallingford.

Figure 2 The five steps of the Framework

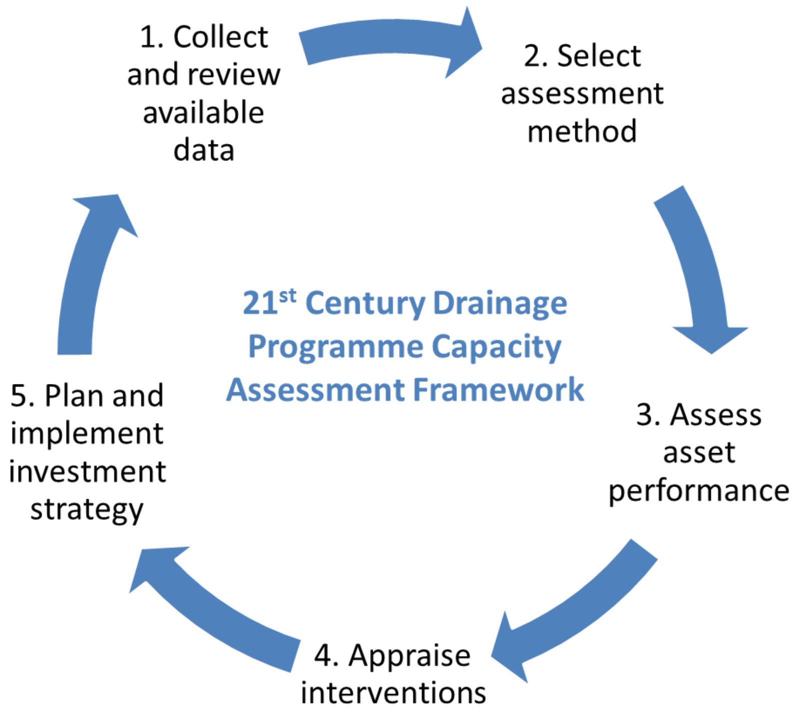
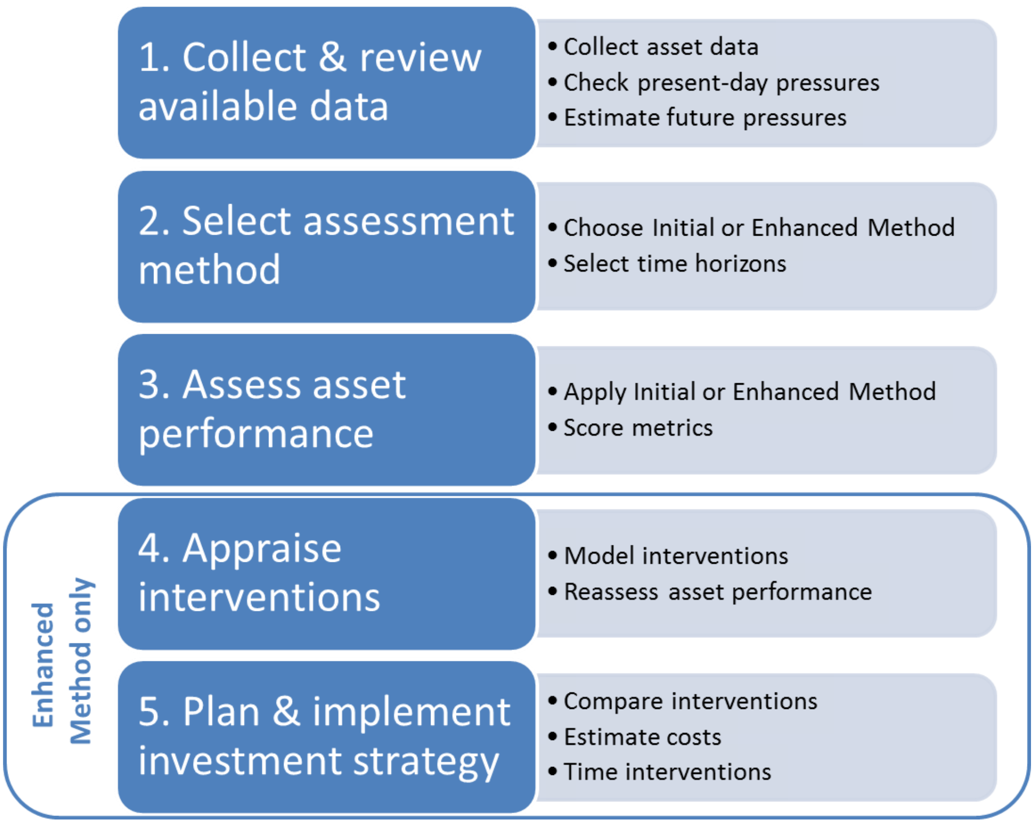


Figure 3 A breakdown of the five steps of the Framework



2.3 Time horizons

The Framework is aimed at a long-term horizon, which has been taken to be 25 years. However, the Framework also allows the consideration of alternative time horizons.

Some intervention strategies may have a design horizon that is longer than 25 years. For example, many city strategies that are focusing on implementing green infrastructure, integrating the whole water cycle or creating completely separate systems in the longer term (e.g. Rotterdam, Copenhagen, New York, Philadelphia, Oregon) have time horizons of 30 years or longer. Therefore, where sewerage undertakers see a need for a more distant time horizon, they can apply the Framework methodology to do this.

The Framework also enables sewerage undertakers to look at whether the options they have identified as part of their 5-year planning cycle are resilient in the long-term, as well as proving beneficial in the short-term, by using 5-yearly snapshots. These snapshots can either be determined by undertaking additional model simulations or by interpolating the projected change between the present-day and the 25-year time horizon.

Guidance on selecting time horizons is provided in Section 4.2 of the Guidance Document. Guidance on how to use these results to compare interventions is provided in Section 7.1 of the Guidance Document.

2.4 Metrics

2.4.1 Selection

As stated earlier, the aim of this project and the Framework was to provide a high-level understanding of available capacity across the UK, along with information on “projected” change of the system state over time and an appraisal of potential long-term interventions to address any change.

Also stated earlier, the choice of metrics needed to be such that analysis could be carried out rapidly and simply, but also as comprehensively as possible. In other words, the picture for the UK needs to be sufficiently complete that a high-level view can be taken now regarding long-term investment needs, not at some unknown point in the future when there may be more models, better network data, etc.

Therefore, suitable metrics were identified based on the following requirements:

- They should provide an indication of the available capacity of all foul and combined sewerage assets;
- They can be used in combination (i.e. a range of metrics could be used);
- They are equally applicable for measuring present-day and future available capacity;
- They are able to indicate change in available capacity as a result of intervention;
- They can be measured (quantified) rapidly and simply;

- They can be applied to a sufficiently large proportion of networks across the UK to provide the "big picture";

- They are, ideally, leading indicators of Level of Service (LoS).

Key to understanding the selection of metrics is the differentiation between the LoS and the underlying available capacity of a sewerage system. The focus of this project was on how to define and manage available capacity, but with an understanding of how this can provide an indication of LoS. To clarify:

- Available capacity is seen as a total network/catchment-wide measure of performance using a range of metrics.

- LoS is seen as being a specific term used by the industry which often focuses at points of failure in the catchment (i.e. impacts on customers).

- The metrics for reporting change in available capacity should aim to provide a good correlation with changes in LoS and, hence, act as leading indicators of that change.

There are two fundamentally different categories of available capacity information that can be provided. These are:

- Asset-based information (flow rate/surcharge analysis);

- Performance-based information (flooding/spills analysis).

Asset-based information is not directly linked to performance-based information, but both are important. Similarly performance-based metrics associated with LoS are a specific set of metrics.

Measures such as volumes of flooding, number of points of flooding, numbers of property or people flooded provide quantification of performance as alternatives to pipe flow rate analysis.

Similarly for CSOs, spill frequency and spill volume reflect performance as an alternative to flow rate analysis (incoming and outgoing pipes).

This project looked for appropriate ways of measuring available capacity of the system, but also investigated the relationship between this information with LoS, to establish which metrics can act as leading indicators for LoS. The results of these investigations are provided in Section 7.

Return periods used for each type of metric need to be appropriate to ensure that the full range of capacities in all networks is assessed. Similarly TSR analysis needs to bear in mind the seasonal focus that is important for some, if not all, catchments.

The metrics that were considered by this project, following the discussion at the workshop in December 2016, are listed in Table 1.

Table 1 Metrics considered by this project

Pipes	CSOs
Pipe full capacity / Dry weather flow (DWF) Surcharge return period Flooding return period Flood volume for a specified return period	Continuation pipe full capacity / DWF CSO spill potential (i.e. Continuation pipe full capacity / Incoming pipe full capacity) Number of CSO spills per year Number of CSO spills per summer (June, July, August) CSO spill volume per year

These metrics were tested on the four pilot catchments:

- To check that the metrics selected were effective at highlighting where pipe and CSO capacities were or were not adequate, and
- To show that the metrics were a reasonable surrogate for indicating the Level of Service.

This resulted in the rationalised list given in Table 2. This selection was based on the following conclusions, which are discussed in more detail in Section 8.

- Ten times DWF provides greater sensitivity to the ratio of pipe capacity to DWF.
- The use of 10 x DWF for CSO assessment effectively is a measure of 5 times pass forward for a DWF factor of 2.
- By using the same DWF factor for assessing pipes and CSOs, the number of simulations required is reduced.
- Pipe surcharge provides a more complete picture of pipe capacity for an entire drainage system compared to flooded nodes, yet still gives a strong indication of likely flooding.
- CSO spill potential (i.e. continuation pipe full capacity / incoming pipe full capacity) does not show change over time and, therefore, has little value as a metric for this Framework.
- CSO spill volume can only be used as an indicator of performance if coupled with the characteristics of the receiving water course, which would have been too challenging for this Framework at this stage.

Table 2 Selected metrics for the Framework

	Initial Method	Enhanced Method
Pipes	Pipe full capacity / Factored DWF	Surcharge return period
CSOs	Continuation pipe full capacity / Factored DWF	Number of CSO spills per year Number of CSO spills per summer

2.4.2 Scoring

Indicator measures or "scores" based on the results obtained for the metrics are needed to help form a judgement on asset performance. However, in the absence of specified LoS targets, these are arbitrary and can be modified depending on what the user of the data is looking for. Thus rather than 30% and 50% of the pipe capacity be used, 25% and 60% might be used instead.

Two stages to the scoring process have been developed for the Framework:

- Firstly, the **individual score** for each pipe or CSO in the drainage system needs to be scored.

- Then an **aggregate score** is determined for the area of the assessment and this is dependent on the scale being considered (i.e. national, regional or catchment-specific).

A key consideration for the Framework was how the aggregate score should be reported, e.g. based on total number of pipes, total length of pipe or the population equivalent upstream. For normalisation of information, the population equivalent upstream was considered potentially useful.

Disaggregation of the information, based on (for example) pipe diameter (see Figure 4) was also considered.

As part of the testing of the pilot catchments, these alternatives were reviewed for their benefit compared to effort in reporting. It was concluded that:

- Number of pipes is too dependent on the characteristics of the network and does not give an overall picture of available capacity.

- By far the majority of pipes are 300 mm diameter or less, whilst those with insufficient pipe capacity generally have diameters of more than 300 mm. Therefore, reporting based on pipe diameter would be fairly onerous if it were to be meaningful.

Scoring for an example metric is provided in Table 3. Proposed scoring for all metrics is provided in the Guidance Document.

Figure 4 Example RAG scoring based on pipe diameter

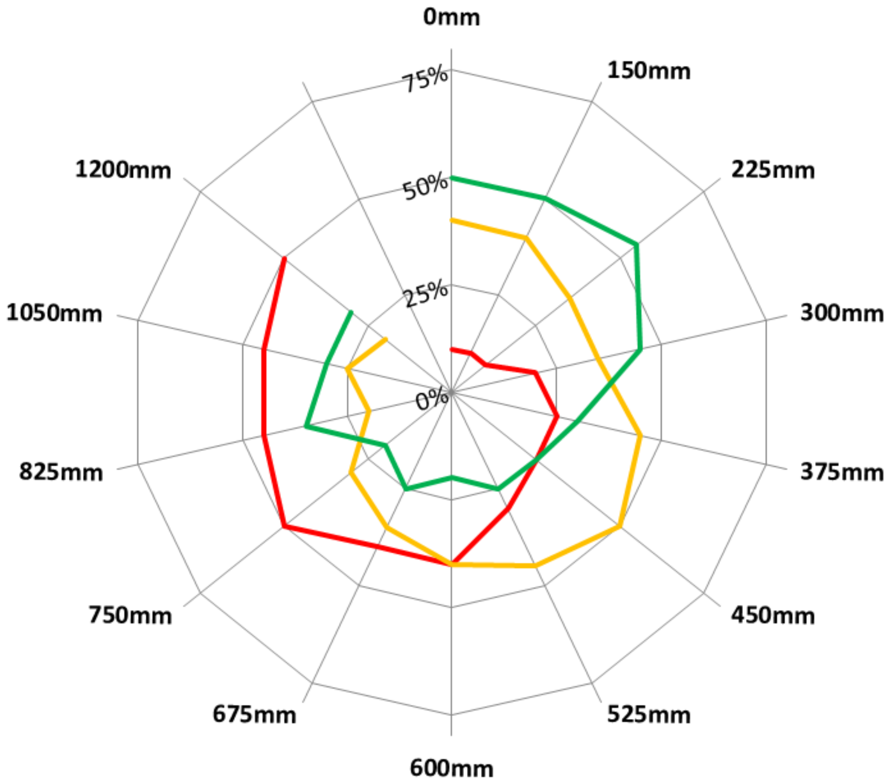


Table 3 Scoring of metric - Enhanced Method - Surcharge return period

Individual score		**Aggregate score**	
Colour	**Range (RP)**	**Colour**	**Range (%)**
Green Amber Red	> 10 > 2, but ≤ 10 ≤ 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100

3 Modelling approach

The modelling approach adopted for assessing asset performance for an individual drainage system is dictated by whether an hydraulic model is available and whether it is suitable for use (see Section 3.2.1).

The following sections provide descriptions of the two methods available in the Framework:

1. The Initial Method, if there is no existing model or the existing model is not suitable for use, and

2. The Enhanced Method, if there is an existing model suitable for use.

3.1 Initial Method

If there is no existing hydraulic model of the network, then the Initial Method should be applied to determine available capacity. However, this assumes that all of the required network information is available and this can be imported into modelling software for analysis purposes (see Section 3.1.1).

There are limitations with using this method that should be taken into consideration:

- This method cannot be applied if there is not sufficient data on pipe connectivity and gradient.
- This method cannot be applied if there is missing data for ancillaries, such as CSOs and pumping stations.
- This method does not include consideration of infiltration, which may mean that DWF is underestimated.
- This method does not include contributing areas. Therefore, system performance and future pressures that are related to rainfall response are not assessed.
- This method precludes appraisal of high-level interventions, as interventions used by this Framework are only based on area removal (see Section 5.1).

Application of the Initial Method results in more limited measures of asset performance than the Enhanced Method and only provides a limited understanding of drainage capacity. This has been demonstrated by comparing the Initial Method results and the Enhanced Method results for the four pilot catchments (see Section 7.8).

Where sufficient data is not available for undertaking the Initial Method, no assessment is carried out. This in itself provides useful information and it is seen as a means of identifying future needs in improving network data.

Over time, the number of catchments where the Initial Method will need to be used is expected to decrease as models of all systems get developed.

3.1.1 Model creation

It is felt that a GIS based assessment of asset performance has too many difficulties, but where it is possible to produce a model of the network with reliable asset data and connectivity then performance assessments based purely on dry weather flow is worth measuring.

If this strategy is taken, it is believed that the application of the Framework would create sufficient incentive that these “Initial Models” would be created in areas without existing models, and over time these would be developed into “Enhanced Models”.

The steps to be undertaken to build an Initial Model are provided in Section 5.1.1 of the Guidance Document.

3.1.2 Model simulations

The full list of simulations required is provided in Section 5.1.2 of the Guidance Document.

As the Initial Method only models dry weather flows, the number of simulations required is small (i.e. only four simulations are needed for modelling present-day and the 25-year time horizon only).

3.1.3 Model outputs

Model outputs are needed for both calculating the metrics and for visualisation purposes.

A full list of the model outputs that need to be exported is provided in Section 5.1.3 of the Guidance Document.

3.2 Enhanced Method

If there is an existing hydraulic model of the network, then the Enhanced Method should be applied to determine available capacity. Existing models are assumed to be verified, and although the verification of these networks will vary in quality (for example only parts of the modelled network might have been verified), the Framework assumes that all models can be used.

The decision not to use an existing model, due to the belief that it is not a 'good' model or 'demote' it and apply the Initial Method would be a matter for the sewerage undertaker.

It was considered that trying to stipulate a minimum quality of model for use in the Framework would be fraught with difficulty and would add a considerable burden on sewerage undertakers.

The main benefits of applying the Enhanced Method rather than the Initial Method are:

- The metrics used with the Enhanced Method are more robust and likely to give a more reliable indication of available capacity;

- The impact of future pressures and the effects of possible interventions can only be carried out using the Enhanced Method.

The premise of the Enhanced Method is that the sewerage undertaker will take all existing models and apply simple rules for assessing the drainage system (for present-day and future pressures) without making any detailed model investigations and interventions. However, there will be drainage systems where investment strategies have been developed and where future models have already been produced that include interventions. The Framework does not preclude applying the Enhanced Method to these pre-existing models. But the Framework does not distinguish between the results from these models and those based on the method described in the Guidance Document.

3.2.1 Model requirements

Hydraulic models should be used where they exist. Details of what would be deemed a suitable model are provided in Section 3.1.1 of the Guidance Document.

As stated earlier, the Framework does not address the quality of existing models. Most existing models will have been verified, although the verification of these networks will vary in quality (for example only parts of the modelled network might have been verified). The Framework treats all of these models the same. The presumption is that for the purposes of a high-level assessment, any model with contributing areas will be sufficiently more advanced than an Initial Model that the assessment of the metrics used by the Enhanced Method will be meaningful.

Although models in the past have been simplified, it is assumed for this Framework that all owned assets are represented in the models (pipes and manholes and other structures). Other assets such as local highway drainage that contribute flows to foul systems should be included (but distinguishable as not being owned by the sewerage undertaker), or at least the contributing areas providing the flows are represented.

There may be downstream boundary conditions that could influence the capacity assessment for some pipes and, therefore, these boundary states should be modelled.

If there is more than one model for the area, the decision of which model to use lies with the sewerage undertaker. It is likely that the summer version will be more pertinent if the receiving environment or flood risk is critical, but winter models would be more pertinent where there are very high infiltration rates or high risks associated with countryside overland flow impacting on the catchment.

3.2.2 Rainfall

Rainfall data is only required for determining runoff response and, therefore, is only used with existing models as part of the Enhanced Method.

Both design storms and time series rainfall (TSR) are required for assessment purposes with the Enhanced Method.

The rainfall data used should, wherever possible, be the same as that used with the existing model.

Details of the rainfall data required for the present-day and the future are provided in Section 3.2.2 and Section 3.3.4 respectively in the Guidance Document.

3.2.3 Model simulations

The number of simulations required for the Enhanced Method is much greater than the Initial Method due to the need to model multiple design storms and TSR and the model will be used to assess present-day and future pressures and interventions.

The total number of simulations is dependent on the approach adopted to take into account uncertainties in future pressures. Assessing future pressures is very uncertain due to the nature of the assumptions that need to be made (see Section 4.1). However if this information is treated as being indicative, i.e. 'What if', rather than a best estimate based on a detailed examination of the evidence, it enables scenarios to be considered rather than dependence on obtaining a single prediction. This does not mean that a best estimate cannot be made of a future state, but it does enable an assessment of other states. More than one future scenario would need to be run in the model to enable this approach to be used. The options are as follows:

1. If population, growth and urban creep are assessed independently, then analysis of various system states in the future would probably become overly complicated due to the very large number of combinations.

2. If one assumes two parameters of area and climate change (where area is a function of urban creep and growth and population), then a central forecast with a plus/minus high – low range would result in 9 combinations and therefore 9 runs (see Table 4). This still results in a lot of simulations.

3. Alternatively, if the two parameters of area and climate change are considered together, i.e. low area is combined with low climate change, etc., then the number of combinations could be limited to three (see Table 4).

Table 4 Model simulations for assessing future pressures - Enhanced Method

<table>
<tr><td colspan="2"></td><td colspan="3">Area change</td></tr>
<tr><td colspan="2"></td><td>Low</td><td>Central</td><td>High</td></tr>
<tr><td rowspan="3">Climate change</td><td>Low</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>Central</td><td>✓</td><td>✓</td><td>✓</td></tr>
<tr><td>High</td><td>✓</td><td>✓</td><td>✓</td></tr>
</table>

On the basis of applying option 3 above, Table 5 provides an overview of the number of model simulations that would be required when applying the Enhanced Method. In this table it has also been assumed that for the appraisal of interventions, only the central/central estimate of future pressures (area central estimate and climate change central estimate) will be used. Hence, this table shows the minimum number of model simulations required. Sewerage undertakers may wish to carry out additional simulations when appraising interventions, if decision-making is deemed sensitive to this uncertainty.

Table 5 Minimum number of model simulations required - Enhanced Method

	Present-day	Future	Future with interventions	Total
Design storms	12*	36**	12***	
TSR	1	3	1	
Interventions	_	_	4 (see Section 5.1)	
Total number of simulations	13	39	52	**104**

Notes:

* assuming only 3 storm durations are needed

** with climate change (low, central, high)

*** with climate change (central only)

Table 5 is based on only having one future time horizon to assess (which is assumed as 25 years). If the 5-yearly snapshots were to be based on results from model simulations for each time period, then the number of simulations would multiply by five to assess future available capacity and future available capacity with interventions, which would result in 468 simulations in total.

Where sewerage undertakers have over 400 foul or combined sewerage systems, this was considered too onerous and some rationalisation is needed - by reducing the number of future scenarios (i.e. only using the central climate change) and/or using interpolation instead.

Ultimately, the decision as to whether to carry out simulations at 5-yearly intervals can lie with the sewerage undertakers. The Framework can accommodate this, should this been seen as beneficial.

Should 5-yearly snapshots be determined by model simulations, this has implications for different TSR being created. It is recommended that only present-day and future 25-year TSR are used, with all future snapshots based on the future 25-year rainfall. This provides a precautionary approach and removes the issue of uncertainty over rate of change in rainfall patterns. There could be a high and low TSR created for 25 years, or any preferred alternative horizon. But this will then also increase the number of simulations significantly.

3.2.4 Model outputs

Model outputs are needed for both calculating the metrics and for visualisation purposes.

A full list of the model simulation results that need to be exported is provided in Section 5.2.3 of the Guidance Document.

4 Present and future pressures

This section discusses the approach to obtaining information for populating Initial models for both their present day as well as future pressures on the system. In the case of Enhanced models the present day state should already be represented in the system unless the model is considered to be either old or deficient in some way.

There is considerable difficulty in projecting future pressures for a time horizon 25 years ahead. This is the case for two reasons; firstly because change is always uncertain for whatever topic area is being considered, but secondly because this Framework is a high-level approach which is constrained in the ways in which change can be applied to the drainage model without detailed intervention. The issue of uncertainty and each of the topic areas for change is discussed in this chapter, with more detail provided in supporting appendices.

4.1 Uncertainty

Uncertainty associated with the prediction of results can be developed either by examining each of the constituent variables and parameters and attempting to represent these explicitly or by carrying out sensitivity analysis to gain an understanding of the influence of variables.

Trends can also be used to extrapolate information, if one assumes that future change is in line with recent past change. Examination of the past 10 years of any rainfall data set can provide an assessment of the mean and distribution of rainfall in each season and across each year. Although future rainfall change is expected, but to some degree is unknown, this type of analysis provides a way of assessing the limits of likely change in the next decade, but this will become less useful as the period extends over which the estimate/prediction is needed.

The time period over which an estimate is being made is a critical feature of change. The population change in an area from the current situation to the next year or two will be small. If a major change is to take place, information on any major development will be known. However, local area development plans will be based on timelines of 5 to 10 years, so information on a 25-year projection cannot really depend on such planning and more generalised information from other sources such as the Office of National Statistics have to be used in conjunction with near-horizon planning

The relative influence of a parameter with uncertainty is also an important consideration. Quite significant population growth may take place based on separate drainage systems, but the increase in foul flow and any misconnected paved runoff is still likely to be small if it drains into a combined system. In this case, assuming that this system remains a combined system, the projected change in rainfall due to climate change is likely to be of greater significance in the assessment of pipe capacity or spill frequency.

A sub-element of the change in future foul flow rates is that of water consumption rate. The pressure on reducing water consumption which has been on-going for many years will continue. Future consumption of potable (and any non-potable) water may result in a drop in flow rates. This, together with changes in lifestyles which influence peak flows released at certain points in the day, will also introduce some change to runoff rates. However, these issues are unlikely to have a significant influence on the total change in flow rate over time, even though these aspects of change cannot be ignored.

Each type of future pressure can be assessed for uncertainty associated with future change, but in most cases there are many assumptions that need to be made and these often have to be based on subjective judgement due to limited information being available.

Due to the nature of this Framework in needing to minimise computational effort as well as minimising manual intervention in the use of models, the potential future change for each loading condition need to be run together and applied uniformly across the model. Therefore, even if one or more of the future pressures were suitable for scientific numeric evaluation of the range of uncertainty, other future pressures have inadequate information with which to do this.

Table 6 provides a qualitative summary of the uncertainty of each type of future pressure. The three measures are:

- Long-term projections – the degree of uncertainty associated with making long-term projections for an existing network (HIGH - LOW)
- Application to the model – the degree of uncertainty in undertaking an automated procedure enabling change to be applied to the model at appropriate locations (GOOD – POOR)
- Impact on the model - the degree of impact on the predicted flows and change in network capacity (HIGH - LOW).

Table 6 Uncertainty associated future prediction and impact of each loading condition

Future pressure	Long-term projections	Application to the model	Impact on the model
Population growth	High	Poor	Low
Urban creep	Medium	Good	Medium
Growth (Re-development)	High	Poor	Low
New development	Medium	Poor	Low
Climate change rainfall	Medium	Good	High

Each section below discusses each of these loading conditions.

4.2 Population and consumption

Present-day population and consumption rates for the Enhanced Method can be based on the modelled population.

For the Initial Method, the population will need to be estimated using available GIS and census data. The consumption rate can be based on an average rate provided by the sewerage undertaker.

Making an estimate of population growth within the existing town envelope is probably not directly related to any increase in contributing area. It is possible that census based information may have projections on growth by ward or sub-ward. Other sources for growth in population may exist, but it is unlikely to distinguish between populations in new development and infill growth. Growth in population might be targeted to specific areas if analysed in detail, but at high-level it would probably be applied as a uniform increase in population.

Therefore, in order to provide consistency with other water industry long-term planning, it is recommended that the population projections used in the relevant Water Resource Management Plan (WRMP) should be used. Details are provided in Section 3.3.1 of the Guidance Document.

Likewise, future consumption rates are recommended to be based on the projections in the WRMP. Details are provided in Section 3.3.2 of the Guidance Document.

4.3 Diurnal profiles and multipliers

It was decided that, for the Initial Method, there was no benefit in using domestic diurnal profiles or trade flow profiles, considering the effort required to obtain this information and applying them to a new model.

A review was carried out of industry practice in representing the peak of the diurnal variation. Both two and three times DWF are commonly used, but no standard practice was found. Therefore, it was decided to use “2 x DWF” as the baseline for this project, which is 2 x domestic flows + 1 x trade flows. (Infiltration is not included in the Initial Method.)

Review of the results from the pilot catchments showed that the metrics for the Initial Method were not giving a broad enough range in performance, so it was decided to use a further multiplier of five on top of this - referred to as 10 x DWF in the rest of this report. As the Initial Method does not use infiltration this equates to 10 x domestic flows + 2 x trade flows.

For the Enhanced Method, 2 x DWF was used for the design storms (as described above). The diurnal profiles for both domestic flows and trade flows, as provided for the existing model, were used for the TSR simulations.

4.4 Urban creep

Urban creep has been studied by a number of researchers. A summary can be found in Appendix 4. In summary, there are four methods for predicting future change (Allitt *et al*, 2010). The most commonly used method is based on property density and this is the method recommended for this Framework. This requires address point data, which is not provided as part of a hydraulic model, but is often used during the model build process, so this was not considered an onerous exercise. Details are provided in Section 3.3.3 of the Guidance Document.

Not all urban areas are residential, but for the purposes of a high-level assessment it is adequate to assume that urban creep is a function of residential areas.

Although the derivation of a growth rate for increasing hard surfacing has been defined, the split to foul and surface sewer is much less well established. The literature review identified that a split of 1/3 to 2/3 foul and separate was found in one study. But in reality, the sewer that is most likely to receive additional runoff will be the one nearest to the additional impermeable area and this depends on the characteristics of the development and sewer networks. Added to this, not all additional impermeable area will be directly connected to either network. Therefore, for the purposes of this high-level assessment and to limit the possibility of double-counting, only 50% of the additional impermeable area should be added to subcatchments that drains to either a foul sewer or surface water sewer.

There is also the issue of time horizon. There is a view that there is a diminishing rate of urban creep in any area, but the literature review does not entirely reflect this. Other factors such as available wealth, the cost of moving house and cultural attitudes to paving and vegetation are all equally important factors. Current practices applied by some sewerage undertakers limit any increase in hard surfacing to 10% of the catchment area. However, a 25-year time horizon potentially allows quite significant change in total impermeability in a catchment.

On the basis of the above, the following has been proposed for the Framework and was applied to the pilot catchments:

- Urban creep should be applied based on property density in line with the UKWIR Allitt study.
- 50% should be applied to the foul and 50% to the surface water sewers where sewers are categorised as separate, and 100% to combined sewers.
- An upper limit of PIMP of 80% should be applied to all sub-catchments (foul or surface water).
- No allowance is provided for growth (see Section 4.5) or development (see Section 4.6) on the basis that the urban creep allowance is relatively high.

There are two considerations with this approach:

- There is a chance of double-counting address points where foul and surface water catchments overlap, which has implications for estimating the additional impermeable area as this is based on property density. However, this is ignored for this high-level assessment as the approximations involved tend to cancel each other out and the assumptions listed above prevent (on the whole) unrealistic estimations.
- Areas of commercial and industrial developments will have a low density of address points. The increase in hard surfacing will therefore be assessed incorrectly as the rule on the rate of increase in urban creep is based on domestic dwellings. However, the total impact of the effect of such area allocations are thought to be too small in terms of the total network to warrant devising an alternative approach and there is no basis on which to derive or apply an alternative approach.

4.5 Growth

Housing "growth" (the redevelopment of urban land) is different from urban creep, as it reflects planned and more predictable increases in the number of properties in a catchment, which means that (in theory at least) planning related information should be available from the local authority.

There is a distinction, however, between "infill development", which is what is being referred to here, and larger urban development, which is discussed in Section 4.6.

Growth not only results in the potential for additional impervious area, but also an increase in population. Also, where urban creep seems to be only related to residential areas, redevelopment of commercial and industrial sites is probably equally likely.

Growth within the urban area is known to be of the same order of magnitude as urban creep. However, there is little evidence available on rates of growth and there are no rules on applying growth to a model.

Growth tends to have a lower impact on predicted future sewer flooding than urban creep, as it is (to an extent) manageable by limiting rainwater connections in the new development to greenfield or another stipulated flow rate.

Once an estimate is made of the amount of infill growth that will take place, the main difficulty is in knowing how this is to be distributed across the catchment and its variability depending on land use.

A further consideration is that most new developments should have SuDS, or at least some form of flow control applied. This needs to be considered in the light of current planning requirements. In practice, most infill sites are small and, therefore, throttling of outflows may have little effect.

On the basis of the above, it has been decided that no allowance should be provided for growth in this high-level assessment, considering that the urban creep allowance is likely to be relatively high.

4.6 Development

Urban development, which takes place on the periphery of a town or city, may drain to a new WwTW or a trunk sewer and hence to an existing works. From the point of view of carrying out a high-level assessment, this is very difficult to apply in terms of loading flow rates, as it probably drains to specific trunk sewers. It also means that, in the majority of cases, these developments have very limited impact on the existing sewerage system. Therefore, development of this type is not considered relevant for a high-level assessment of existing drainage systems.

In addition, the premise of the Framework is that models are run 'off the shelf', possibly applying macros to the data to reflect future pressures and possible interventions. Detailed consideration of potential changes to the network is not required. If a sewerage undertaker wishes to undertake a more detailed assessment for a particular catchment, they can choose to include likely development. But it is important to recognise that the Framework approach would make assumptions regarding the timing of inclusion of this development. For example, if the “future model” for a catchment included development, it would be assumed that all of this development was in place 25 years into the future and the 5-year snapshots (if based on interpolations) would have to assume a proportion of this development had taken place.

Greenfield development will increase flows in some sewers where these developments connect into the existing system. However, only a small percentage of sewers will suffer a significant increase in dry weather flow and as a result of the misconnections that will take place over time from these developments. As these sewers cannot be defined without detailed investigation, this aspect is also ignored for the high-level assessment.

4.7 Climate change

Climate change is expected (already) to alter rainfall characteristics. This change is not simple to represent accurately. Winters are likely to become wetter and summers drier, while extreme events are going to be more intense. Rainfall through the year will also become more variable.

For assessment purposes it is important to consider both design storms and time series rainfall. Details of the rainfall data that should be used for this high-level assessment are provided in Section 3.3.4 of the Guidance Document.

Appendix 6 (issued as a separate document) provides a literature review on assessing future rainfall due to climate change. This details:

- The sources of information available;
- The range of uncertainty due to different scenarios and probabilistic information;
- The limitations of the various models in predicting rainfall;
- The limitations of the datasets in enabling extreme event analysis to be carried out; and
- Outlines methods for producing uplifts for design storms and for producing future time series event data.

At present there is no agreed national approach to climate change rainfall. For assessing the pilot catchments (as part of this project) a simple uplift of 40% for 2100 (which interpolates to approximately 20% for 2042, the 25-year horizon) has been applied for design storm uplifts.

For simplicity, the time series data used for testing the pilot catchments was based on data previously produced for Yorkshire Water for the 2035 epoch. Although this time series data will probably under-predict change in rainfall, the study concept is unaffected by this decision.

For assessing uncertainty/sensitivity, this varies depending on season, and can be in excess of 50%. To avoid complexity this project has recommended the use of +/- 30% for design storms and the P90, P50 High Emissions scenario and P50 for the Medium Emissions scenario for time series analysis. The use of P10 High Emissions scenario was considered (and has been used for the sensitivity analysis for the pilot studies), but as the changes in rainfall resulted effectively in a negative change compared to present day, P10 High is probably not appropriate to use.

Currently, there is little consistency between sewerage undertakers on their climate change procedures. Therefore, it had been suggested that this project should develop a procedure that could provide that consistency. However, current climate change knowledge is associated with UKCP09 and any guidance produced by this project would need to be checked and may need updating once UKCP18 is available after March 2018. Therefore, the recommendations provided in Section 3.3.4 of the Guidance Document should only be considered as interim.

At present, outputs from the UKCP18 project have not been specified. The High/Medium/Low projections of UKCP09 will be replaced, although there will be a mapping of the UKCP18 projections against UKCP09. Current limitations with extremes and sub-daily resolution are unlikely to be significantly improved. Therefore, the principles provided in the Guidance Document are expected to remain largely valid after UKCP18 is available.

In addition, UKWIR is producing further guidance, which should be available in the summer 2017, that will be based on analysis of the high resolution CONVEX model. This means that specific design event uplift values and possibly time series information will need to be reviewed and may be subject to change.

4.8 Infiltration

Infiltration is only considered to a limited extent for this high-level assessment.

Present-day infiltration rates are assumed to be represented in the existing models for use with the Enhanced Method.

Obtaining infiltration data for drainage systems without an existing model has been deemed too onerous for use with the Initial Method and is, therefore, ignored.

Future infiltration is dependent on sewer condition, which is outside of the scope of this project

5 Interventions

5.1 Selecting catchment-scale interventions

There are two ways in which long-term interventions can be considered:

- Investment in a radical change where, for instance, a planned programme of SuDS along with universal sewer separation could take place, or

- A business-as-usual approach, based on making the most cost-effective changes to try and maintain the status quo.

This project is aimed at the latter option.

There are five principle types of intervention carried out by sewerage undertakers:

1. Lining of sewers – to reduce infiltration

2. Addition of storage and throttles – to attenuate flows downstream

3. Pipe upsizing – to remove a local throttle (but therefore passing larger flows on downstream)

4. Disconnection – to remove contributing areas

5. SuDS – to reduce flow rates and runoff volumes.

Lining of sewers, additional storage and pipe upsizing have been ignored as part of the high-level assessment. This is because each of these interventions requires "local" changes to be made to a model, rather than catchment-wide changes and this requires a detailed assessment to be carried out. However, as the Framework is also intended to be applicable for models where detailed catchment studies are carried out, these interventions could be considered in this context.

This leaves only SuDS and disconnection that could be considered as catchment-wide interventions. In modelling terms, SuDS is effectively the same as disconnection, although in reality some SuDS are less effective than others. Usually their effectiveness (depending on the type and design of the SuDS element) is related to the size of rainfall event; small events show virtually no runoff while their response in large events is very variable from very low runoff rates and volumes through to almost unrestrained runoff response. Nevertheless, it is proposed that for a high-level assessment SuDS are treated as being effective in disconnecting area.

Disconnections are associated with properties with misconnections and other contributing areas where surface water sewers are available to re-direct areas from foul systems. Therefore, in areas where sewers are fully combined disconnections are less likely to take place.

In both cases the greatest opportunity and benefit is likely to be associated with areas of higher density of contributing area. This may possibly be better subdivided by looking at roof rather than total PIMP, as roads are often a dominant element of paved area and their disconnection may be more difficult to achieve.

For the purpose of this study, it is assumed that prioritisation of intervention will be based on roof density and road density separately and that, whether it is SuDS or a full disconnection, the subsequent response is effectively to achieve full disconnection.

There are no rules on disconnection based on studies of opportunities to disconnect. A few studies have been carried out that have applied this approach, but they range from assessment of catchment characteristics through to universal changes made to all subcatchments.

Conceptually, it is relatively easy to consider interventions as being made to all roof runoff and designing to the rainwater harvesting code of practice (BS8515:2009). This could achieve no runoff from any roof for say 50mm of rainfall. This is roughly equivalent to a 100- year 6-hour event. This means that, for the purposes of urban performance assessment, no runoff will take place for all events of interest to this study.

The opportunity for road runoff reduction is much less as only around 20% of paved surfaces might be associated with car-parking or similar opportunities to manage the runoff.

For this high-level assessment, a simplistic approach has been adopted for modelling area removal - with the same percentage removal being applied to both roads and roofs up to a maximum of 40%. Further details are provided in Section 6.1 of the Guidance Document. The approach for assessing the effect of this area removal is described in Section 6.2 of the Guidance Document.

5.2 Indicative costs

The primary purpose of looking at costs as part of this project is to ensure that we are proposing solutions that are comparable in cost terms with results from “traditional” drainage planning.

For the purposes of this Framework, the cost of intervention is a function of connected area removal. For simplicity, it has been assumed that this will be achieved using SuDS.

Appendix 8 provides details of the literature review undertaken as part of this project to determine a suitable unit cost. The conclusion of this review is a unit cost of £500K/ha should be applied to the first 10% area removal, increasing to £1M/ha for any additional area removal.

Note that costs are not proposed to be part of the visualisation discussed in Section 6.

5.3 Comparing high-level interventions with alternative interventions

One of the aims of the Framework is to enable sewerage undertakers to compare “long-term” interventions, with the types of interventions that will be identified as part of the more detailed 5-year planning cycles.

The main challenge with this is comparing like with like, bearing in mind that different assumptions will have been made regarding future pressures and different design horizons are likely to have been used. Therefore, the approach adopted for this Framework is that the alternative interventions that have been assessed as part of more detailed planning are reassessed using the Framework metrics. This allows a direct comparison of “scores” and the relative performance of assets for each alternative intervention can be compared.

It is proposed that the sewerage undertaker can decide whether to use existing models from detailed planning exercises without any changes or whether to import proposed schemes into the Enhanced Model used with this Framework. Further details on this are provided in Section 7.1 of the Guidance Document.

The visual representation of this comparison can be provided in several ways. Two examples are shown in Figure 5 and Figure 6. The “thermometer” method (Figure 5) provides a means of comparing the aggregate scores for each metric for the whole drainage system for different time horizons and interventions. The value of the “thermometer” method has been questioned during this project, by those looking to use the results for decision-making. However, due to its simplicity it has the potential to be animated and a variation on this might prove useful for sharing information with other stakeholders or the public. Alternatively, the aggregate scores for each metric for the whole drainage system can be plotted against a time horizon to provide a “time-varying” comparison, as illustrated in Figure 6.

Figure 5 Drainage system performance for alternative interventions (thermometer method)

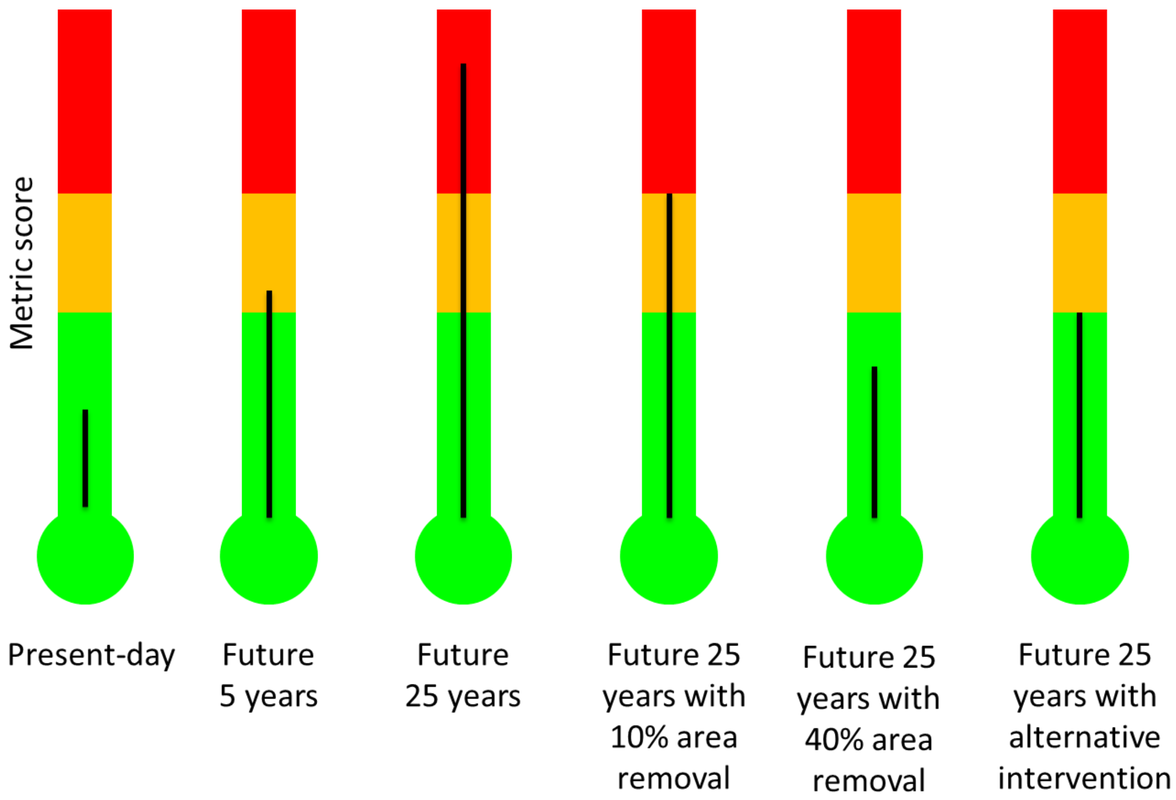
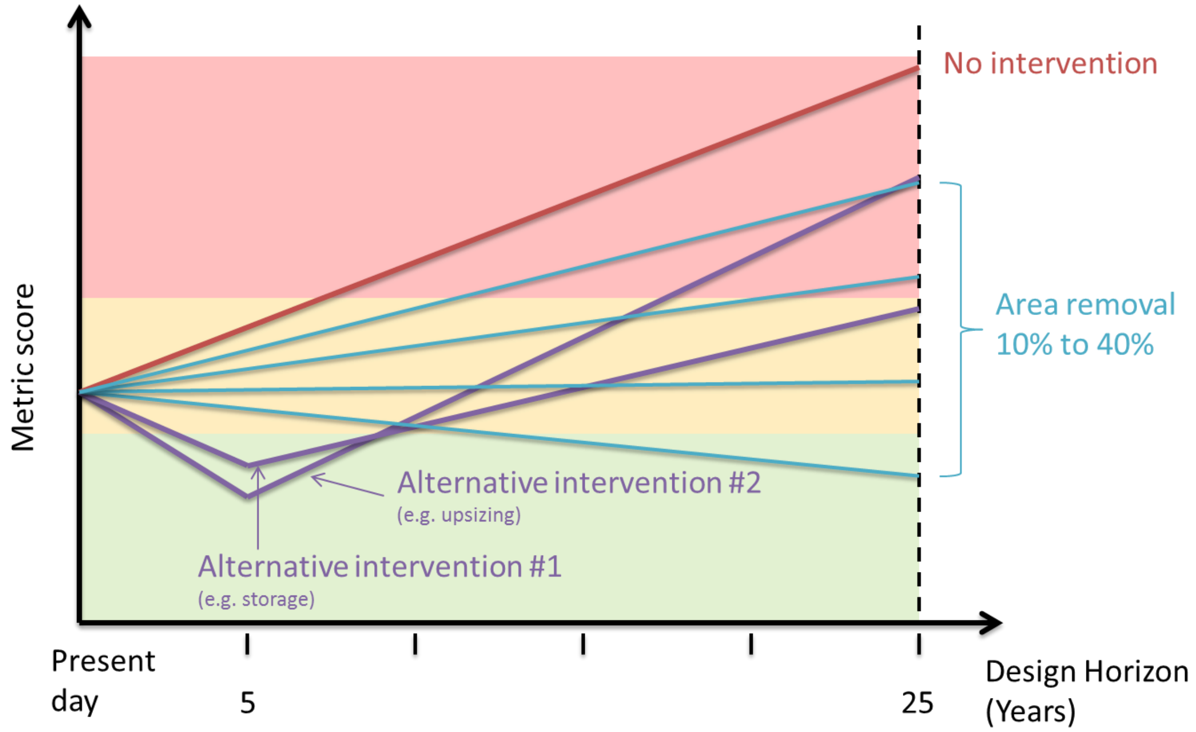


Figure 6 Drainage system performance for alternative interventions (time-varying method)



5.4 Timing of interventions

The high-level intervention of area removal used by this Framework has been assumed to be a continuous process across the whole drainage system (or multiple drainage systems). Therefore, timings of individual interventions cannot be determined in full. However, by using an approach similar to Figure 6, it is possible to assess the extent of performance improvement achieved by different levels of intervention and when thresholds in that performance are reached.

Further guidance on this is provided in Section 7.3 of the Guidance Document.

6 Visualisation

6.1 Purpose

The purpose of the visualisation is to be able to communicate the scores obtained for the metrics to stakeholders. The visualisation method needs to display the outputs and summary information to the stakeholder so that they can be easily understood and consistently interpreted.

This project proposes an online dashboard visualisation approach, as it allows for the user to view the information at different scales and can show change over time and with interventions.[2] This would be delivered at the national scale, i.e. it is not proposed that each sewerage undertaker produces their own version of this online tool or prepare outputs that reproduce the geo-spatial results. However, the sewerage undertaker would be expected to provide data that would be uploaded to a central database. The visualisation would show the aggregate scores, based on the individual scores provided by the sewerage undertakers, as described in Section 2.4.2. Details of what that data should be are provided in Section 8.1 of the Guidance Document.

It is not part of the project scope to deliver the online visualisation tool, rather to provide "a set of recommended visualisation approaches for specified audiences". However, the metrics and assessment methods proposed by this project have been designed for use by such a tool.

Further work would be required to develop the visualisation concept. In particular, the process for data sharing and setting up a UK-wide database would require development.

Coupled to the technical aspects of the visualisation tool would be the development of appropriate messaging for sharing information with the public. For example, care needs to be taken to ensure that where areas are shown as "red" it is clear what this means to the industry and the public.

The following sections describe the different facets of the proposed visualisation tool.

6.2 Displaying pipe and CSO metrics

It is envisaged that visualisation of CSO information would be separate from pipe capacity information, with the user selecting one of the other. The metrics available to view would vary depending on whether pipes or CSOs have been selected. For pipes, there would also be an option for selection the aggregate scoring method: length of pipes or population equivalent upstream. Figure 7 and Figure 8 provide examples of how the dashboard could look.

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[2] An illustration of a live website with a dashboard is the EDgE project: http://edge.climate.copernicus.eu/Tools/

Figure 7 Example of online visualisation tool for pipes

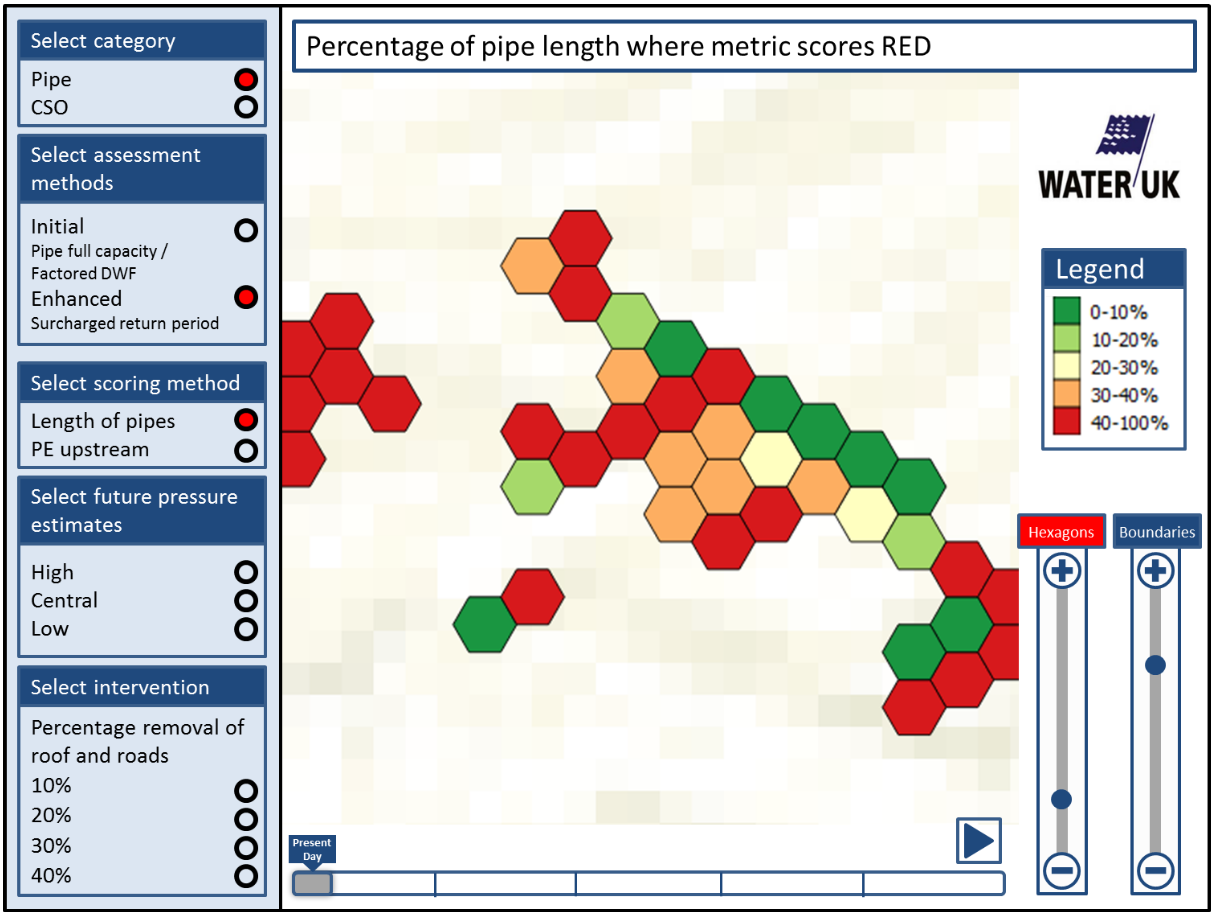
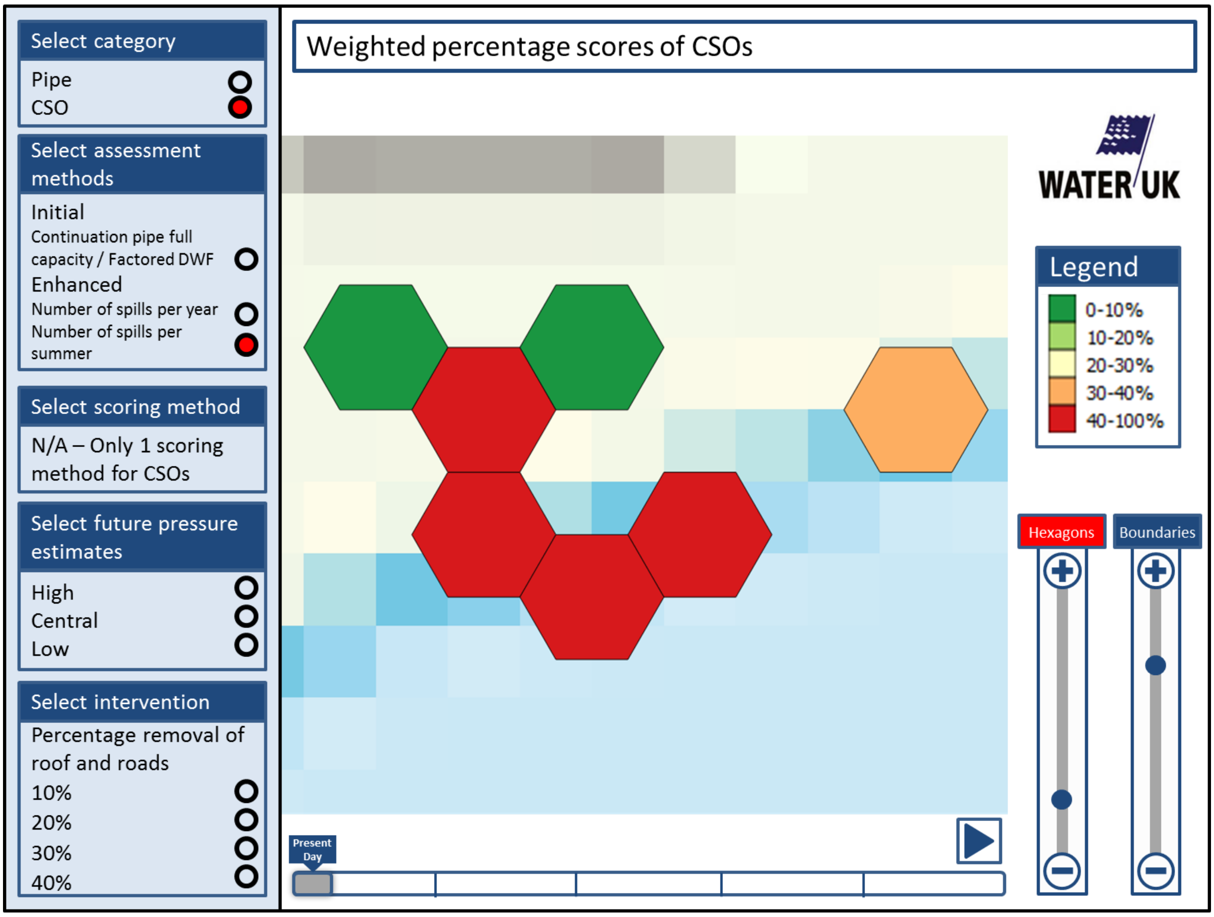


Figure 8 Example of online visualisation tool for CSOs



6.3 Results from different methods

Within an area there may be different types of information:

- The area might have no drainage systems at all
- The area might include drainage systems where neither the Initial Method or Enhanced Method were possible
- Some areas will have results generated by the Initial Method
- Some areas will have results generated by the Enhanced Method
- Or combinations of the above.

Where there is no information in the area at all it could be left blank. Where there is one or more drainage systems but it was not possible to carry out either the Initial or Enhanced Method on any of these, this area could be coloured grey. Where there is some information present (i.e. some of the drainage assets have been assessed) it would be coloured according to that information. The proportion of the missing data and where there are results, these can be displayed in a more detailed manner when a particular boundary is queried (see Section 6.6). The user could further specify which combinations of information they are able to see using selection boxes.

6.4 Geo-spatial scales

Reporting of information in the past has generally been at a catchment scale. However, this project has found that using catchment boundaries are problematic for showing summary data and that boundaries that tessellate may be more effective for visualisation purposes. Such boundaries could be post code regions, local authority boundaries, river basin catchments, water company boundaries, "water recycling catchments" or geometric hexagons, etc.

Post code areas lend themselves to having three levels of resolution, for example OX, OX10 or OX10 8 scale. But this data needs to be purchased and is subject to regular change. The size of the areas also vary a great deal, similar to catchment boundaries.

Sewerage undertakers may favour the sewerage authority boundaries, and at a finer resolution their sub-boundaries, so that they can easily identify their regions. This has not been reviewed during this project, as the data for all of the sewerage undertakers was not readily available.

Alternatively, the UK could be represented by geometric hexagons that can be used at any resolution and would capture all of the data that fell within their boundaries. For CSOs this could be the coordinates of CSO chamber or the location for the outfall. It is currently proposed to use the coordinates of the CSO chamber, but this should be reviewed when the tool is developed. Pipes would be associated with their upstream manhole coordinates to define which boundary area they fell within. As the size of the hexagon (or any other boundary type) changes, the updated metric score for the area(s) being viewed are recalculated based on all pipes or CSOs that fall within the boundary area.

Therefore, two alternative methods of displaying the data are worth further consideration:

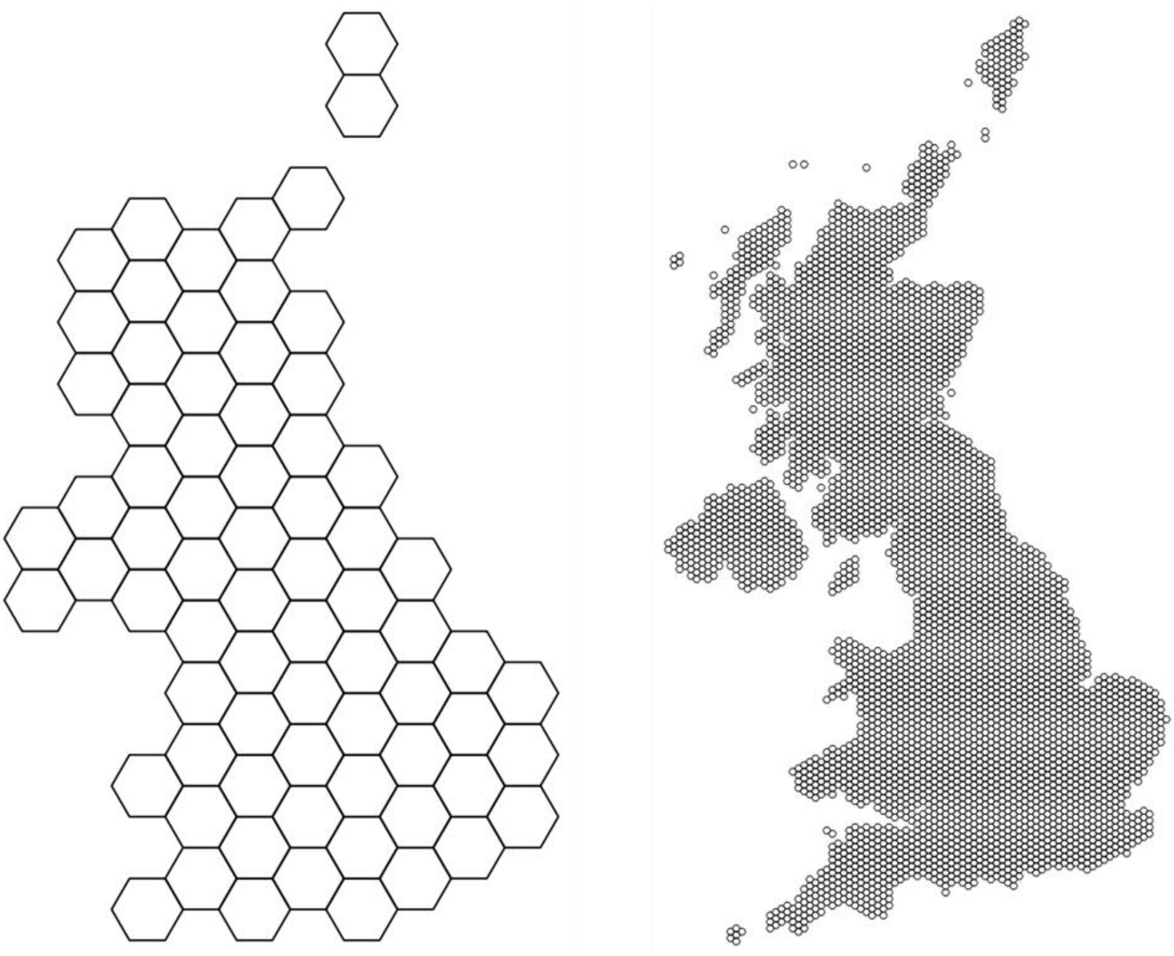
- The sewerage undertaker boundaries (Figure 9) and sub-boundaries
- Geometric hexagons at three different scales, for example 1 km diameter, 10 km diameter and 100 km diameter.

Figure 10 shows how hexagons at 100 km diameter and 10 km diameter scales might look, although consideration would need to be made regarding the different projection used for Northern Ireland. The 100 km diameter scale might prove too large once there is sufficient data to review this in more detail, in which case a 50 km diameter might be more appropriate.

Figure 9 Sewerage undertaker boundaries

Source: Water UK

Figure 10 Example of geometric hexagon maps of the UK at 100 km and 10 km scales



The level of detail and the number of areas that the user sees at any one time could be controlled by the user. The user could control whether they view sewerage undertaker boundaries or geometrics hexagons, and they could control the size of the hexagons they view by using the sliders in the bottom right corner of the dashboard. By zooming in and out of the map with the mouse wheel the user could view many or few elements at once.

6.5 Use of colours for scoring

Although Red, Amber and Green were the original three colours proposed for this Framework, five colours are recommended for the aggregate scoring based on the results from the pilot testing. An example of using five rather than three colours is shown in Figure 7.

Alternatively, a finer resolution of colour banding could be set by the user or pre-defined. Allowing the user to adjust the colours in this way would enable them to look more closely at hotspots within a region. It would also make the tool more future proof.

6.6 Displaying detailed information

At any scale, the user could select an area (either within a sewerage undertaker boundary or hexagon) for more detailed information. This information would vary depending on whether the user is viewing pipe capacity or CSO performance information.

For pipes, the detailed information could include (for example):

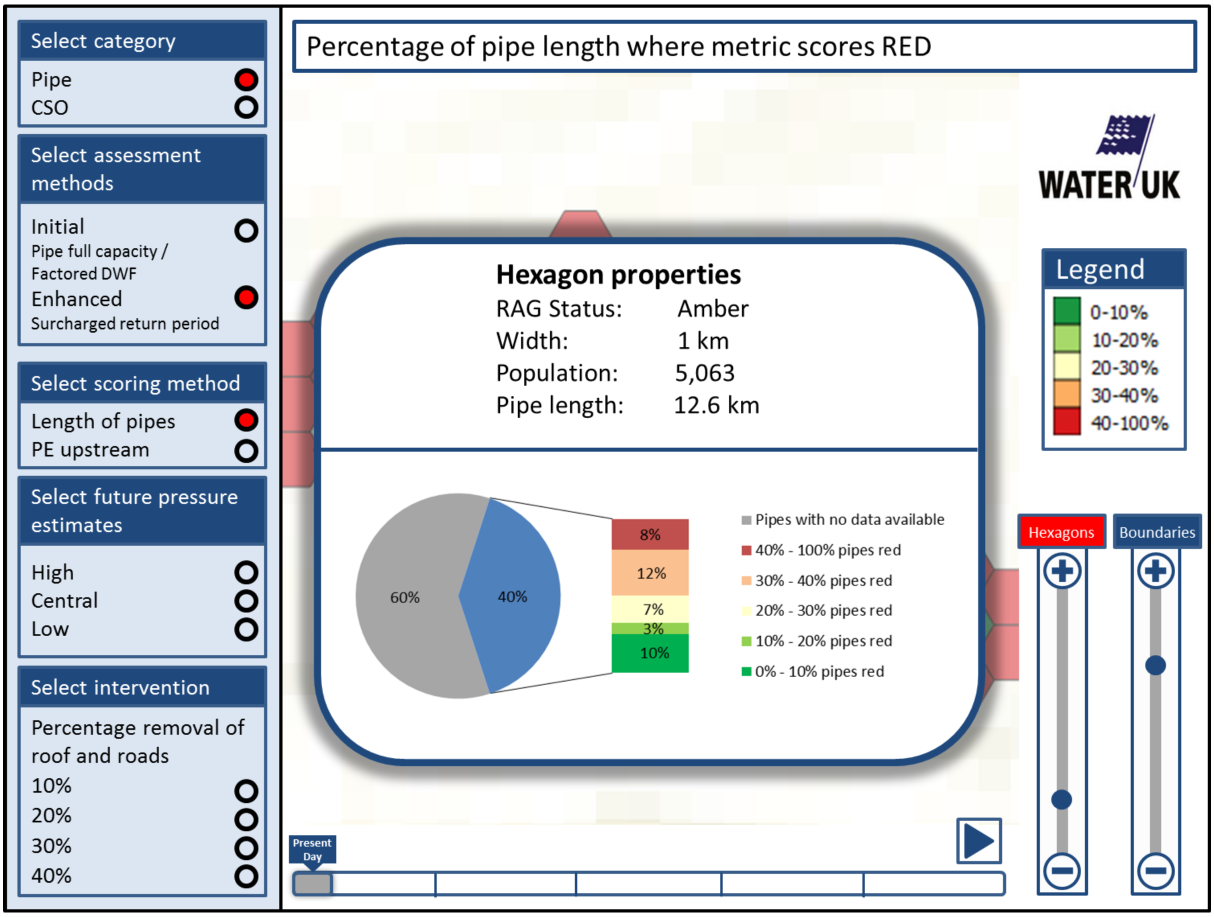
- Key properties of the area selected, including:
    - Overall metric score
    - Area (in km^2)
    - Population
    - Population equivalent
    - Total length of pipes
- Pie chart showing the proportion of Enhanced Model results, Initial Model results and where there is no information. Where there is information the breakdown of metric scoring is shown in a bar chart. This scoring breakdown could be done by pipe length or population equivalent served.

For CSOs, the detailed information could include (for example):

- Key properties of the area selected, including:
    - Overall metric score
    - Area (in km^2)
    - Population
    - Population equivalent
    - Total number of CSOs
- Pie chart showing the proportion of Enhanced Model results, Initial Model results and where there is no information. Where there is information the breakdown of metric scoring of individual CSOs is shown in a bar chart.

An example of what this could look like is provided in Figure 11.

Figure 11 Example of more detailed information for a selected area



6.7 Showing change over time

A slider and play button would allow the user to view changes over time at 5-year snapshots up to the 25-year time horizon. If there are results at any 5-yearly interval they would be used, otherwise the information would be linearly interpolated between the present day and 25-year results.

There could also be the option of three estimates of future pressures being applied to the systems - high, central and low - allowing the user to compare results over time based on these different potential futures.

6.8 Representing the effect of interventions

The central forecast of future pressures would then be viewable with no interventions or with interventions. The interventions available to view for all Enhanced Models would be the four degrees of percentage removal of impermeable area (ranging from 10% to 40% over the 25-year time horizon).

The interventions would be based on the results for the 25-year horizon and interpolated at the 5-yearly intervals, unless model results were available at any of the 5-yearly intervals, in which case these would be used instead.

If a sewerage undertaker has tested other interventions through more detailed modelling and calculated the associated metrics, the visualisation tool could be designed to have an option to view the effect of these interventions on the metrics.

6.9 Producing the pilot catchment visualisation results

The pilot catchment results were produced using the hexagon visualisation approach. This was done using FME software, which allows the user to easily manipulate GIS data without the need to code. Two FME workbenches were set up: one for pipes and one for CSOs.. Each workbench was set up to load in the individual pipe or CSO metric values from a CSV file. The workbench then calculated the individual score for each pipe/CSO before overlaying a hexagon grid to produce an aggregate score for each hexagon.

Using an FME workbench has the advantages that:

- Many datasets can be rerun quickly with different metrics or for different time horizons
- Scoring thresholds can be altered for either the individual pipe or CSOs or for the aggregate scores
- The boundaries can be altered to different sized hexagons or different types of boundaries
- The way the aggregate scores are calculated can be altered. For example pipes can be scored based on population equivalent upstream as well as on pipe length.

The shapefile output from the FME workbench can then be themed in any way.

7 Pilot catchments

7.1 Catchment selection

Sewerage undertakers across England, Wales, Scotland and Northern Ireland were asked to put forward suitably representative foul/combined sewerage systems that could be used to test the potential metrics and associated methods for assessing system capacity.

A 'Method for selecting pilot catchments' (Appendix 9) document was circulated to outline the criteria models would need to meet and the method for selecting pilot catchments.

To put forward a pilot catchment, sewerage undertakers were asked to fill in a 'Pilot catchment submission questionnaire' (Appendix 10) which was used to check whether a proposed catchment meets the requirements and allowed the potential benefits of different catchments to be compared.

Sixteen questionnaires were received from nine sewerage undertakers. Following a review of the questionnaires, five models and supporting documentation were requested for further detailed assessment of the hydraulic models. Four were taken forward as pilot catchments, one from each country to ensure the metrics and method proposed are applicable across the UK.

7.2 Catchment characteristics

Table 7 shows a summary of the pilot catchment hydraulic models. The catchments have been labelled A to D.

All pilot catchments experience flooding, CSO spills and infiltration.

Table 8 shows a summary of the number of overflows and types of overflows within each pilot catchment.

Table 9 shows a summary of which future pressures had been applied in each of the pilot catchment detailed modelling studies and received by HR Wallingford.

Short descriptions of each catchment are provided in Sections 7.2.1 to 7.2.4. Further details of the models are provided in Appendix 11.

Table 7 Pilot catchment hydraulic model summary

Pilot Catchment		**A**	**B**	**C**	**D**
Country		Northern Ireland	Wales	Scotland	England
Number of nodes		3799	2001	5284	3040
Number of overflows		15	3	16	7
Population		35,575	5,565	49,444	13,856
System type		F/C	F/C	F/C	F/C + PS
Types of manhole	Lost	0.3%	19%	30%	35%
	Sealed	5%	0.2%	2%	14%
	Stored	95%	81%	67%	51%
Number of pump stations		7	13	9	5

Key: F/C = Foul/combined; PS = Partially-separate

Table 8 Pilot catchment types of overflows

Catchment	A	B	C	D
Total number of overflows	15	3	16	7
Number of CSOs	13	0	12	6
Number of EOs at pumps	1	3	7	1
Number of WwTW tank overflows	1	0	0	0

Table 9 Pilot catchment modelling future pressures summary

Catchment	A	B	C	D
Has the model been used to assess future system performance?	Yes	Yes	Yes	Yes
Was climate change accounted for?	Yes	Yes	No	No
Was urban creep accounted for?	No	No	Yes	Yes
Was infill development accounted for?	No	No	No	No
Was “strategic” new development accounted for?	Yes	Yes	Yes	Yes

7.2.1 Catchment A

Catchment A is historically a concentrated area of settlement, with recent urban development. There are some large industrial and commercial developments within the study area.

The drainage area is largely flat with approximately 90% of the network draining by gravity, with the remaining being pumped into the gravity network by seven wastewater pumping stations.

The combined sewers account for approximately 35% of the network and are located primarily around the town centre. The remainder of the sewerage network (approximately 65%) comprises separate foul and surface water systems. There are small, sparse areas with nominally separate drainage, where the surface water sewers discharge into the combined network.

7.2.2 Catchment B

Catchment B is a river valley catchment with the largest settlement being a market town. The centre of the market town is old with newer developments radiating out. The central town is predominately flat and served predominantly by small pipes. The flows from outlying villages and hamlets are pumped in.

The majority of the catchment flow gravitates towards a terminal SPS before being transferred to the WwTW. The composition of the sewerage network consists, by percentage length, of approximately 6% combined sewers, 59% foul sewers, 7% surface water sewers and 27% rising mains. There are 13 pumping stations within the catchment. Of the foul sewers, 50% are actually partially combined with a proportion of impermeable area applied.

7.2.3 Catchment C

Catchment C is a large seaside catchment. There are a number of natural (and partly culverted) watercourses which run through the catchment. Several CSOs discharge to into these watercourses. There is a designated bathing water and a non-designated bathing water in the vicinity of the catchment.

The sewerage network is predominately composed of combined system but with separate system in the newer parts of the catchment. Approximately 63% of the sewer network is combined, 14% of the sewer network is foul and 23% of the network is surface water.

Flows are mainly conveyed under gravity to the WwTW, however there are a number of pumping stations located throughout the catchment which pump flows into sewers located at higher levels.

7.2.4 Catchment D

With the exception of one main town Catchment D covers an extensive area of largely rural land, with numerous farms, hamlets and small villages. The sewage system from the main town as well as a number of villages/hamlets discharge to one STW. A number of other sewered villages discharge to satellite treatment works, some of which have been included in the model and some of which have not.

The catchment is steeply undulating with a number of river valleys dissecting the area.

The sewerage network is a mixture of combined system, separate system and partially separate system. Approximately 44% of the sewer network is combined, 25% of the sewer network is foul and 30% of the network is surface water.

7.3 Testing method

The present-day models received from the sewerage undertakers were taken as the baseline models for the Enhanced Models. These models were modified for use with the Initial Method by removing any representation of ground infiltration. Both the Initial and Enhanced Models were then updated to represent the future 5-year and 25-year time horizons, and the Enhanced Models only were updated to represent the 25-year plus intervention scenarios.

DWF, design storm and TSR simulations were carried out on all the Enhanced Models whilst only DWF simulations were run for the Initial Models. The Initial and Enhanced metric scores were calculated for each pilot catchment. More metrics were tested through the pilot catchments than are recommended in the guidance and a number of different scoring thresholds were trialled before settling on the current thresholds outlined in the guidance.

Section 7.4 provides more detailed information on how the networks were altered for the different scenarios and Section 7.8 outlines the results from the pilot catchments.

7.4 Changes made to models and data collection

7.4.1 Present-day assessment

The 'Existing system' networks (as outlined in Appendix 11, which describes the networks received from the sewerage undertakers) were taken as the baseline 'clean' models to be used as the basis for the present-day analysis. The networks were originally either built to represent 2013 or 2014, but were assumed to be accurate in representing present day conditions (2017).

The following information was extracted from each model:

- Total network population
- Total network equivalent population

The total network equivalent population was calculated as the total network population plus the trade flows divided by the per capita dry weather flow rate (assumed to be 120 l/d).

The following information was extracted for each pipe within each model:

- Upstream manhole coordinate
- Population upstream
- Population equivalent upstream
- Length
- Diameter
- Pipe capacity

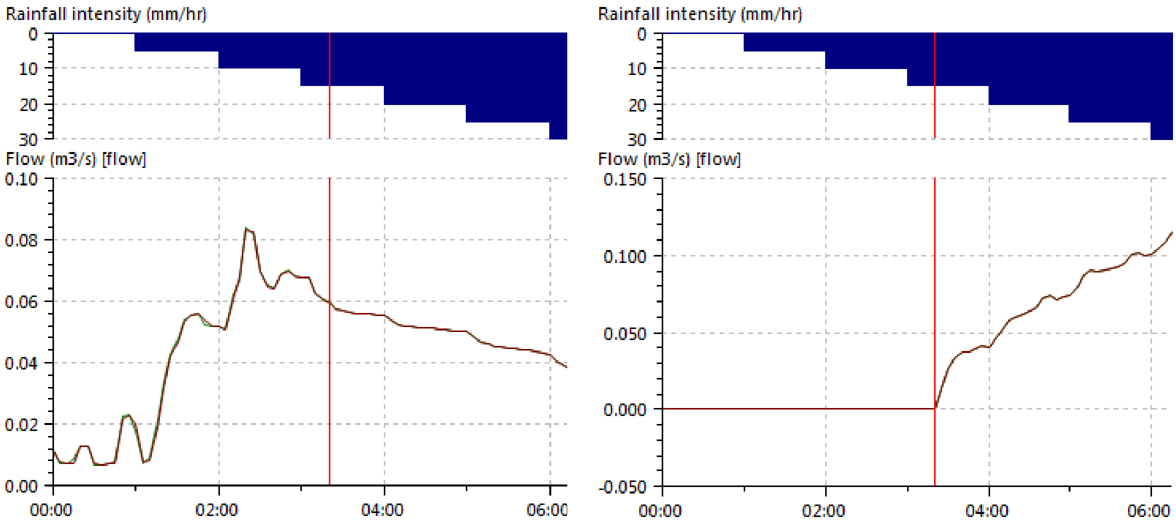
The following information was extracted for each CSO within each model:

- Manhole coordinate
- Manhole type
- River reach the CSO spills into
- Incoming pipe(s)

- Incoming pipe capacity
- Continuation pipe(s)
- Continuation pipe capacity
- Population upstream
- Population equivalent upstream
- Population upstream of CSO, but downstream of any other CSO on the same branch
- Population equivalent upstream of CSO, but downstream of any other CSO on the same branch

The continuation pipe capacity was calculated by running the models with increasing flows and extracting the flow through the continuation pipe just at the point the CSO starts to spill (see Figure 12).

Figure 12 Determining the continuation pipe flow capacity



Continuation pipe flow CSO pipe flow

7.4.1.1 Initial Method

The only changes made to the models to assess the pilots catchments using the Initial Method were the removal of base flows (representing infiltration) in the subcatchments and the removal of the ground infiltration inflow in the run parameters. The model was run for 2 x DWF, 10 x DWF and diurnal profile.

The following information was extracted for each pipe from the DWF model results:

- Maximum modelled DWF (for 2 x DWF, 10 x DWF and diurnal profile)

Figure 13 shows the information extracted from each pipe in a SQL database table.

Figure 13 SQL database table of the information reported for each pipe in the Initial Model

	Pipe	Manhole X	Manhole Y	Total net...	Popul...	Length	Diam...	Pipe full cap...	Maximum flow ...	Max flow rate / Pipe full ...	Total net...	Pip...	Equival...
1	Blockag...	341340.6	387799.9	35575.3	71.4	3.026...	230	0.0981153...	0.000119826...	0.00122128039688546	39103.3	1	71.4
2	CSO02Fl...	341414.4	387557.5	35575.3	482.5	38.98...	395	0.3678953...	0.000809751...	0.00220103649313577	39103.3	1	482.5
3	MHC07	341346.4	387482.2	35575.3	0	20	225	0.0649753...	1.447124211...	2.2271907009506E-23	39103.3	1	0
4	NM0013...	341251....	387876....	35575.3	0	7.282...	150	0.0330582...	1.893056335...	5.72641980325468E-23	39103.3	1	0
5	NM0013...	341090....	387580....	35575.3	0	9.218...	225	0.0340171...	9.065336101...	2.66493194782802E-23	39103.3	1	0
6	NM0013...	340846....	388397....	35575.3	0	14.30...	150	0.0257884...	7.664783575...	2.97217250576351E-23	39103.3	1	0
7	NM0013...	340044....	388087....	35575.3	4305.6	35.59...	450	0.4439183...	0.002346683...	0.00528629670988566	39103.3	1	4305.6
8	NM0013...	339750....	388438....	35575.3	132.3	12.07...	150	0.0256294...	0.000222031...	0.00866311881454928	39103.3	1	132.3
9	NM0013...	341311....	389159....	35575.3	816.4	34.04...	150	0.0258064...	0.000870671...	0.0337385155969563	39103.3	1	816.4
10	NM0013...	341185....	389386....	35575.3	0	33.53...	150	0.0415332...	0	0	39103.3	1	0
11	NM0013...	341040....	387408....	35575.3	0	18.89...	150	0.0297338...	-7.542542210...	-2.53668134133867E-20	39103.3	1	0
12	NM0013...	340805....	388577....	35575.3	0	56.07...	150	0.0065558...	5.959657277...	9.09053529758825E-23	39103.3	1	0
13	NM0013...	340212....	388005....	35575.3	0	29.70...	150	0.0341964...	1.531308488...	4.47797781412623E-23	39103.3	1	0
14	NM0013...	339551....	388457....	35575.3	37.8	19.52...	250	0.2367117...	6.343750283...	0.000267994785058229	39103.3	1	37.8
15	NM0013...	341307....	388818....	35575.3	0	13.61...	150	0.0273170...	7.134851224...	2.61186547048812E-24	39103.3	1	0
16	NM0013...	341106....	388910....	35575.3	0	6.071...	150	0.0241740...	-2.006756577...	-8.30128136465499E-15	39103.3	1	0
17	NM0013...	340809....	387531....	35575.3	0	21.83...	150	0.0201125...	6.149591810...	3.05759592598973E-23	39103.3	1	0
18	NM0013...	340733....	388422....	35575.3	0	22.35...	150	0.0320223...	9.997602058...	3.12207179501359E-23	39103.3	1	0
19	NM0013...	340318....	388527....	35575.3	0	19.84...	150	0.0228786...	0	0	39103.3	1	0

The following information was extracted for each CSO from the DWF model results:

- Maximum modelled continuation pipe DWF (for 2 x DWF and 10 x DWF)

7.4.1.2 Enhanced Method

No changes were made to the models to assess the pilot catchments using the Enhanced Method.

The models were run for 2 x DWF, 10 x DWF and design storm events (2, 5, 10 and 30 year return periods and 30, 60, 120, 240, 300 and 600 minute durations). The models were also run for 3 years' time series rainfall.

The following information was extracted for each pipe from the DWF and design storm model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Minimum return period for surcharge (design storms)
- Minimum return period for flooding (design storms)

The following information was extracted for each CSO from the DWF and TSR model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Spill events from a single CSO (based on a 3 hour gap between events, a 6 hour gap between events and EDM events - see below for a description of these three methods of defining spill events)

- Spill events into a single river reach (based on a 3 hour gap between events, 6 hour gap between events and EDM events)

EDM events were those calculated following the EDM approach to counting and reporting spills. That is, spill counting starts when the first discharge occurs. Any discharge in the first 12 hour block is counted as 1 spill and any discharge(s) in the next and subsequent 24 hour blocks are each counted as 1 additional spill per block. This counting continues until there is a 24 hour block with no discharge. For the next discharge after the 24 hour block with no discharge, the 12 hour and 24 hour block spill counting sequence begins again.

The 3 hour and 6 hour gap spill counting methods are defined as follows. Spill counting starts when a first discharge occurs. Any discharge in the next 3 hours or 6 hours respectively is counted as 1 spill. This counting continues until there is a 3 hour or 6 hour block with no discharge.

For simplicity, each different receiving watercourse was defined as a river reach. A receiving watercourse was not sub-divided into multiple river reaches.

7.4.2 Future assessment (5 years)

The present day Initial and Enhanced Models were used as the base model to make changes to represent the future assessment. The time horizon for the 5-year assessment was 2022.

7.4.2.1 Initial Method

The only future pressure applied to the Initial Method at the 5-year time horizon was increased population.

The present-day baseline model and the most long-term future model received from the sewerage undertaker were used to determine the increase in population per year for each pilot catchment. This information is shown in Table 10.

The population growth rate was used to calculate the central estimate increase in population by 2022. The percentage increase in population compared to the present day model was then calculated. The upper estimate percentage increase for the sensitivity analysis was calculated as 1.3 times the central percentage increase and the lower estimate percentage increase as 0.7 times the central percentage increase.

Table 10 Pilot catchment present day and future model received - population

Catchment	Present day population	Present day year	Future population (from future model)	Time horizon of future model	Increase in population / year
A	35,575	2013	42,025	2040	239
B	5,565	2013	7,384	2038	73

C	49,444	2014	55,291	2026	487
D	13,856	2013	17,318	2025	289

The three estimates for percentage increase in population were used as multipliers for each subcatchment population to create three new network scenarios: upper, lower and central estimates. These are shown in Table 11.

Table 11 Pilot catchment future assessment (5 year) - population

Catchment	Central population estimate 2022	Central % increase in population	Upper population estimate 2022	Upper % increase in population	Lower population estimate 2022	Lower % increase in population
A	37,725	6.0	38,370	7.9	37,080	4.2
B	6,220	11.8	6,416	15.3	6,024	8.2
C	53,342	7.9	54,512	10.3	52,173	5.5
D	16,453	18.7	17,231	24.4	15,674	13.1

The following information varied from the present-day model and therefore was extracted for each pipe for all three sensitivity models:

- Population upstream
- Population equivalent upstream

The following information varied from the present-day model and therefore was extracted for each CSO for all three sensitivity models:

- Population upstream
- Population equivalent upstream
- Population upstream of CSO, but downstream of any other CSO on the same branch
- Population equivalent upstream of CSO, but downstream of any other CSO on the same branch

The three sensitivity models were run for 10 x DWF and diurnal DWF profile.

The following information was extracted for each pipe from the DWF model results:

- Maximum modelled DWF (10 x DWF and diurnal profile)

The following information was extracted for each CSO from the DWF model results:

- Maximum modelled DWF (10 x DWF and diurnal profile)

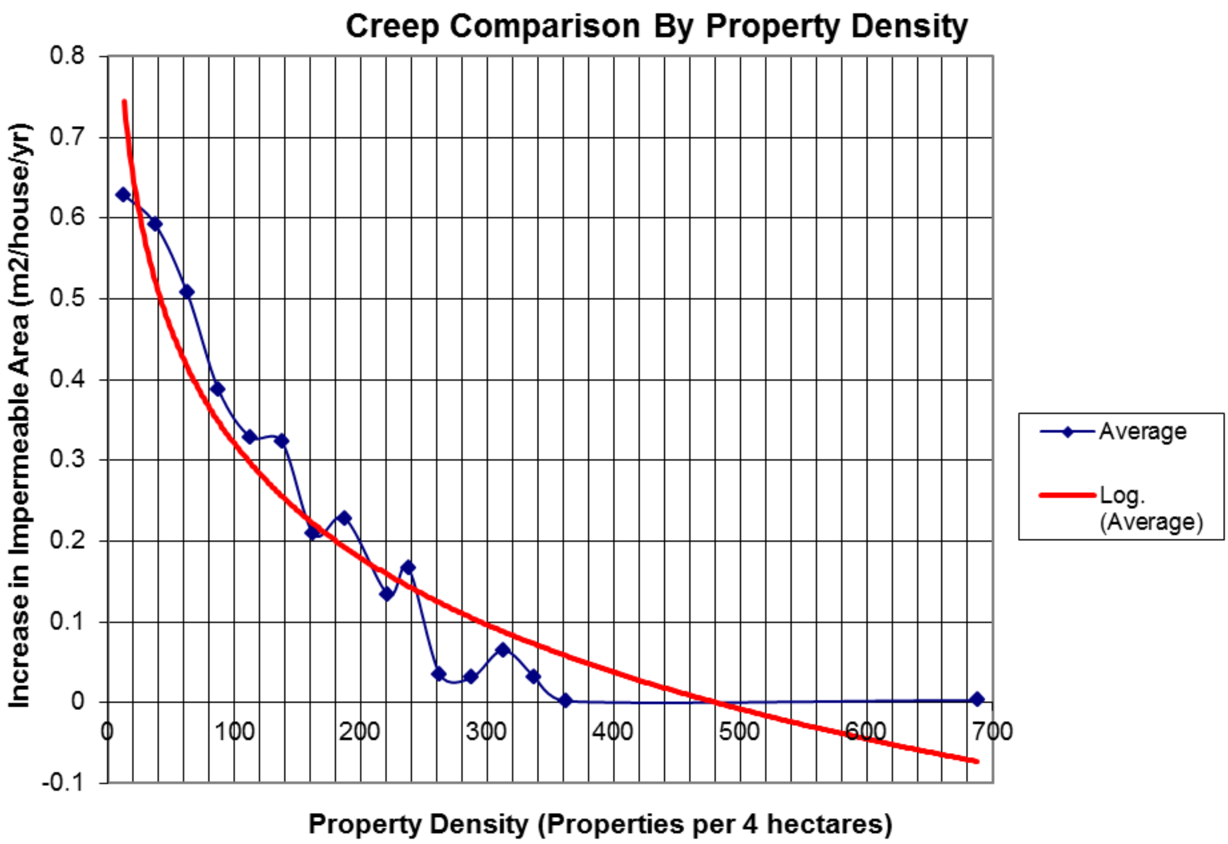
7.4.2.2 Enhanced Method

The future pressures applied to the Enhanced Method at the 5-year time horizon were population and urban creep.

Changes to the Enhanced Model for population growth are the same as for the Initial Method and are explained in Section 7.4.2.1.

Urban creep was calculated outside of the modelling software in a spreadsheet. Firstly, address points were used in GIS to calculate the property density of each subcatchment. The average urban creep by property density set out in Allitt *et al.* (2010) was used to determine a logarithmic equation which could be used to calculate the increase in impermeable area for each subcatchment. The logarithmic equation is shown in Figure 14.

Figure 14 Relationship between property density and increase in impermeable area



Source: United Utilities Creep calculator spreadsheet (average urban creep by property density values and logarithmic formula based on (Allitt *et al*, 2010)

The central increase in impermeable area (ha) for each subcatchment for the 5-year time horizon was multiplied by 1.3 and 0.7 to determine the upper and lower sensitivity estimates. If the subcatchment was defined as foul or surface water, the increase in impermeable area was reduced by 50%, if the subcatchment was defined as combined the increase in impermeable area remained at 100% (i.e. no change made to the calculated value).

A check was carried out to ensure that no subcatchment had an impermeable area greater than 80% of the contributing area. If the original subcatchment did have an impermeable area greater than 80%, the urban creep was set to zero, otherwise the urban creep was limited so that the maximum amount of impermeable area was 80% of the contributing area.

The urban creep area was added to a new runoff surface within the subcatchments. The runoff surface for all pilot catchments was set with the parameters in Table 12.

Table 12 Pilot catchment creep runoff surface parameters

Runoff routing type	Rel
Runoff routing value	1
Runoff volume type	Fixed
Surface type	Impervious
Ground slope (m/m)	0
Initial loss type	Slope
Initial loss value (m)	0.000071
Routing model	Wallingford
Fixed runoff coefficient	0.8

Table 13 shows the absolute and percentage impermeable area for the present-day model. For the central, lower and upper 5-year future estimates, Table 13 shows the absolute and percentage increase in PIMP (i.e. urban creep) as well as the new absolute and new percentage impermeable area.

The three sensitivity models were run for 2 x DWF, 10 x DWF and design storm events. The models were also run for 3 years' time series rainfall. As climate change was not considered at the 5 year time horizon these were the same rainfall events as for present day.

The following information was extracted for each pipe from the DWF and design storm model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Minimum return period for surcharge (design storms)
- Minimum return period for flooding (design storms)

The following information was extracted for each CSO from the DWF and TSR model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Spill events from a single CSO (EDM events)
- Spill events into a single river reach (EDM events)

Table 13 Pilot catchment future assessment (5 year) - urban creep

		Pilot Catchment			
		A	**B**	**C**	**D**
Present day	Total contributing area (ha)	271	208	1648	598
	PIMP (ha)	77	5.6	449	90
	PIMP (%)	29	2.7	28	15
Central estimate	Increase in PIMP (ha)	0.9	0.1	3.3	0.9
	% Increase in PIMP (%)	1.2	1.0	0.7	1.0
	New PIMP (ha)	78	5.6	462	91
	New PIMP (%)	29	2.7	28	15
Upper estimate (+30%)	Increase in PIMP (ha)	1.2	0.1	4.3	1.2
	% Increase in PIMP (%)	1.5	1.3	0.9	1.3
	New PIMP (ha)	79	5.6	463	91
	New PIMP (%)	29	2.7	28	15
Lower estimate (-30%)	Increase in PIMP (ha)	0.6	0.0	2.3	0.6
	% Increase in PIMP (%)	0.8	0.7	0.5	0.7
	New PIMP (ha)	78	5.6	461	90
	New PIMP (%)	29	2.7	28	15

7.4.3 Future assessment (25 years)

The present-day Initial and Enhanced Models were used as the base model to make changes to represent the future assessment. The time horizon was for the 25-year assessment was 2042.

7.4.3.1 Initial Method

The future pressures applied to the Initial Method at the 25 year time horizon are population and consumption rate. The same approach was used to calculate future population values as for the 5-year future assessment (see Section 7.4.2), except with the population growth rate multiplied for the 2042 time horizon instead of 2022.

Table 14 shows the central, upper and lower population estimates and percentage increases in population compared to the present-day models for each of the pilot catchments.

Table 14 Pilot catchment future assessment (25 year) - population

Catchment	Central population estimate 2042	Central % increase in population	Upper population estimate 2042	Upper % increase in population	Lower population estimate 2042	Lower % increase in population
A	42,503	19.5	44,581	13.6	40,424	25.3
B	7,675	37.9	8,308	26.5	7,042	49.3
C	63,087	27.6	67,180	19.3	58,994	35.9
D	22,223	60.4	24,732	42.3	19,713	78.5

Table 15 shows the present-day and future model per capita flows for each pilot catchment as received from the sewerage undertakers. Two of the four pilots have different per capita flows for their future models (one increasing, one decreasing). These were used for the 25-year time horizon simulations. No variation in the per capita flows were used for sensitivity.

Table 15 Pilot catchment present day and future assessment - per capita flow

Catchment	Per capita flow present day (l/day)	Per capita flow future model (l/day)
A	145	145
B	150	150
C	148	158
D	138	130

The following information varied from the present-day and 5-year models and therefore was extracted for each pipe from all three sensitivity models:

- Population upstream
- Population equivalent upstream

The following information varied from the present-day model and -year models therefore was extracted for each CSO from all three sensitivity models:

- Population upstream
- Population equivalent upstream
- Population upstream of CSO, but downstream of any other CSO on the same branch
- Population equivalent upstream of CSO, but downstream of any other CSO on the same branch

The three sensitivity models were run for 10 x DWF and diurnal DWF profile.

The following information was extracted for each pipe from the DWF model results:

- Maximum modelled DWF (10 x DWF and diurnal profile)

The following information was extracted for each CSO from the DWF model results:

- Maximum modelled DWF (10 x DWF and diurnal profile)

7.4.3.2 Enhanced Method

The future pressures applied to the Enhanced Models at the 25-year time horizon were population, urban creep, consumption rate and climate change.

Changes to the Enhanced Models for population growth are the same as for the 5-year future assessment (see Section 7.4.2.1), except with the population growth rate multiplied for the 2042 time horizon instead of 2022.

Changes to the Enhanced Model for urban creep use the same approach as for the 5-year future assessment (see Section 7.4.2.2), except with the time horizon set for 2042 instead of 2022.

Table 16 shows the absolute and percentage impermeable area for the present-day model. For the central, lower and upper 25-year future estimates, Table 16 shows the absolute and percentage increase in PIMP (i.e. creep) as well as the new absolute and new percentage impermeable area.

As with the Initial Method, the modelled future consumption rate has been used where it varies from the present-day future consumption rate (see Table 15), but the same value is used for all three sensitivity simulations.

The three sensitivity models were run for 2 x DWF, 10 x DWF and design storm events. The models were also run for 3 years' time series rainfall.

Table 16 Pilot Catchment future assessment (25 year) - urban creep

		Catchment			
		A	**B**	**C**	**D**
Present day	Total contributing area (ha)	271	208	1648	598
	PIMP (ha)	77	5.6	449	90
	PIMP (%)	29	2.7	28	15
Central estimate	Increase in PIMP (ha)	4.5	0.3	16.5	4.6
	% Increase in PIMP (%)	5.9	5.0	3.6	5.1
	New PIMP (ha)	82	5.8	475	94
	New PIMP (%)	30	2.8	29	16
Upper estimate (+30%)	Increase in PIMP (ha)	5.9	0.4	21.4	6.0
	% Increase in PIMP (%)	7.6	6.54	4.7	6.7
	New PIMP (ha)	83	5.9	480	96
	New PIMP (%)	31	2.8	29	16
Lower estimate (-30%)	Increase in PIMP (ha)	3.2	0.2	11.5	3.2
	% Increase in PIMP (%)	4.1	3.5	2.5	3.6
	New PIMP (ha)	81	5.8	470	93
	New PIMP (%)	30	2.8	29	16

Climate change was also considered as part of the future pressures. Table 17 shows the combination of sensitivity model, design storm uplift and TSR that was used for the simulations.

The following information was extracted for each pipe from the DWF and design storm model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Minimum return period for surcharge

- Minimum return period for flooding

The following information was extracted for each CSO from the DWF and TSR model results:

- Maximum modelled DWF (for 2 x DWF and 10 x DWF)
- Spill events from a single CSO (EDM events)
- Spill events into a single river reach (EDM events)

Table 17 Pilot catchment future assessment (25 year) - design storms and TSR

Sensitivity model	Design storms	TSR
Upper estimate model	26% uplift	2030s High emissions P90
Central estimate model	20% uplift	2030s High emissions P50
Lower estimate model	14% uplift	2030s High emissions P10

7.4.4 Future assessment (25 years) with interventions

The 25-year central estimate future models were used for intervention assessment.

7.4.4.1 Initial Method

As the only changes made to the models were reductions in impermeable area, this cannot be applied to the Initial Method. Therefore, no information was calculated for the Initial Method.

7.4.4.2 Enhanced Method

Interventions were limited to impermeable "area removal" for achieving an improvement in system performance. Other methods of intervention were considered, but were rejected as being too complex for a high-level analysis (see Section 5).

A 10% removal of impermeable area was applied to all subcatchments at the 25-year time horizon. This was achieved by removing 10% of roof area and 10% of road area within a single subcatchment. Three further runs were made for three other levels of intervention to be tested for the 25-year time horizon: 20%, 30% and 40% reduction in contributing impermeable area.

A minimum threshold of 5% of the subcatchment contributing area was set for the road area and 5% for the roof area. This meant that if any subcatchment reduced the present day roads (or roofs) to 5% the road (or roof), the remaining reduction of impermeable area was removed from the urban creep impermeable surfaces which had been added. If a subcatchment originally had less than 5% road (or 5% roof) then the area remained the same (not increased or decreased), but the removal of the urban creep component was limited to prevent the percentage of total contributing impermeable surface (either roof or road) dropping below 5%.

Any reduction in impermeable area was replaced by the equivalent increase in pervious area.

Table 18 shows the absolute and percentage impermeable area for the future 25-year central estimate models. It also shows the absolute and percentage decrease in impermeable area for each degree (-10%, -20%, -30% or -40%) of PIMP removal as well as the new absolute and percentage PIMP for each degree of PIMP scenario.

When compared to the future 25-year (central estimate) model, the actual reduction in percentage PIMP for each pilot catchment is not as great as the possible 10% to 40% PIMP removal. This is due to the 5% PIMP threshold set for road and roof areas for individual sub-catchments. There is a significant decrease in percentage impervious area between the future 25-year model and the -10% impervious area model (except for Pilot Catchment B where there is very little PIMP originally) and subsequent decreases in PIMP reduces for each increasing level of area removal.

Table 18 Pilot catchment future assessment (25 year) - impermeable area removal

		Catchment			
		A	B	C	D
Present day	Total contributing area (ha)	271	208	1648	598
	PIMP (ha)	77	5.6	459	90
	PIMP (%)	29	2.7	28	15
Future 25 years (central estimate)	PIMP (ha)	82	5.8	475	94
	PIMP (%)	30	2.8	29	16
Area removal: -10% PIMP	PIMP removed (ha)	25	1.6	153	37
	% Removal of PIMP (%)	30	27	32	39
	New PIMP (ha)	57	4.0	322	57
	New PIMP (%)	21	1.9	20	9.6
Area removal: -20% PIMP	PIMP removed (ha)	36	2.1	237	55
	% Removal of PIMP (%)	44	36	50	56
	New PIMP (ha)	46	3.5	238	40
	New PIMP (%)	17	1.7	14	6.7
Area removal: -30% PIMP	PIMP removed (ha)	42	2.5	279	61
	% Removal of PIMP (%)	52	42	59	65
	New PIMP (ha)	40	3.4	196	33
	New PIMP (%)	15	1.6	12	5.5
Area removal: -40% PIMP	PIMP removed (ha)	46	2.5	306	64
	% Removal of PIMP (%)	57	44	65	68
	New PIMP (ha)	35	3.3	169	30
	New PIMP (%)	271	208	1648	598

7.4.5 Detailed interventions

Solution models were received for Catchment B from the sewerage undertaker. These were models developed as part of the application of their detailed modelling framework. Three solution models were received, a present-day scenario with short-term solutions, a 5-year future scenario with medium-term solutions and a 25-year future scenario with long-term solutions. A description of the options included in each solution model are provided in Table 19.

The detailed interventions were copied into the models used for the Framework. This was done in preference to using the detailed intervention models as received from the sewerage undertaker because:

- The baseline present-day models used for the detailed solutions and for the Framework differed (the baseline model used for the Framework was a more recent version), and

- The future pressures applied to the Framework models differed from those applied by the sewerage undertaker within their detailed intervention models.

By placing the detailed interventions into the models used for the Framework, this allowed the detailed intervention model results to be compared directly with the other Framework results.

The Framework future models include urban creep, whilst this was not applied to the future models received from the sewerage undertaker. The sewerage undertaker's modelling specification requires urban creep to be considered at the 25-year time horizon. However, it was not included in the model received, as it was not considered an issue for this particular catchment. Therefore, the Framework's future models for Catchment B are potentially too conservative.

After reviewing the intervention models received, it was found that the medium-term scenario model did not include any interventions beyond those provided in the short-term scenario, because the medium-term options consist of sewerage pumping station rehabilitation options. Therefore, the only detailed interventions added to the Framework models were the short-term solutions at the present-day and both the short-term and long-term solutions at the 25-year time horizon.

Table 19 Detailed solutions modelled within each time horizon – Pilot Catchment B

Model	Option	Description of solution	Capital Costs (£)
Short-term	Option 2 Surface Water Removal	Remove 0.5 ha of connected road area and roof area in same region. Assume a swale could be constructed to accommodate the required volume.	266,803
	Option 3 Relining & Surface Water Removal	Reline and seal the covers to remove surface water ingress. Additionally remove all connected road (1.5 ha) and roof area and assume a swale could be constructed to accommodate the required volume.	483,597
	Option 4 Tank Upsizing & Realigning	Upgrade tanks including an additional 290m^3 storage at the tanks as well as re-lining and sealing the covers along the route.	827,261
	Option 5 Tank	Upsizing approximately 417m of sewer.	555,503
	Option 6 SPS Rehab	Fully refurbish Sewage Pumping Station.	545,632
Medium-term	Option 7 WwTW	Upgrade WwTW plant.	Not estimated
	Option 8 SPS Renewal	Fully refurbish Sewage Pumping Station.	545,632
	Option 9 SPS	Overhaul of pumps currently installed at the Sewage Pumping Station and potential full replacement.	271,584
Long-term	Option 10 SPS	Identify source of infiltration in upstream catchment of Sewage Pumping Station, then rehab were appropriate.	152,972
	Option 11 Relining	Identify sources of infiltration, then rehab were appropriate.	152,972
	Option 12 Storage	Approximately 40m^3 additional storage upstream of a WwTW.	359,693

7.5 Rainfall data

7.5.1 Design storms

The FEH13 rainfall catchment descriptors were downloaded for each pilot catchment from the FEH web service. These descriptors are shown in Table 20. The catchment area was adjusted to match the catchment area used within the rainfall files provided with each pilot catchment model.

The FEH13 rainfall parameters were input into the ReFH2 rain event generator and any initial conditions (NPI, UCWI, evaporation etc.) required for runoff models were copied from the rainfall files received from the sewerage undertakers.

Rainfall events were created for 2, 5, 10 and 30 year return periods and for 30, 60, 120, 240, 300 and 600 minute event durations. Only summer rainfall events were created.

Table 20 Pilot catchment rainfall catchment descriptors

Catchment	A	B	C	D
C	-0.024	-0.025	-0.014	-0.026
D1	0.452	0.393	0.427	0.43
D2	0.518	0.386	0.421	0.468
D3	0.272	0.315	0.258	0.3
E	0.26	0.285	0.242	0.306
F	2.274	2.505	2.153	2.44
Catchment area (ha)	617.8	554	1500	200
SAAR (mm)	1043	1156	788	1161
BFIHOST	0.328	0.768	0.514	0.449
PROPWET	0.52	0.47	0.45	0.36

7.5.2 TSR

To save time and effort, for testing the pilot catchments pre-existing present and future TSR were used. TSR data was available for eight sites in Yorkshire Water's region. Checks were carried out to ensure the most representative site's TSR was used for each pilot catchment. Although the TSR may not be particularly representative for some of the catchment locations, this approach is considered sufficiently adequate for illustrating the Framework in assessing CSO performance.

The FSR maps were used to calculate the absolute percentage difference between the pilot catchments and all eight of the Yorkshire Water regions (used for the development of climate change TSR data) for SAAR, M5-60 depth and the ratio of M5-60 depth to M5-2day depth. These absolute percentage differences for the three parameters were summed to calculate a total percentage difference for each pilot catchment compared to each of the eight Yorkshire sites. The Yorkshire site with the smallest percentage difference compared to the pilot site was chosen, as shown in Table 21.

Table 21 Differences between pilot catchments and Yorkshire site chosen for TSR

Catchment	Pilot Catchment (values from FSR maps)			Yorkshire site chosen (values from FSR maps)			Total % difference between Pilot Catchment and Yorkshire site chosen
	SAAR (mm)	M5-60 (mm)	r (M5-60 / M5-2day)	SAAR (mm)	M5-60 (mm)	r (M5-60 / M5-2day)	
A	1000	16.5	0.30	950	17.8	0.330	0.23
B	1200	19.0	0.29	1200	19.0	0.275	0.05
C	725	13.0	0.25	750	19.0	0.350	0.90
D	950	19.0	0.32	950	17.8	0.330	0.09

The Yorkshire TSR was produced with 25 years of data. As only 3 years of TSR was needed for the pilot catchments, checks were carried out to choose a representative 3 years from the 25 year series.

The 25 years of TSR data was assessed to determine the average annual depth, average number of events (greater than 2, 5 and 20mm) per year and maximum depths for 1, 6, 12 and 24 hour rainfall events. The same parameters were then calculated for a randomly selected 3 years of data taken from the 25 years of data. If no extreme events were found within the chosen 3 years of data and the parameters closely aligned with the parameters calculated for the 25 year series, the 3 year series was taken forward, otherwise another 3 years of data was selected and checked until a suitable 3 years of data was found for each pilot catchment.

7.6 Other run files

7.6.1 Domestic waste profile

Domestic waste profiles were used for the pilot catchment Initial and Enhanced Models for all simulations. No changes were made to the modules from those received from the sewerage undertakers.

For design events a multiplier of 2 or 10 was used for the design profile.

7.6.2 Trade waste profile

Trade waste profiles were used for the pilot catchment Initial and Enhanced Models for all simulations. No changes were made to the modules from those received from the sewerage undertakers.

For design events a multiplier of 1 was used for the design profile.

7.6.3 Ground infiltration

The ground infiltration modules were not used for the Initial Models.

Ground infiltration modules were used for the pilot catchment Enhanced Models for DWF, design storms and TSR simulations as specified in the documentation and model files supplied with the pilot catchment models. No changes were made to the modules from those received from the sewerage undertakers.

7.7 Model simulations

Table 22 and Table 23 show the simulations that were carried out for each of the pilot catchments.

Table 24 show the simulations that were carried out for the detailed intervention models for Pilot Catchment B.

Table 22 Pilot catchments model simulations - Initial Method

	Present day	Future 5 years	Future 25 years
DWF	Diurnal	Diurnal x 3*	Diurnal x 3*
	2 x DWF		
	10 x DWF	10 x DWF x 3*	10 x DWF x 3*

Notes: * With sensitivity of future pressures (low (-30%), central, high (+30%))

Table 23 Pilot catchments model simulations - Enhanced Method

	Present day	Future 5 years	Future 25 years	Future 25 years with interventions
DWF	2 x DWF	2 x DWF x 3*	2 x DWF x 3*	2 x DWF x 4**
	10 x DWF	10 x DWF x 3*	10 x DWF x 3*	10 x DWF x 4**
Design Storms	2, 5, 10 and 30 year RP, multiple durations	(2, 5, 10 and 30 year RP, multiple durations) x 3*	(2, 5, 10 and 30 year RP, multiple durations) x 3*	(2, 5, 10 and 30 year RP, multiple durations) x4**
TSR	3-year series	3-year series x 3*	3-year series x 3*	3-year series x 4**

Notes: * With sensitivity of future pressures (low (-30%), central, high (+30%)); ** With the four area removal interventions and central only future pressures

Table 24 Pilot catchment B detailed model simulations - Enhanced Method

	Present day with present day detailed interventions	Future 25 years with present day detailed interventions	Future 25 years with 25- year detailed interventions
DWF	10 x DWF	10 x DWF	10 x DWF
Design Storms	2, 5, 10 and 30 year RP, multiple durations	2, 5, 10 and 30 year RP, multiple durations	2, 5, 10 and 30 year RP, multiple durations

7.8 Results

7.8.1 Pilot catchment scoring

Table 25, Table 26 and Table 27 set out the individual and aggregate scores the pilot catchment results are based on in Sections 7.8.2 to 7.8.5. Two aggregate scoring approaches have been used to display the pilot catchment results for CSOs, but only one aggregate scoring approach for pipes. This is because the aggregate ranges differ for the two aggregate scoring approaches for CSOs, whilst the aggregate ranges are the same for the two pipe aggregate scoring approaches.

Note that the aggregate scoring method of CSOs based on absolute number of red individual CSOs is not recommended in the Guidance document, but was tested with the pilot catchments.

Table 25 Scoring of pipe metrics for the pilot catchments

Metric	Individual score		Aggregate score**	
	Colour	Range	Colour	Range (%)
Pipe full capacity / Factored DWF*	Green Amber Red	> 3.0 1.5 - 3.0 < 1.5	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100
Surcharge return period (years)	Green Amber Red	> 10 > 2, but < 10 < 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100
Flooding return period (years)	Blue Green Amber Red	> 30 > 10 and ≤ 30 > 5 and ≤ 10 ≤ 5	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100

* 10 x DWF

** Aggregate score can either be based on percentage length of red individual pipes or based on percentage of red pipes scaled by population equivalent upstream

Table 26 Scoring of CSO metrics for pilot catchments – aggregate score based on absolute number of red CSOs score

Metric	Individual score		Aggregate score Score based on absolute number of red individual CSOs***	
	Colour	Range	Colour	Range
Continuation pipe full capacity / Factored DWF*	Green Amber Red	> 2 > 1, but < 2 <1	Green Amber Red	< 1 ≥ 1 ≥ 2
CSO spill potential (i.e. Continuation pipe full capacity / Incoming pipe full capacity)	Green Amber Red	< 5 ≥ 5 and < 10 ≥ 10	Green Amber Red	< 1 ≥ 1 ≥ 2
Number of CSO spills per year**	Green Amber Red	< 20 > 20 , but < 40 > 40	Green Amber Red	< 1 ≥ 1 ≥ 2

Number of CSO spills per summer (June, July, August)**	Green Amber Red	< 3 > 3, but < 10 > 10	Green Amber Red	< 1 ≥ 1 ≥ 2

* Based on 10 x DWF

** Based on 2 x DWF

*** Scoring method not used in the Guidance

Table 27 Scoring of CSO metrics for pilot catchments – aggregate score based on weighted points score

Metric	Individual score			Aggregate score Score based on weighted points score of CSOs	
	Colour	**Range**	**Points**	**Colour**	**Range**
Continuation pipe full capacity / Factored DWF*	Green Amber Red	> 2 > 1, but < 2 <1	0 1 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100
CSO spill potential (i.e. Continuation pipe full capacity / Incoming pipe full capacity)	Green Amber Red	< 5 ≥ 5 and < 10 ≥ 10	0 1 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100
Number of CSO spills per year**	Green Amber Red	< 20 > 20, but < 40 > 40	0 1 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100
Number of CSO spills per summer (June, July, August)**	Green Amber Red	< 3 > 3, but < 10 > 10	0 1 2	Green Pale Green Pale Amber Amber Red	0-10 10-20 20-30 30-40 40-100

* Based on 10 x DWF

** Based on 2 x DWF

7.8.2 Present-day assessment

7.8.2.1 Pipes

Figure 15 shows the pipe metric scores for all 4 pilot catchments. Scores have been calculated based on percentage length of pipes within each pilot catchment.

Figure 15 Pilot catchments: all pipe metrics – present day

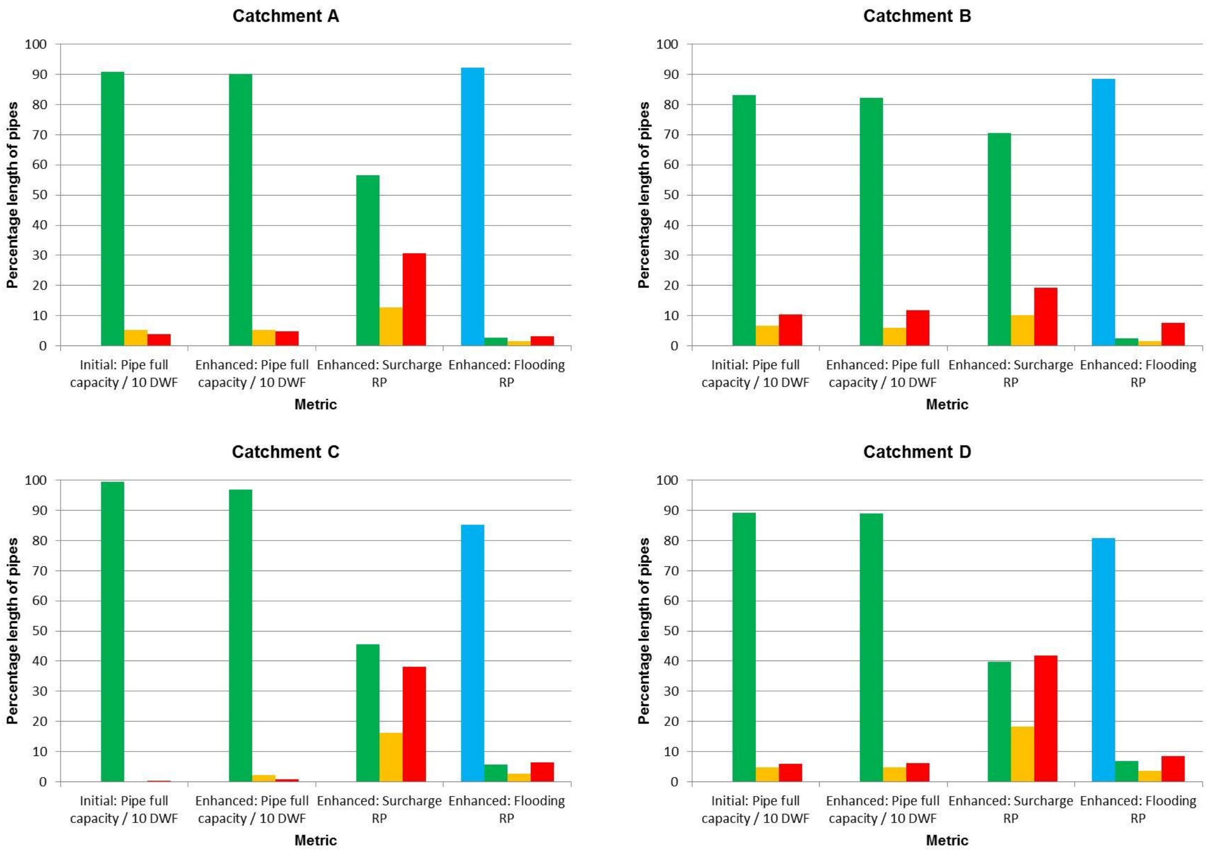


Figure 16 shows the Enhanced surcharge return period scores for the 3 pipe counting methods which were tested. These were the percentage number of pipes, percentage length of pipes and total number of pipes scaled by population equivalent served by each pipe as a percentage. The number of pipes is an artifice of modelling, whilst length is a reflection of reality and, therefore, this is preferred. Scaling by population equivalent served has been calculated by totalling up the equivalent population upstream of every pipe scoring red and dividing that number by the average equivalent population upstream for all pipes in the network.

There is a difference between the scores for length of pipes and population equivalent served, with 3 of the 4 pilots showing more 'red' scores when scaled by population. This reflects the fact that the trunk sewers, which serve a greater number of people, are under greater pressure and allows them to stand out. Catchment D does not follow this trend, which suggests that the larger pipes have a relatively lower loading condition than upstream pipes. This may be because of the protective effect of the CSOs in the system.

Figure 16 Pilot catchments: Enhanced surcharge return period scores for alternative individual scoring methods – present day

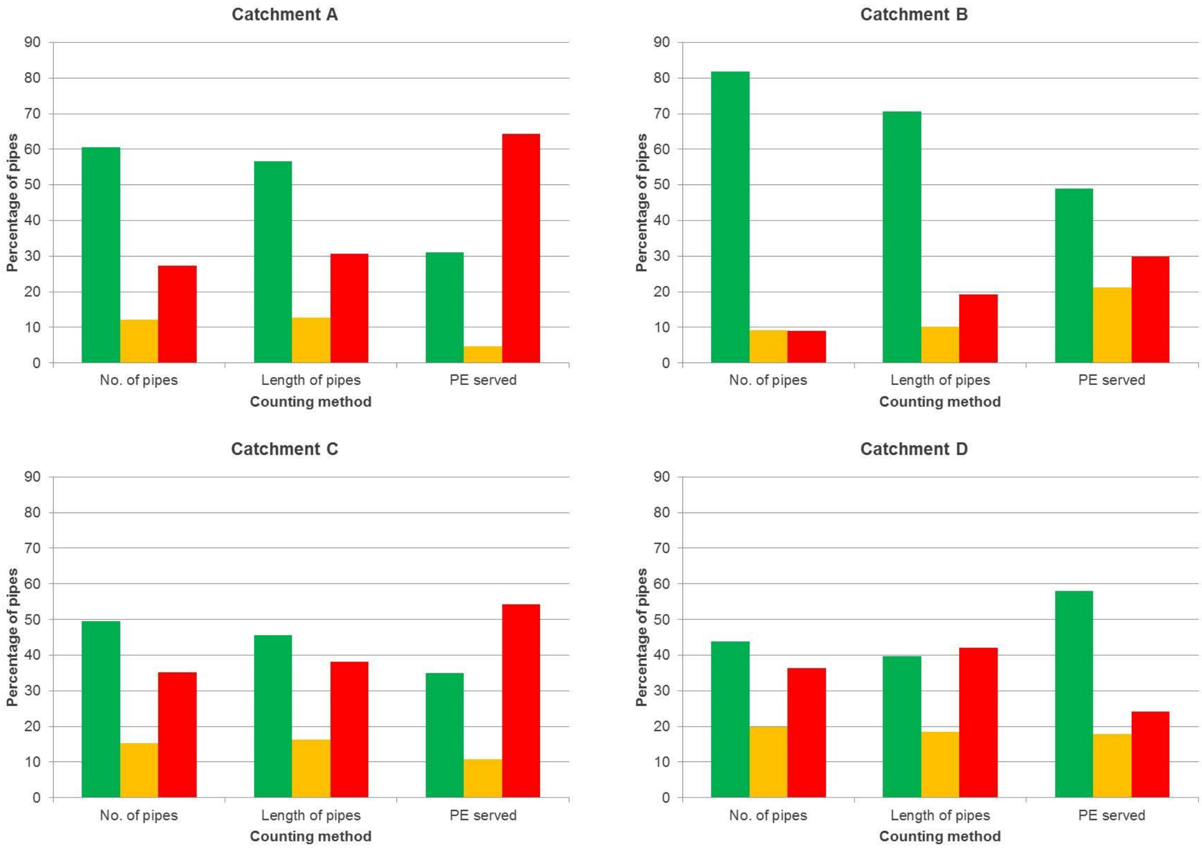


Figure 17 compares the pipe full capacity / 10 x DWF scores for the Initial and Enhanced models. This shows that infiltration included within the model has a marginal impact on the score results.

Figure 17 Pilot catchments: Initial pipe full capacity / 10 x DWF score vs Enhanced pipe full capacity / 10 x DWF score – present day

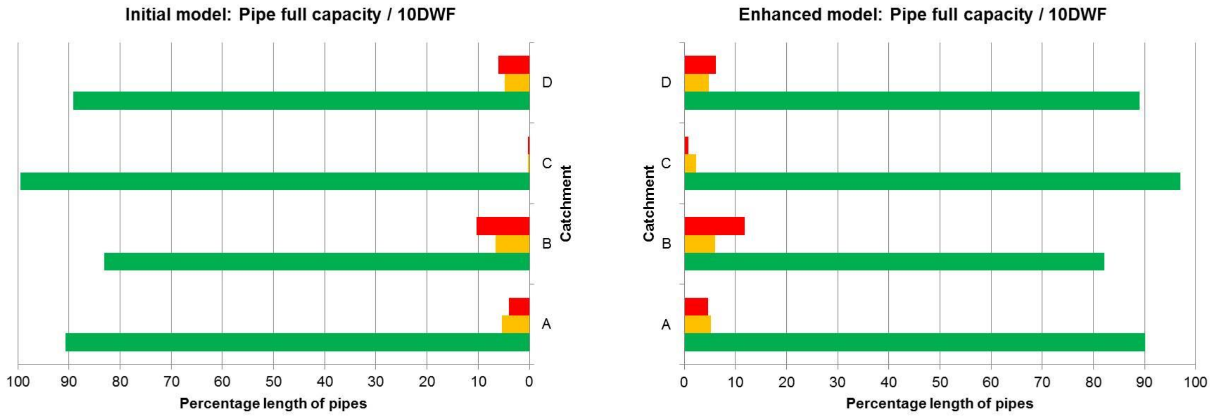


Figure 18 compares the pipe full capacity / 10 x DWF scores for the Initial Model with the surcharge return period metric for the Enhanced Model. This shows that without the inclusion of area within the model the capacity is overestimated. It also does not show any similitude (correlation between the pilot models). This can be seen by the fact that Catchment B has the highest proportion of 'red' pipes in the Initial model, while it scores lowest for the Enhanced model. Catchment C has the exact converse result. It effectively means that the Initial metrics have limited value.

Figure 18 Pilot catchments: Initial pipe full capacity / 10 x DWF score vs Enhanced surcharge return period score – present day

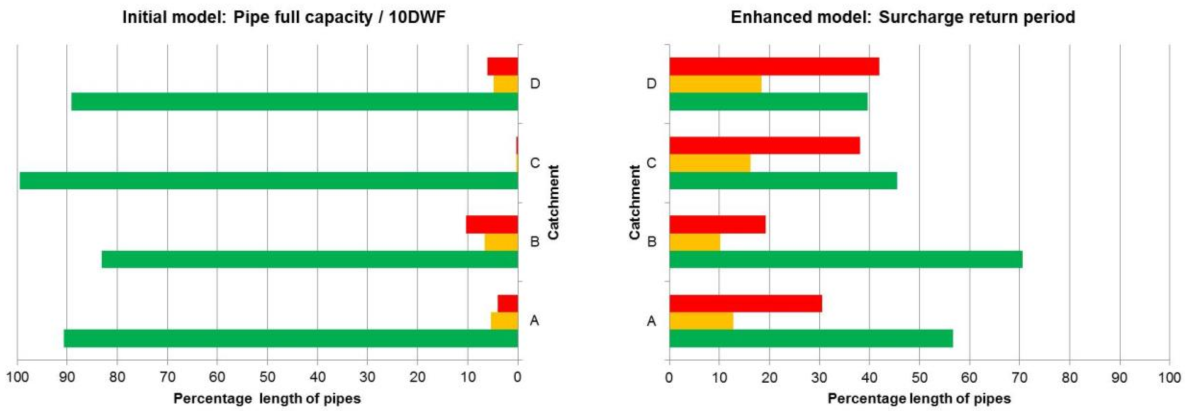
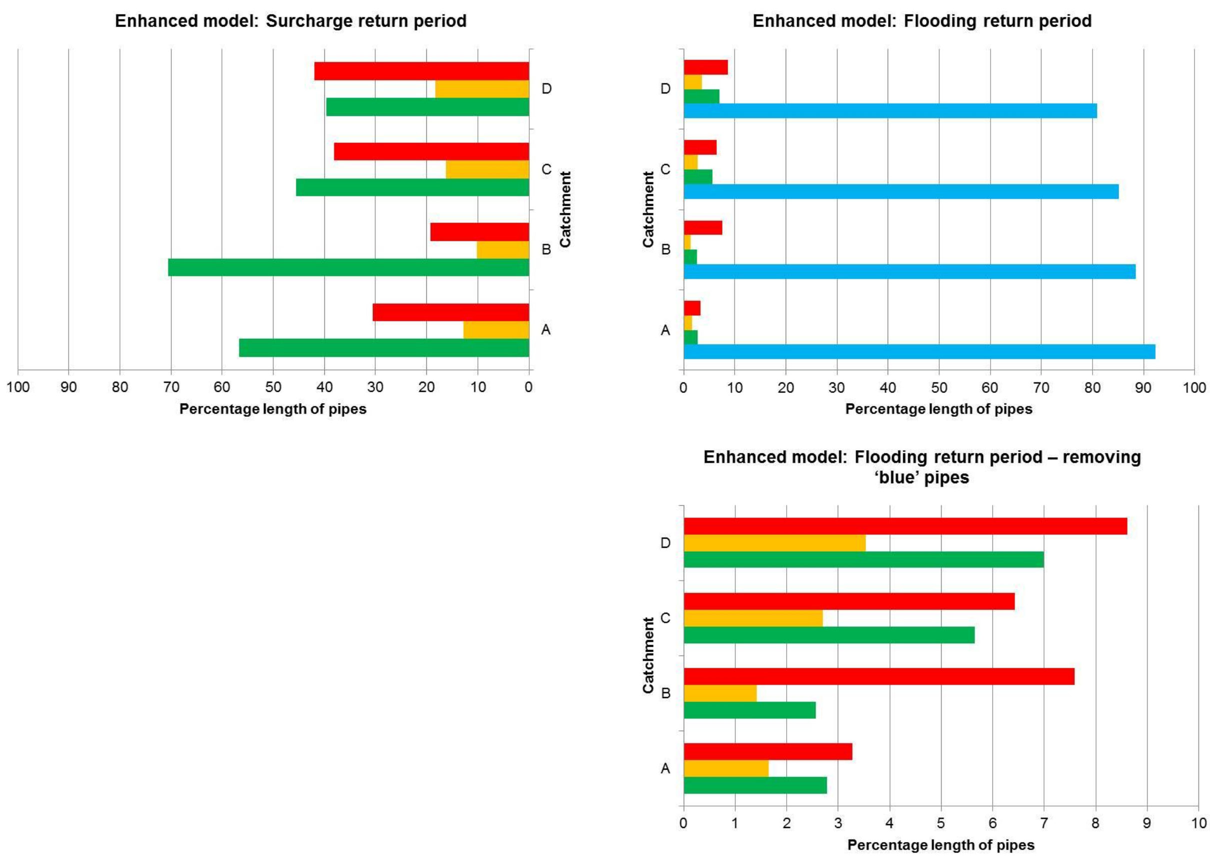


Figure 19 compares the surcharge return period scores to the flooding return period scores for the Enhanced Model. The top right graph shows all the scores for the flooding return period scores whilst the bottom right graph removes the blue scores (pipes that do not flood at the 30 year return period) and rescales the x-axis to show the shape of the red, amber and green scores.

Table 28 shows the percentage length of ‘red’ pipes for both the surcharge return period and flooding return period metrics, and the ratio of these ‘red’ scores. It shows that this ratio for three of the 4 pilot catchments varies between 4.9 and 9.3, a difference factor of only 2. As usual Catchment B is slightly out of step by having a red ratio of only 2.5. This shows that flooding return period and surcharge return period metrics are reasonably closely aligned.

Figure 19 shows that surcharge (a measure of capacity) is a more sensitive metric than using nodes which flood (a measure of level of service). Although the similitude between pilot catchments is limited, there is a reasonable relationship bearing in mind the proportion of nodes in Red / Amber / Green for flooding is only a few percent of the total number of nodes in the model. As the majority of pipes do not flood at the 30-year return period (blue category) there is very limited sensitivity to scoring networks in this way. The red scoring pipe length percentage range is very small being between 3.3% and 8.6%. Surcharge is, therefore, considered to be an effective measurement of the performance of networks.

Figure 19 Pilot catchments: Enhanced surcharge return period score vs Enhanced flooding return period score – present day



Note: different x-axis scale for ‘Flooding return period – removing the ‘blue’ pipes’ graph

Table 28 Pilot catchments: Enhanced surcharge return period red score vs Enhanced flooding return period red score – present day

	Pilot Catchment			
	A	B	C	D
Surcharge return period metric: Percentage length of RED pipes	30.6	19.3	38.2	42.0
Flooding return period metric: Percentage length of RED pipes	3.3	7.6	6.4	8.6
Surcharge RP - % length of RED pipes / Flooding RP - % length of RED pipes	9.3	2.5	6.0	4.9

7.8.2.2 CSOs

Figure 20 shows the CSO metric scores for all 4 pilot catchments. Breakdown of RAG scores have been calculated based on absolute number of CSOs within each pilot catchment.

Figure 20 Pilot catchments: all CSO metrics – present day

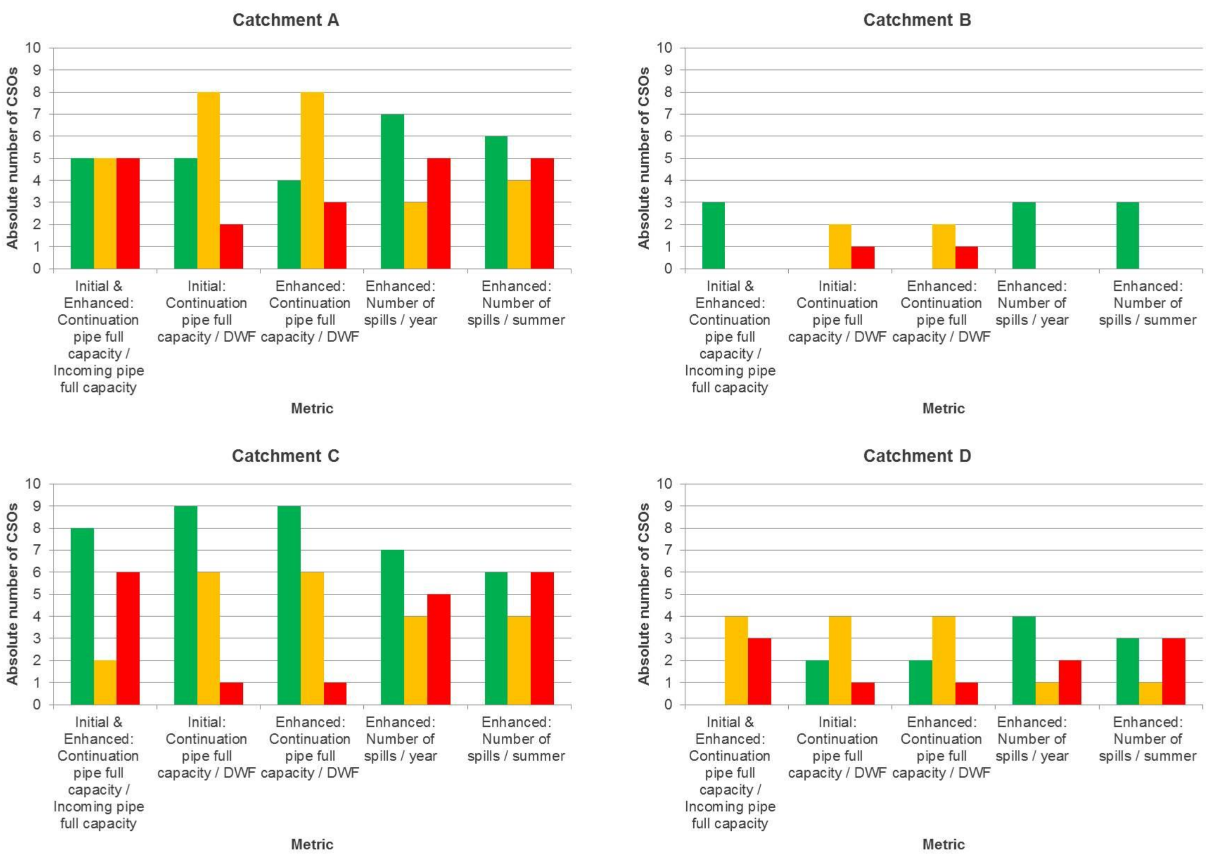


Figure 21 shows the Enhanced metric number of spills per year scores for the 3 aggregate scoring methods which were tested. These were absolute number of CSOs, percentage number of CSOs and total number of CSOs scaled by population equivalent upstream of each CSO as a percentage.

Scaling by population equivalent served has been calculated by totalling up the equivalent population upstream of every CSO scoring red and diving the total number by the average equivalent population upstream for all CSOs in the network. If there is another CSO on the same branch upstream, the population equivalent was also calculated as the population equivalent downstream of the upstream CSO. However, this approach was considered unnecessary additional effort for the Framework and has not been included in the guidance.

Absolute number of CSOs and percentage number of CSO scores show the same pattern of results (the difference is a factor of 100 divided by the total number of CSOs in the catchment). Absolute number is preferred because unlike pipes there are many fewer CSOs in a catchment and therefore when one CSO changes from one RAG score to another there is a large change in percentage results which could hide whether this large change is down to only one CSO result.

Scoring using the total number of CSOs scaled by population equivalent upstream of each CSO, compared to percentage number of CSOs without any scaling, results in a reduction of green individual scores, and an increase in either or both of amber and red scores.

Figure 21 Pilot catchments: Enhanced number of spills / year scores for alternative individual score counting methods – present day

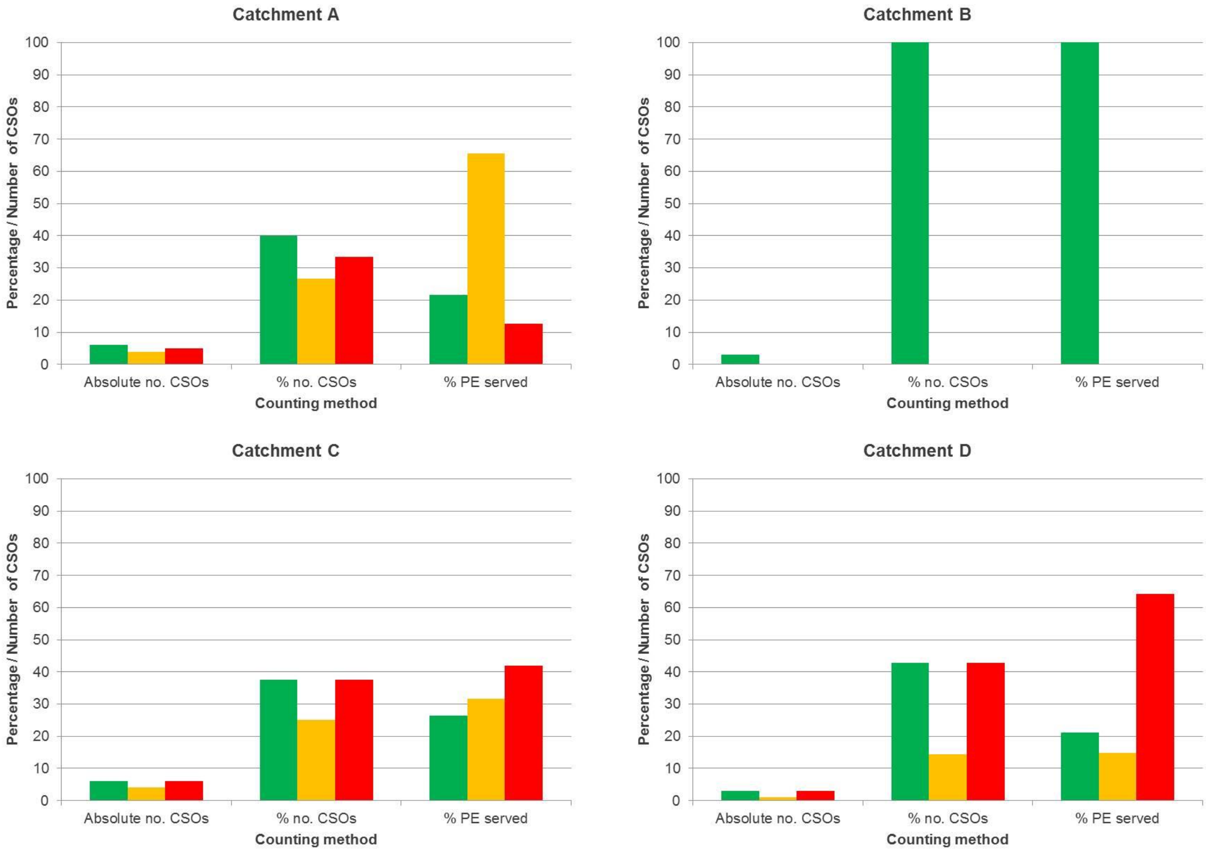


Figure 22 compares the continuation pipe full capacity / 10 x DWF scores for the Initial and Enhanced Models. The results are the same for three out of the four catchments, with Catchment A only showing a change in category for one CSO. Therefore, including infiltration does not significantly influence the results for this metric.

Figure 22 Pilot catchments: Initial continuation pipe full capacity / 10 x DWF score vs Enhanced continuation pipe full capacity / 10 x DWF score – present day

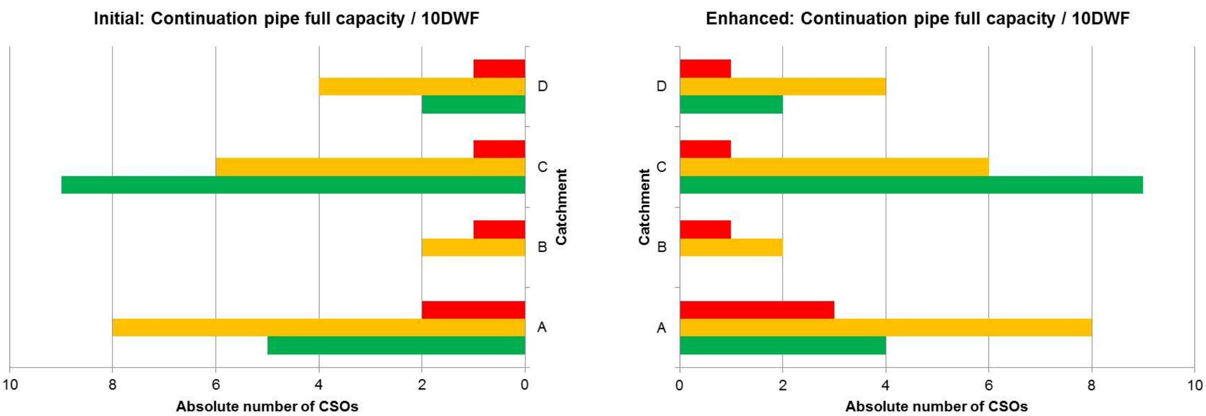


Figure 23 compares the continuation pipe full capacity / 10 x DWF scores for the Initial Model and number of spills per year for the Enhanced Models. The results vary, with an increase in the number of red CSOs for the Enhanced metric compared to the Initial metric for 3 out of the 4 pilot catchments. For Catchment B, where all the overflows are EOs, the Enhanced metric scores the catchment significantly more favourably. This is because the continuation pipe full capacity / 10 x DWF metric does not take account of any storage at the CSO and, therefore, may not be appropriate for EOs and overflows with storage.

The DWF analysis shows very different results from the TSR spills analysis. Changing the scoring of either metric is unlikely to provide a better agreement between the methods; again indicating that the Initial Method has very limited benefit in showing CSO performance.

Figure 23 Pilot catchments: Initial continuation pipe full capacity / 10 x DWF score vs Enhanced number of spills / year score – present day

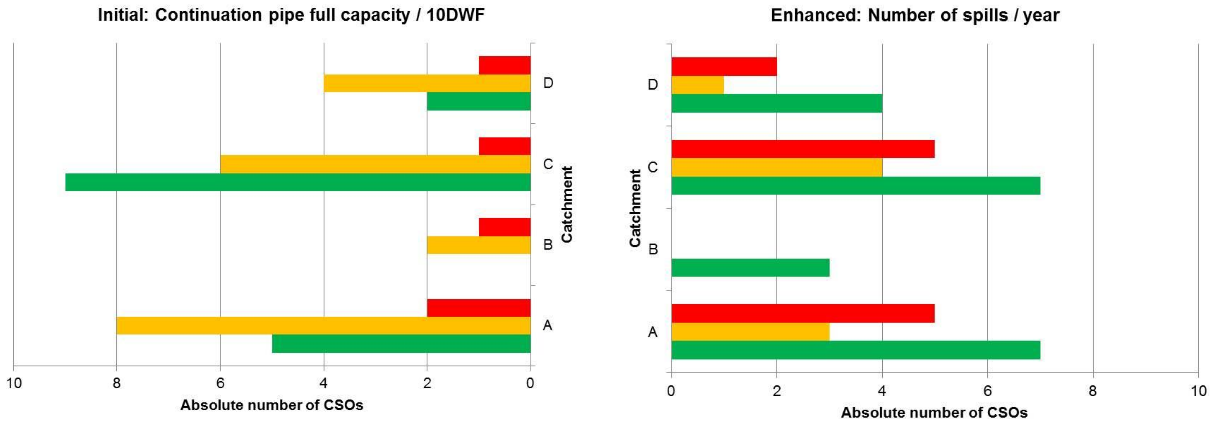


Figure 24 compares the number of spills per year and number of spills per summer for the Enhanced Models. The scores closely align, with the number of spills per summer scores slightly worse. Catchment A and Catchment C have bathing beaches.

Figure 24 Pilot catchments: Enhanced number of spills / year score vs Enhanced number of spills / summer score – present day

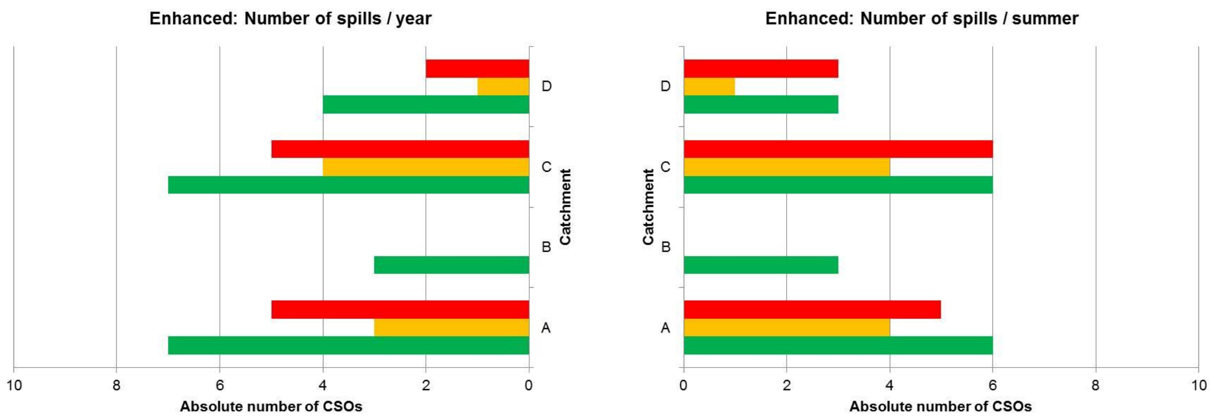


Figure 25 shows number of spills per year scores for three different spill counting methods. The three methods are:

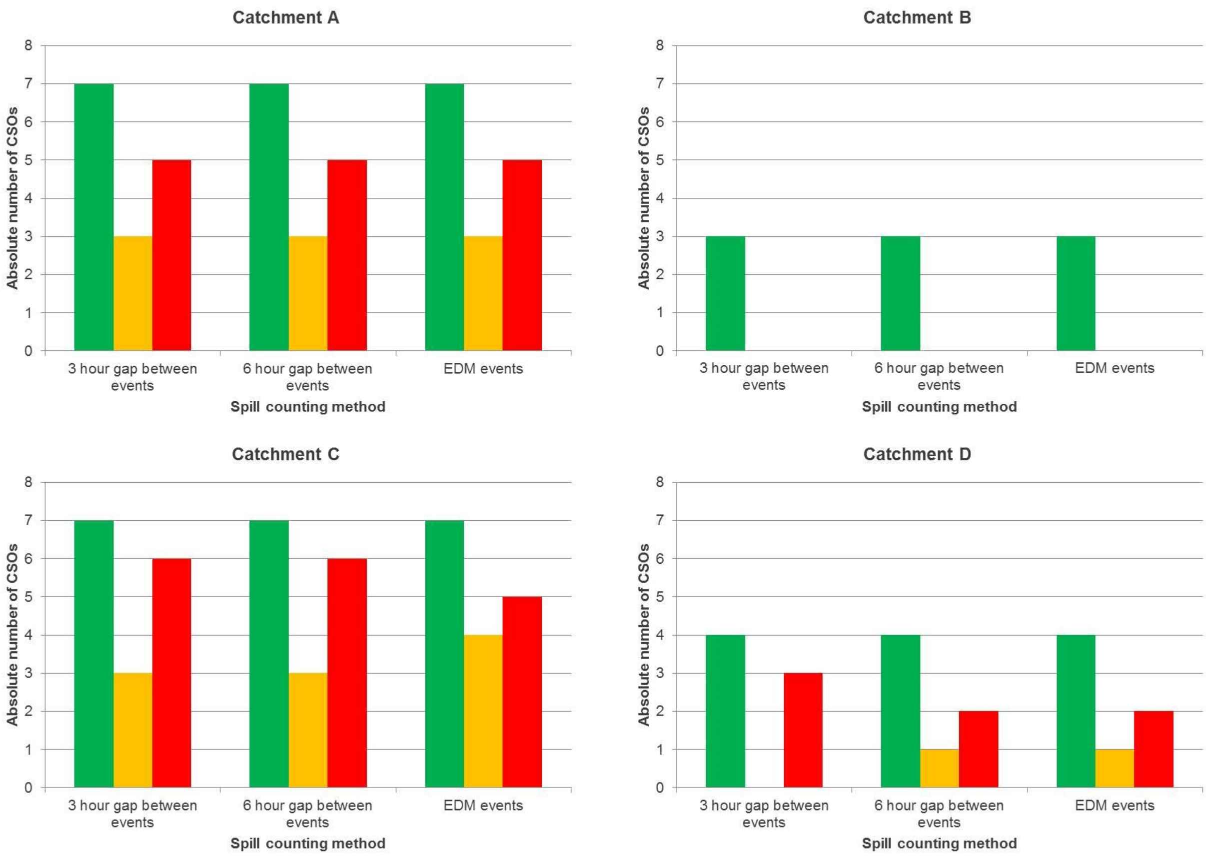
- Spill counting starts when the first discharge occurs. Events within 3 hours of the first discharge is counted as the same spill. A new count starts after there has been a 3 hour gap without any discharge.

- Spill counting starts when the first discharge occurs. Events within 6 hours of the first discharge is counted as the same spill. A new count starts after there has been a 6 hour gap without any discharge.

- EDM spill counting starts when the first discharge occurs. Any discharge in the first 12 hour block is counted as 1 spill and any discharge(s) in the next and subsequent 24 hour blocks are each counted as 1 additional spill per period. This counting continues until there is a 24 hour period with no discharge.

Figure 25 shows that there is almost no difference in the scores between the different spill counting methods. The EDM spill counting method is preferred because it will be directly comparable with EDM reported data.

Figure 25 Pilot catchments: Enhanced number of spills / year score for alternative spill counting methods – present day



7.8.2.3 Area (aggregate) scores

Pipes

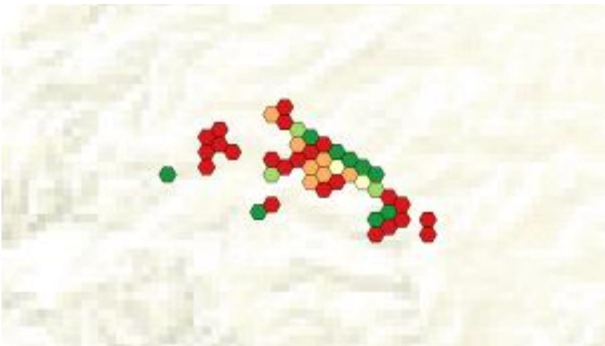
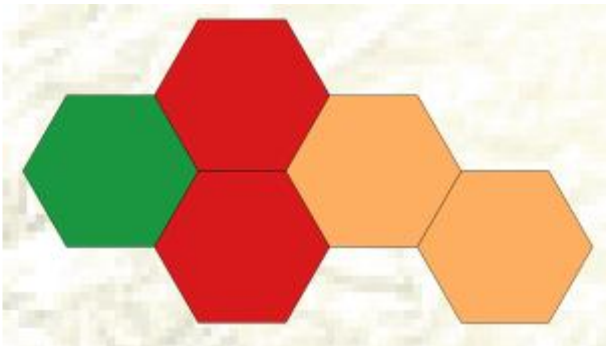
Figure 26 shows the aggregate pipe scores which were developed from individual pipe scores within each aggregate score boundary. The aggregate scores can be shown at different spatial scales and with different boundaries - based on the concept described in Section 6.

The aggregate score for an area (in the example provided this is in the form of hexagons and postcodes) is calculated by the percentage length of individual red pipes within the area. Five scoring thresholds have been used to allow the variation in scores spatially or temporally to be more distinguishable. It also allows a gradation in colours from 'good' to 'bad' rather than artificially implying an area is either at the good end or bad end of the scale with only one category in between. See Table 25 which outlines the aggregate scoring approach for pipes.

Figure 26 shows the pipe scores using two different hexagon scales, 1 km and 10 km diameters, as well as with postcode boundaries. The postcode boundaries used are at level 4 out of 5 scale e.g. OX10 8. The approximate diameter of these postcode regions are between 0.5 km and 5 km, with significantly smaller areas in more populated regions.

The 1 km hexagons provide a greater level of detail and are suitable for comparing performance at a catchment scale. The larger hexagons provide a coarser overview of performance and would be more suitable to comparing performance across a sewerage undertaker or county region. Postcode regions are easier for stakeholders to understand the geographic region they are viewing. Postcode regions could also be produced at a coarser scale, for example OX10. However, the variation in the size of the postcode regions does introduce a number of challenges regarding visualisation scale and interpretation of the data. Post codes also change in their boundaries from time to time.

Figure 26 Pilot Catchment D: Enhanced surcharge return period aggregate scores for alternative scales and boundaries – present day

1 km diameter hexagons 	10 km diameter hexagons 
Postcode regions (at e.g. OX10 8 scale)	Legend:

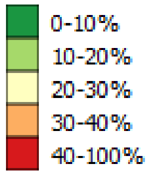
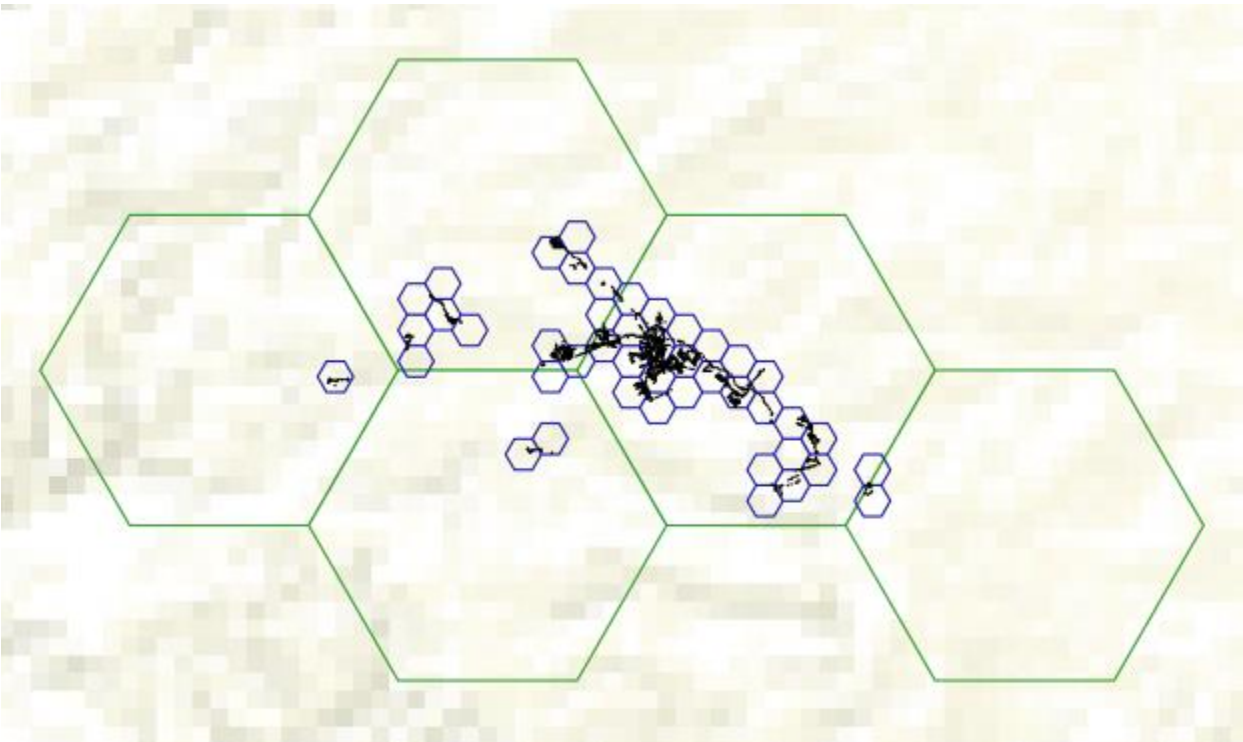
	% length of individual red pipes within each boundary: 

Figure 27 shows the relationship between the 1 km and 10 km diameter hexagons. The aggregate scores of the larger hexagons are calculated from the individual pipe scores and not from the combined scores of the smaller hexagons.

Figure 27 Pilot Catchment D: Pipe locations and hexagon boundaries at 1 km and 10 km scales



CSOs

Figure 28 and Figure 29 show the individual CSO score results aggregated into area scores which have been shown at 1 km and 10 km diameter hexagon scales. The hexagons in Figure 28 have been scored on absolute number of red CSOs within a hexagon (see Table 26), whilst the hexagons in Figure 29 have been scored based on the weighted CSO scoring method – the preferred approach (see Table 27).

For the absolute number of red CSO scoring method, the hexagon scores:

- Green if there are no individual red CSOs, or
- Amber if there is one individual red CSO, or
- Red if there are two or more individual red CSOs within the hexagon boundary.

For the weighted CSO scoring method the number of 'points' are added up within the hexagon and the total number of points is divided by 2 times the total number of CSOs within the hexagon (i.e. the maximum possible score). Points are awarded to CSOs within the hexagon boundary as follows:

- A red CSO is awarded 2 points,
- An amber is awarded CSO 1 point, and
- A green CSO is awarded 0 points.

The absolute number of red CSO scoring method works reasonably well at a small hexagon scale, but it makes less sense at a coarser scale when there are many more CSOs within a single hexagon.

The percentage of red CSOs (without weighting the scores) works well at the coarser scale. However, when there are few CSOs within a single hexagon, it is difficult to define the aggregate score thresholds because the score becomes dependent on the number of CSOs within the hexagon rather than their individual score. For example, when there are only 1 or 2 CSOs within a hexagon, it is generally only possible to score the hexagon red or green, not amber.

Therefore, on balance the weighted CSO scoring method is the preferred aggregate scoring method for CSOs, because it is applicable at all scales and for any number of CSOs within a hexagon. It also increases the chances of an amber aggregate score, which provides a better gradation of scores.

Figure 28 Pilot Catchment D: Enhanced number of spills / summer aggregate scores – absolute number scoring method – present day

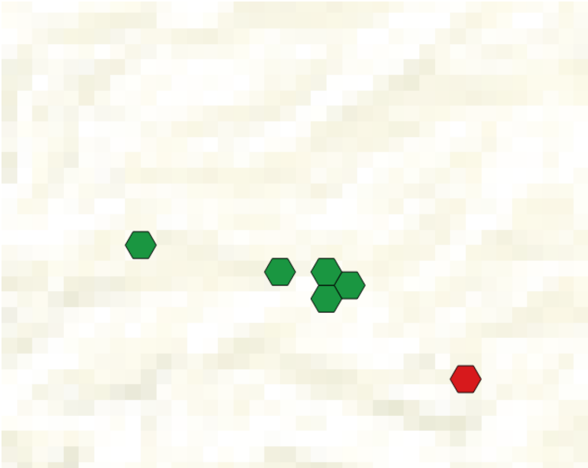
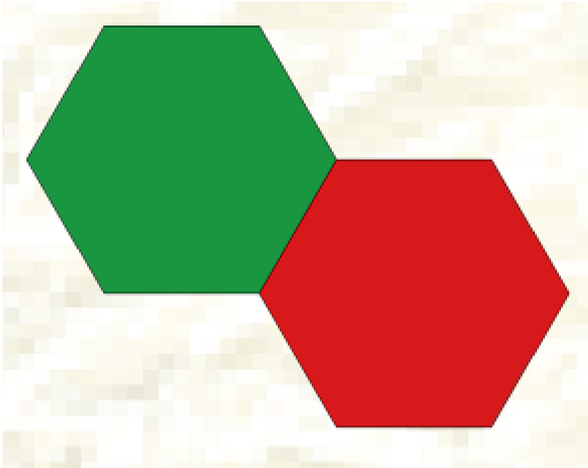
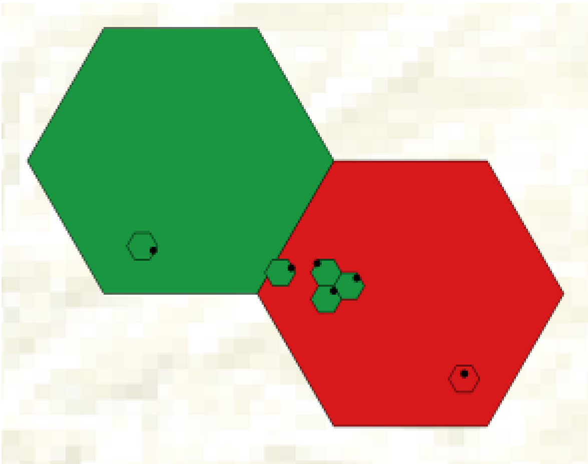
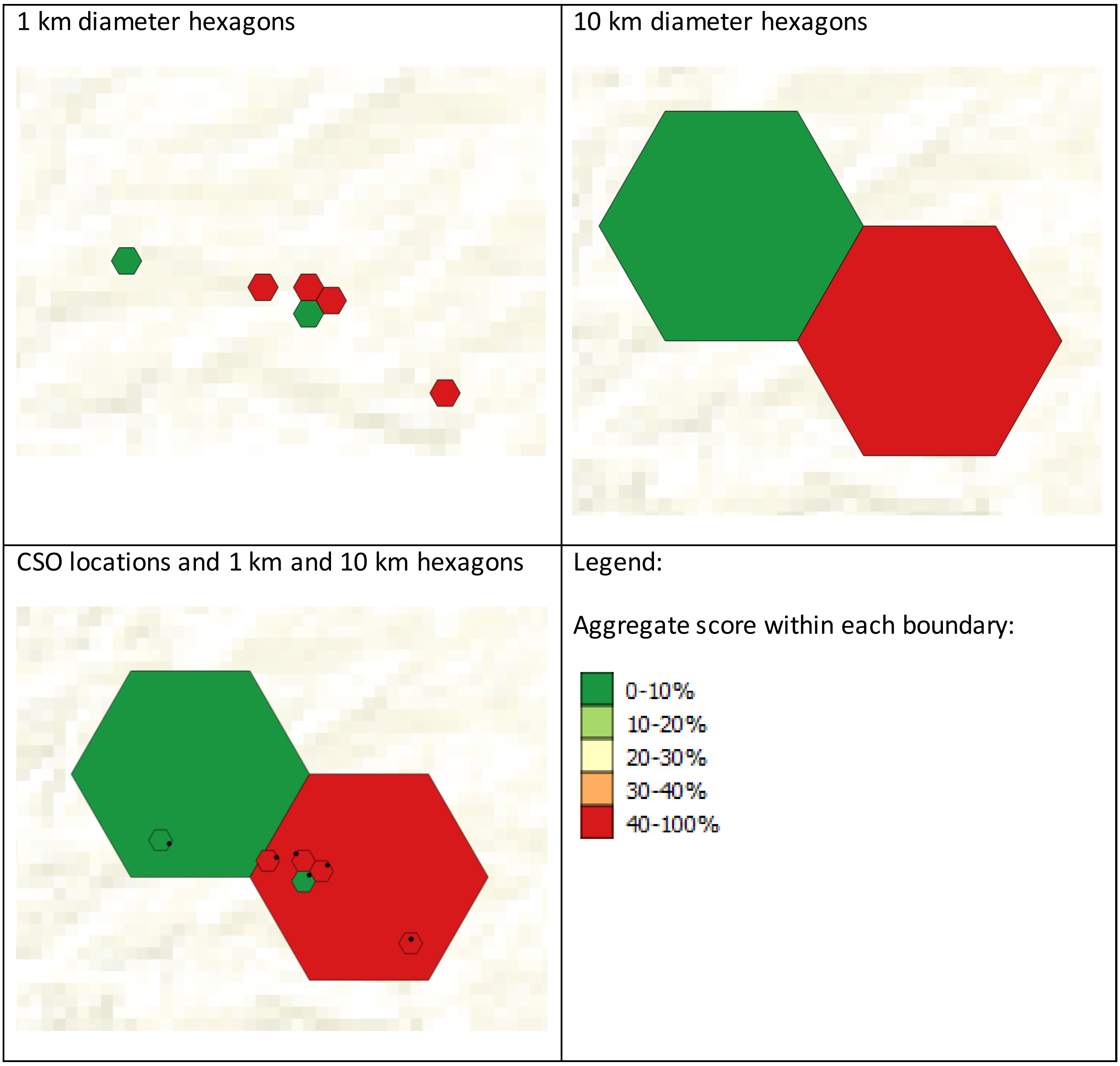
1 km diameter hexagons 	10 km diameter hexagons 
CSO locations and 1 km and 10 km hexagons 	Legend: Absolute number of red individual CSOs within each hexagon: No. red CSOs = 0 No. red CSOs = 1 No. red CSOs = 2 or more

Figure 29 Pilot Catchment D: Enhanced number of spills / summer aggregate scores – weighted scoring method – present day



7.8.3 Future assessment (5 years and 25 years)

The following section provides details on how the application of future pressures has affected the metric scores.

Figure 30 and Figure 32 show how the pipe metrics and CSO metrics vary between present-day, 5-year time horizon (central estimate), 25-year time horizon (central estimate) and the 25-year time horizon with the most extreme area removal tested (-40% PIMP). More details on the varying degrees of area removal are shown in Section 7.4.4.

7.8.3.1 Pipes

Figure 30 shows only a marginal change in the pipe full capacity / 10 x DWF metric scores from present-day to future 25-years. There is a much larger change in the scores for surcharge return period (approximately an increase in 10% 'red' scores) from present-day to future 25-years. This shows that the models are more sensitive to the surcharge metric available with the Enhanced Method, whilst the Initial Method metric will be overestimating pipe capacity for future time horizons.

Figure 30 Pilot Catchment D: all pipe metrics – future assessment

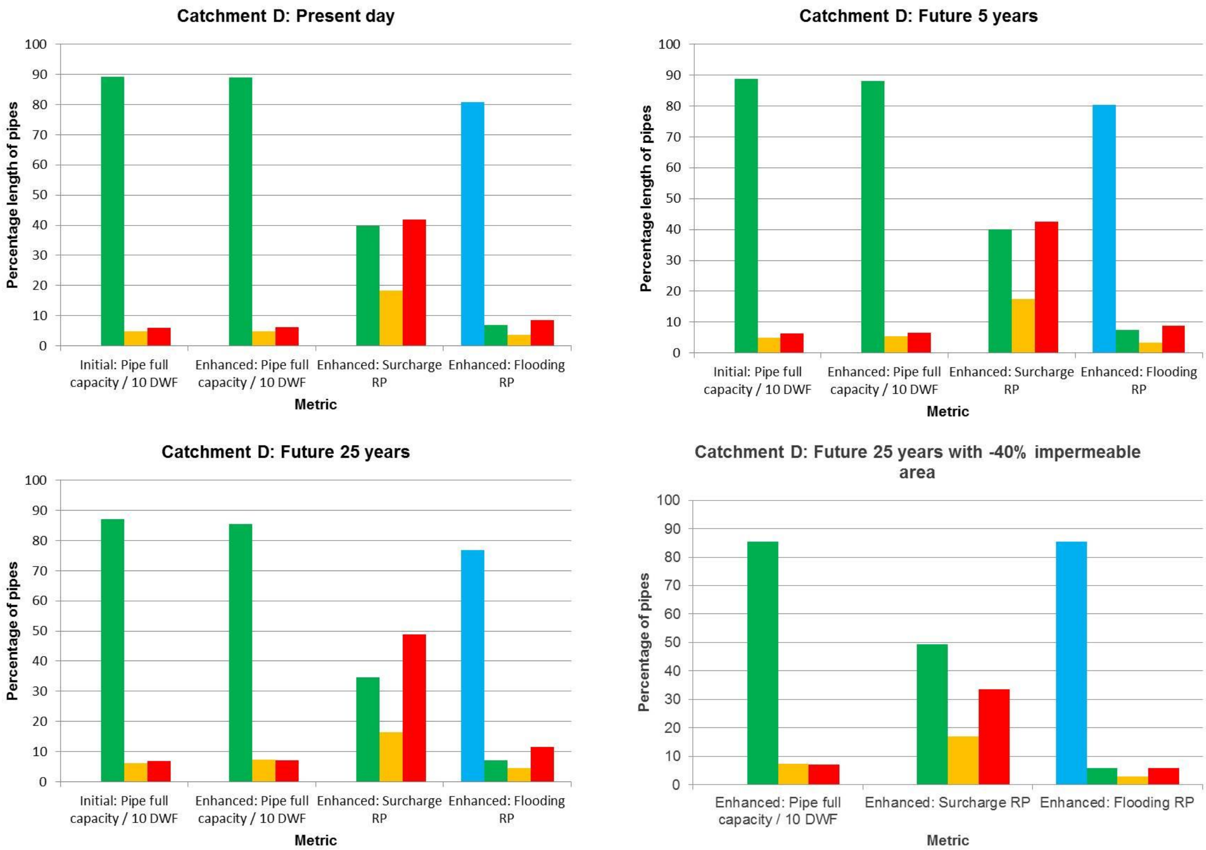
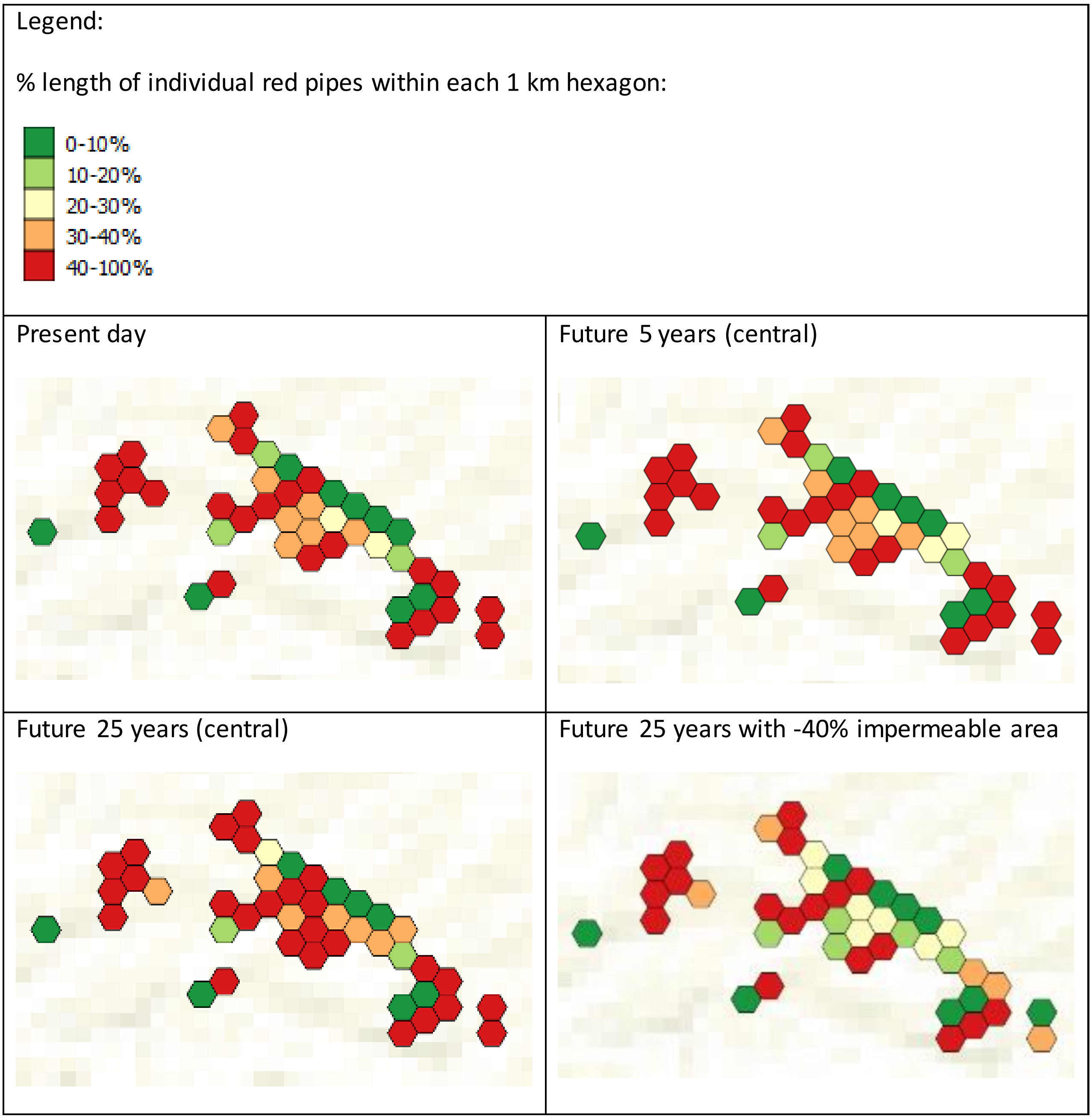


Figure 31 shows the aggregate 1 km diameter hexagon scores for the surcharge return period metric for Catchment D. It shows a general reduction in performance from present-day to future 5 and 25-year time horizons. The thresholds set are sensitive to the changes in metric scores over time. In the bottom right corner is a comparison of the 25-year time horizon with 40% removal of impermeable area, which shows a significant betterment not only compared with the 25-year time horizon but also present-day.

Figure 31 Pilot Catchment D: Enhanced surcharge return period aggregate scores – future assessment



7.8.3.2 CSOs

The metric continuation pipe full capacity / incoming pipe full capacity is a fixed parameter and, therefore, does not vary over time. For this reason this metric has not been recommended in the Guidance Document.

Figure 32 shows that the other Initial metric, continuation pipe full capacity / 10 x DWF is affected by applying a future population.

The Enhanced metrics, number of spills per year and number of spills per summer are also sensitive to the future pressures. One of the benefits of using the weighted aggregate score method over the absolute number of ‘red’ CSO score method is that if an individual CSO’s score changes from ‘green’ to ‘amber’, this will not affect the aggregate area scoring using the absolute number of ‘red’ CSO score method, but it will affect the scoring using the weighted aggregate score method. This is significant when (unlike pipes) there is a limited number of CSOs within a single hexagon, and therefore also using the ‘amber’ CSOs allows the metric to have greater sensitivity.

Figure 32 Pilot Catchment D: all CSO metrics – future assessment

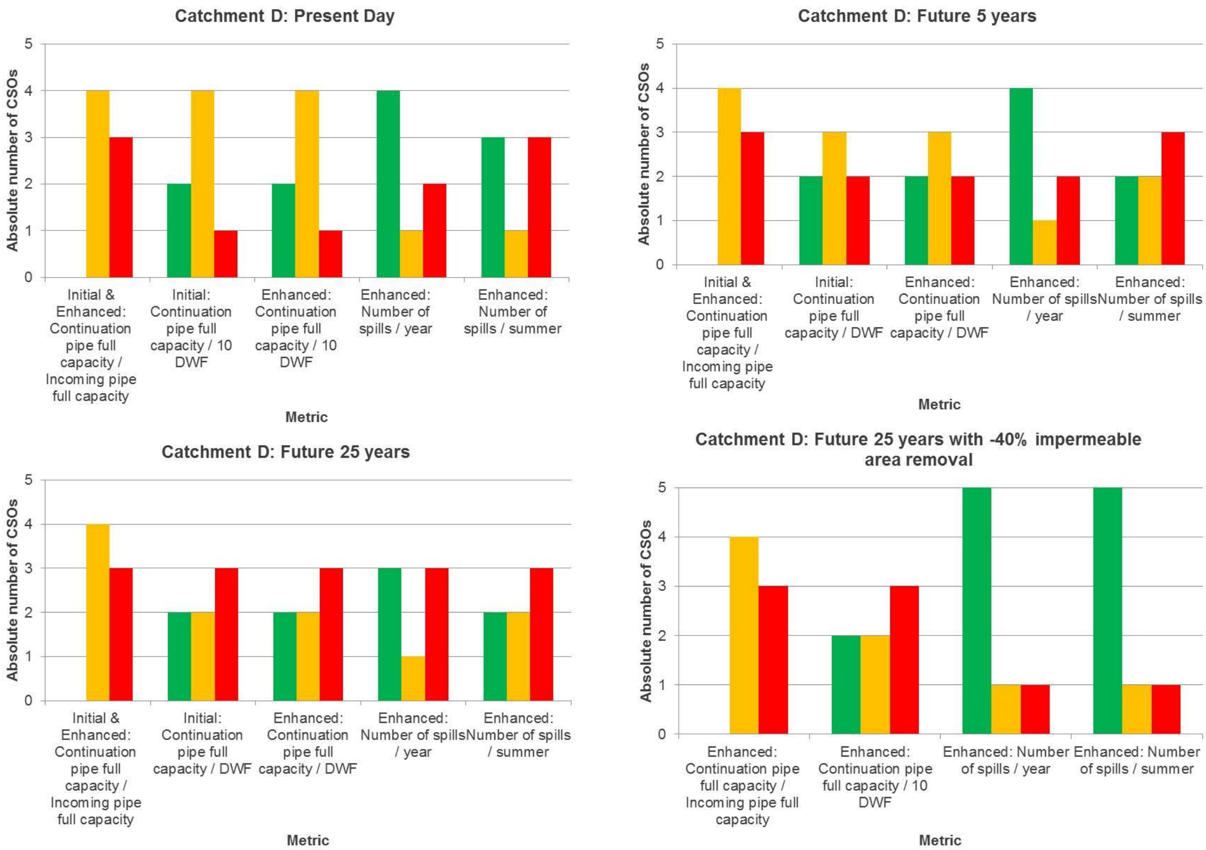


Figure 33 and Figure 34 show the aggregate 1 km diameter hexagon scores for the number of spills per summer metric for Catchment A. Figure 33 shows the aggregate scores based on the absolute number of red individual CSOs scoring approach, whilst Figure 34 shows the aggregate scores based on the weighted CSO scoring approach. Both figures show the location of CSOs within each hexagon for the present day image to help provide context for the scores.

Using the absolute number of red individual CSOs aggregate scoring approach, only one of the seven hexagons crosses a threshold between the present-day scores to future 5 and 25-year time horizons. This is a result of one individual CSO crossing the threshold from green or amber to red. This particular hexagon cannot ever score red using this scoring approach because it only has one CSO within it. In comparison, using the weighted scoring approach, as there is only one CSO in this same hexagon, the hexagon can only be scored green or red. Only when there are more CSOs within a single hexagon can the full range of scoring bands be used, and then the weighted scoring approach will be able to provide greater sensitivity. This is shown in Figure 35 which shows at the 10km hexagon scale, using the weighted scoring approach, four of the five scoring bands have been used by the pilot catchments in the present-day assessment.

In the bottom right corner of Figure 33 and Figure 34 is a comparison of the 25-year time horizon with 40% removal of impermeable area, which shows a betterment not only against the 25-year time horizon, but also present-day.

Figure 33 Pilot Catchment A: Enhanced number of spills / summer aggregate scores – absolute number scoring method - future assessment

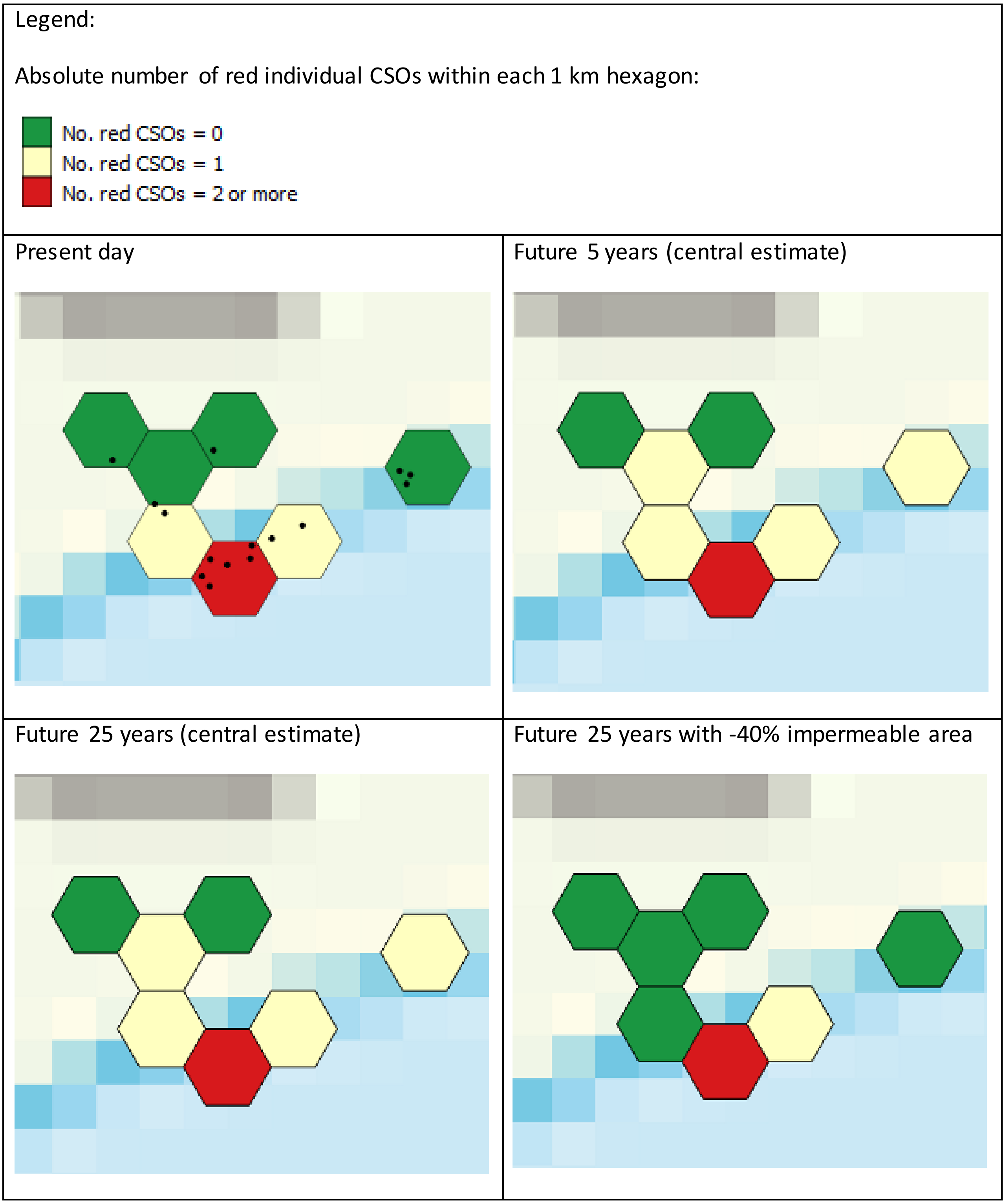
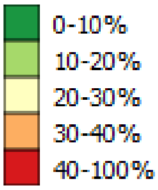


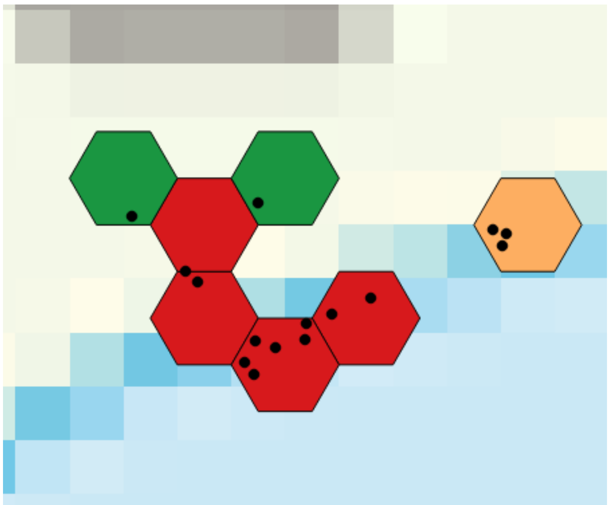
Figure 34 Pilot Catchment A: Enhanced number of spills / summer aggregate scores – weighted CSO scoring method - future assessment

Legend:

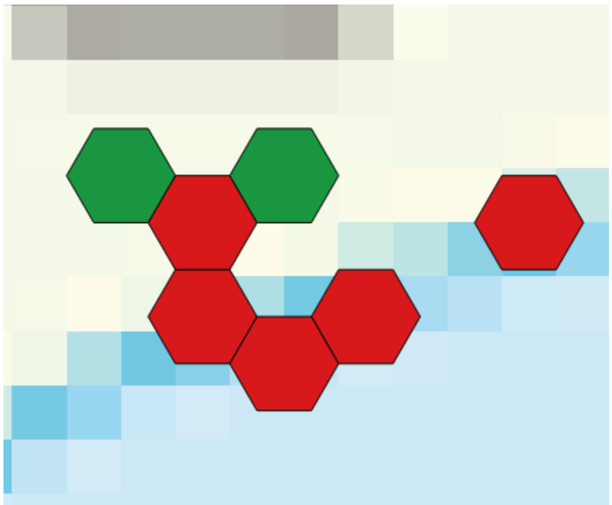
Weighted score within each 1 km hexagon:



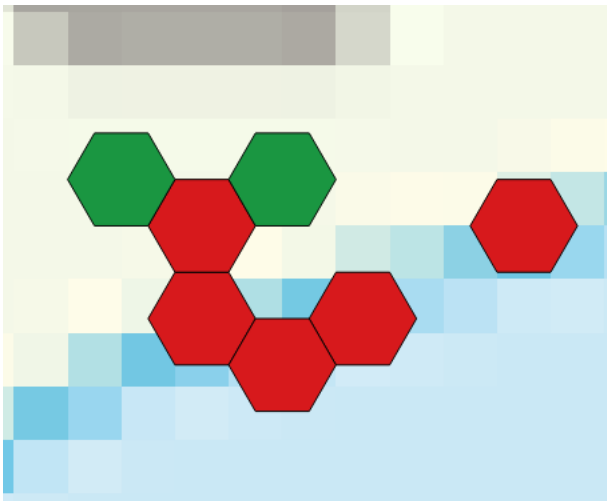
Present day



Future 5 years (central estimate)



Future 25 years (central estimate)



Future 25 years with -40% impermeable area

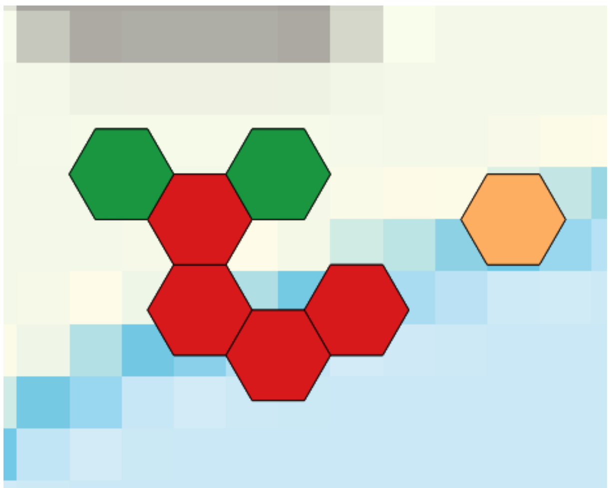
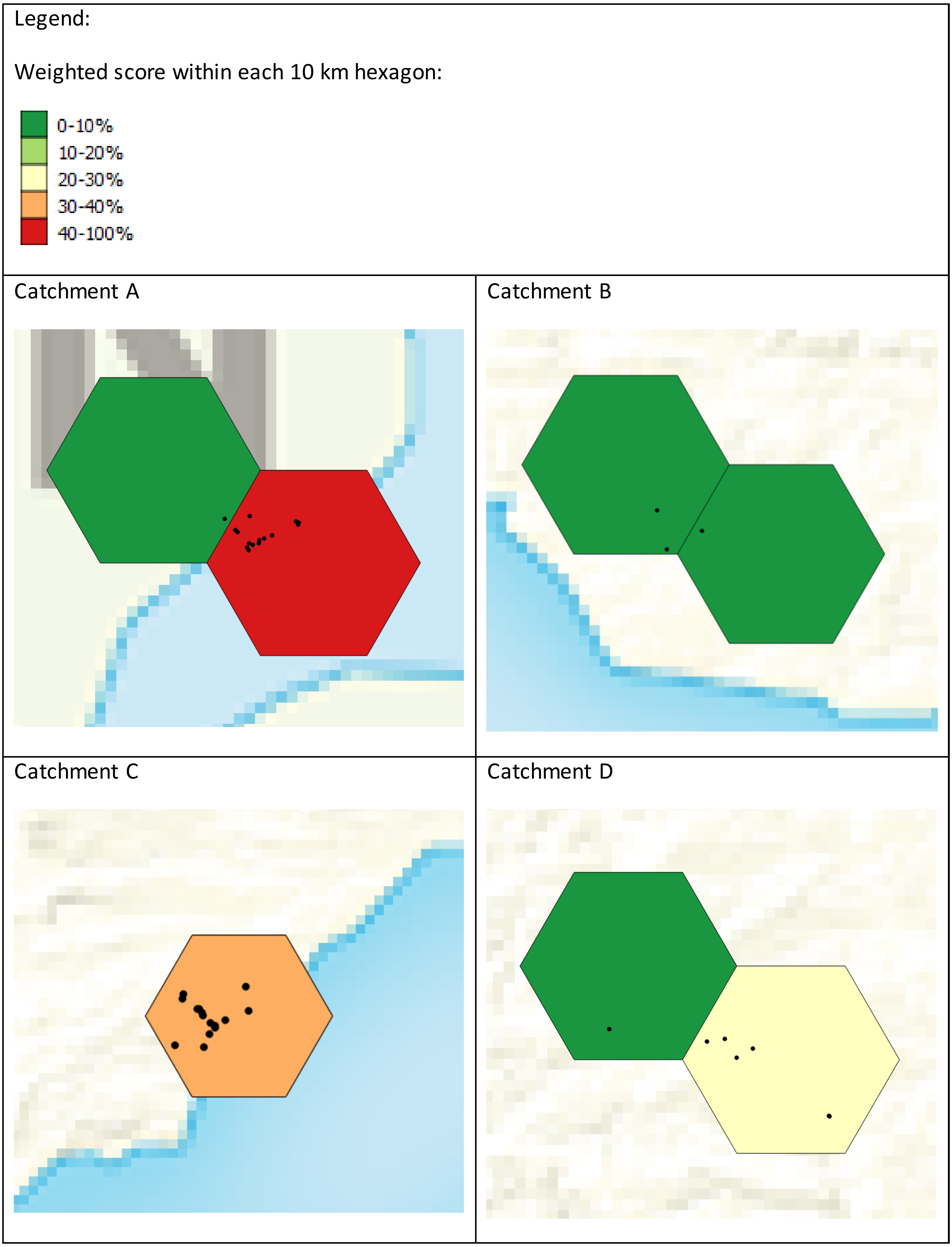


Figure 35 Pilot catchments: Enhanced number of spills / summer aggregate scores – weighted CSO scoring method - present day



The pilot catchments' CSO performance were also investigated in terms of a common river reach as well as individually. Table 29 details the number of CSOs that spill into each river reach. A river reach has been defined as a distinct watercourse or waterbody.

Table 29 Pilot catchments: Breakdown of CSOs by river reaches

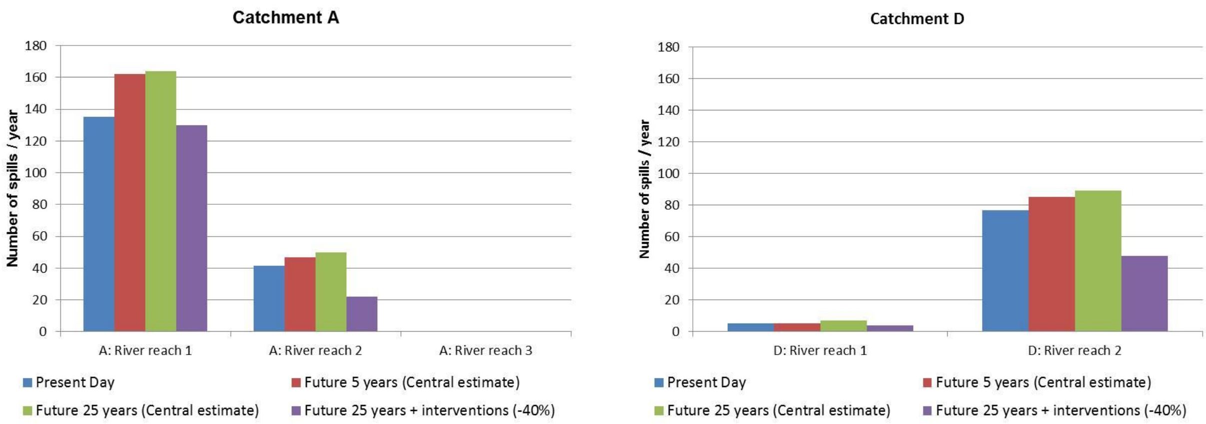
Pilot Catchment	River reach	Number of CSOs on river reach
A	River reach 1	11
	River reach 2	3
	River reach 3	1
B	River reach 1	1
	River reach 2	1
	River reach 3	1
C	River reach 1	4
	River reach 2	4
	River reach 3	6
	River reach 4	1
	River reach 5	1
D	River reach 1	1
	River reach 2	6

Figure 36 shows the results for Catchments A and D. There is a relationship between number of CSOs on the river reach and number of spills per year. The graphs do not indicate whether this is a function of all the CSOs contributing equally to the number of spills or whether it is a results of a single 'bad' CSO which nullifies any 'good' CSOs on the river reach.

The larger the number of spills per river reach may be interpreted as the worse the pollution. However, without looking at other factors, such as the volume of spill or the flows in the receiving watercourse, the impact cannot be determined and, hence, it is not possible to compare river reaches.

The results, however, can be used to compare changes over time on a single river reach. For example for Catchment A river reach 1, the number of spills from present-day to 5-years increases much more than from 5-years to 25-years. It is also clear to see that a reduction in connected impermeable area reduces the number of spills considerably below present-day levels.

Figure 36 Pilot Catchments A and D: Enhanced number of spills / river reach – future assessment



7.8.3.3 Sensitivity

Figure 37 and Figure 38 show the metric scores for surcharge return period and number of spills per year for the upper, central and lower scenarios for Catchments A and C respectively. These show that the metrics are generally not sensitive to the variation in the future pressures that have been applied. At the 25-year future scenario the percentage of 'red' pipes increases from 36% (lower estimate) to 40% (upper estimate) for Catchment A, which would be enough of an increase to result in the aggregate catchment score crossing a threshold.

Figure 38 shows a that the number of CSOs that score 'red' varies by one depending on the sensitivity estimate that is used.

Figure 37 Pilot Catchment A: Sensitivity of Enhanced surcharge return period scores

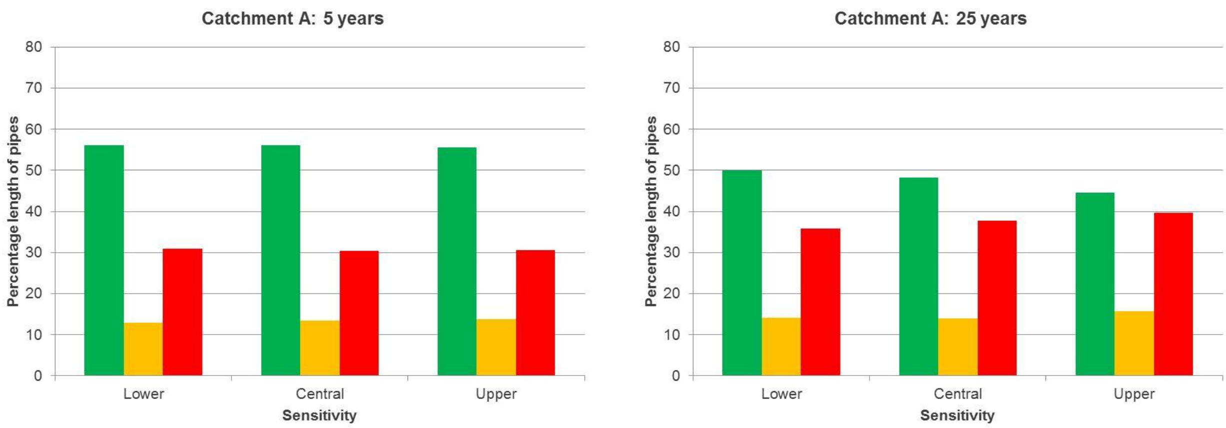
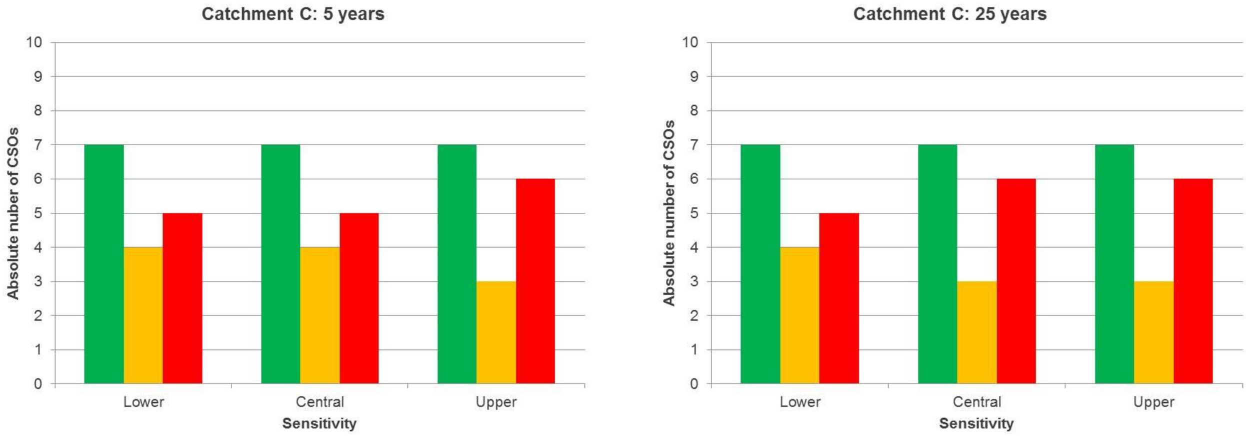


Figure 38 Pilot Catchment C: Sensitivity of Enhanced number of spills / year scores



7.8.4 Future assessment (25 years) with interventions

Metrics could only be measured for interventions for the Enhanced Method, because the interventions involved the removal of impermeable area.

The metric pipe full capacity / 10 x DWF was the same for all impermeable area removal scenarios for all pilot catchments and have therefore not been presented here.

Figure 39 and Figure 41 show the variation in the scores for surcharge return period and number of spills per year for the varying amounts of impermeable area removal. There is a large improvement in the scores between the 25-year without interventions and with interventions (i.e. impermeable area removal). The greatest improvements are seen with 10% and 20% impermeable area removal. Beyond this there is less improvement, because a minimum threshold of 5% of the subcatchment contributing area was set for the road area and 5% for the roof area. This means that many subcatchments had reached the maximum amount of impermeable area they could remove by the '-20%' scenario and thus could not provide any more betterment.

Figure 39 Pilot catchments: Enhanced surcharge return period scores - future assessment with interventions

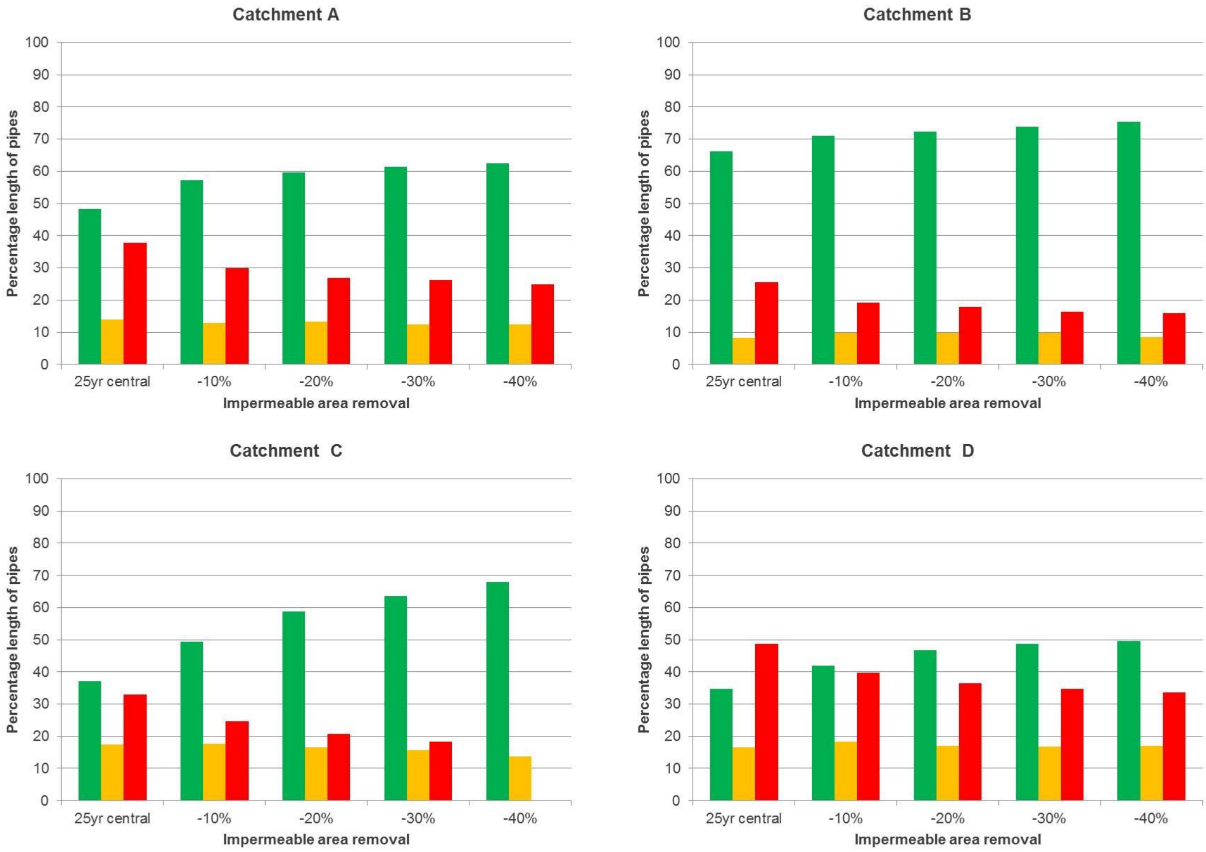
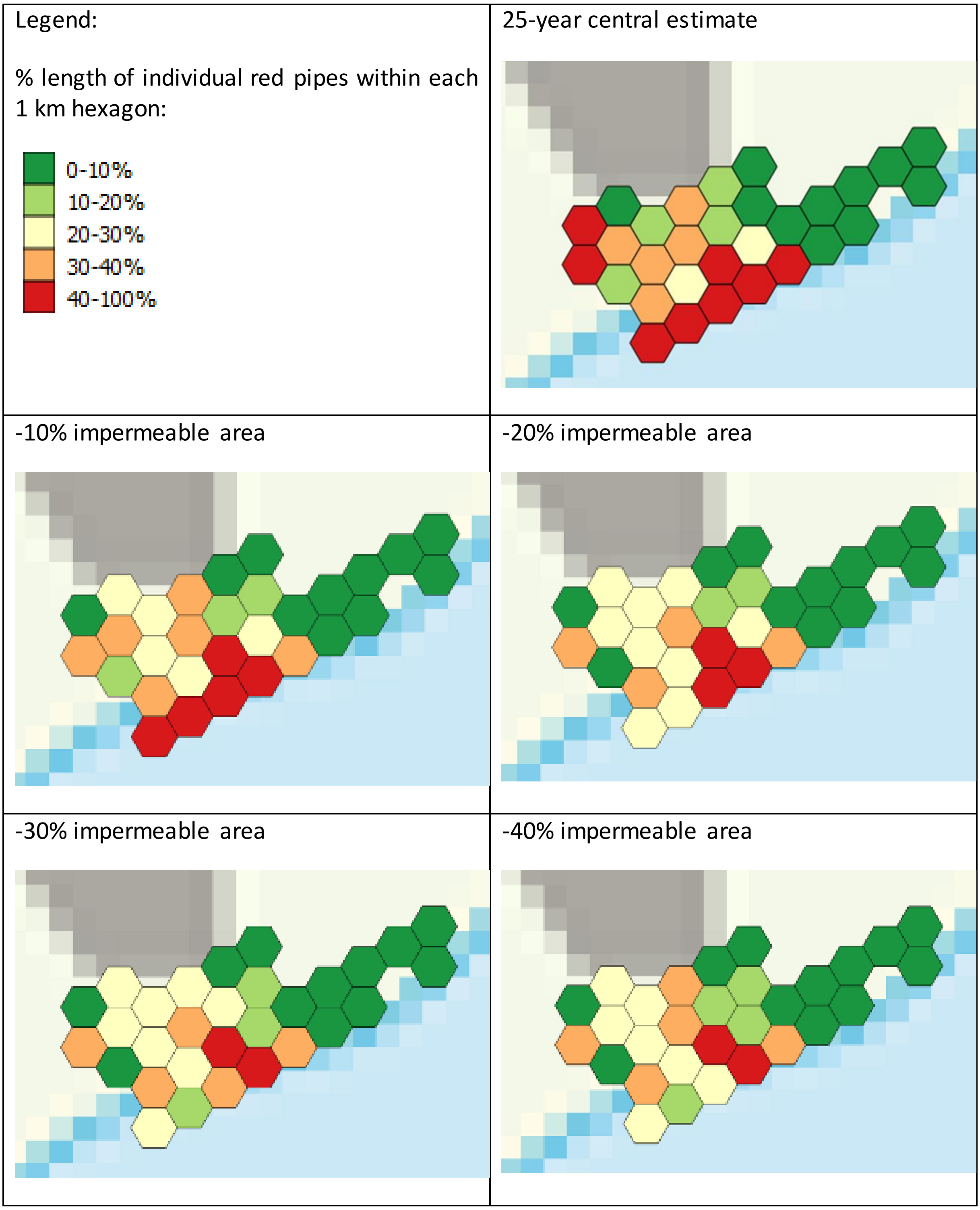


Figure 40 and Figure 42 show the aggregate 1 km diameter hexagon scores for varying amounts of impermeable area removal for the surcharge return period metric and the number of spills per summer metric respectively. Similarly to the breakdown of metric scores within the individual catchments, the greatest betterment of performance is seen with 10% and 20% impermeable area removal. Beyond this there is less improvement.

Figure 40 Pilot Catchment A: Enhanced surcharge return period aggregate scores - future assessment with interventions



Note, one 1 km hexagon within the -40% impermeable area appears to get worse compared with the -30% impermeable area results. This is due to the aggregate score of the polygon being very close to the band score and the hexagon not containing many pipes. Therefore, the results of a few individual pipes can influence the aggregate score of the hexagon and this could be as a result of instability in the model. The more pipes contained within a single hexagon, the less likely a model instability or similar would affect the results.

Figure 41 Pilot catchments: Enhanced number of spills / year scores - future assessment with interventions

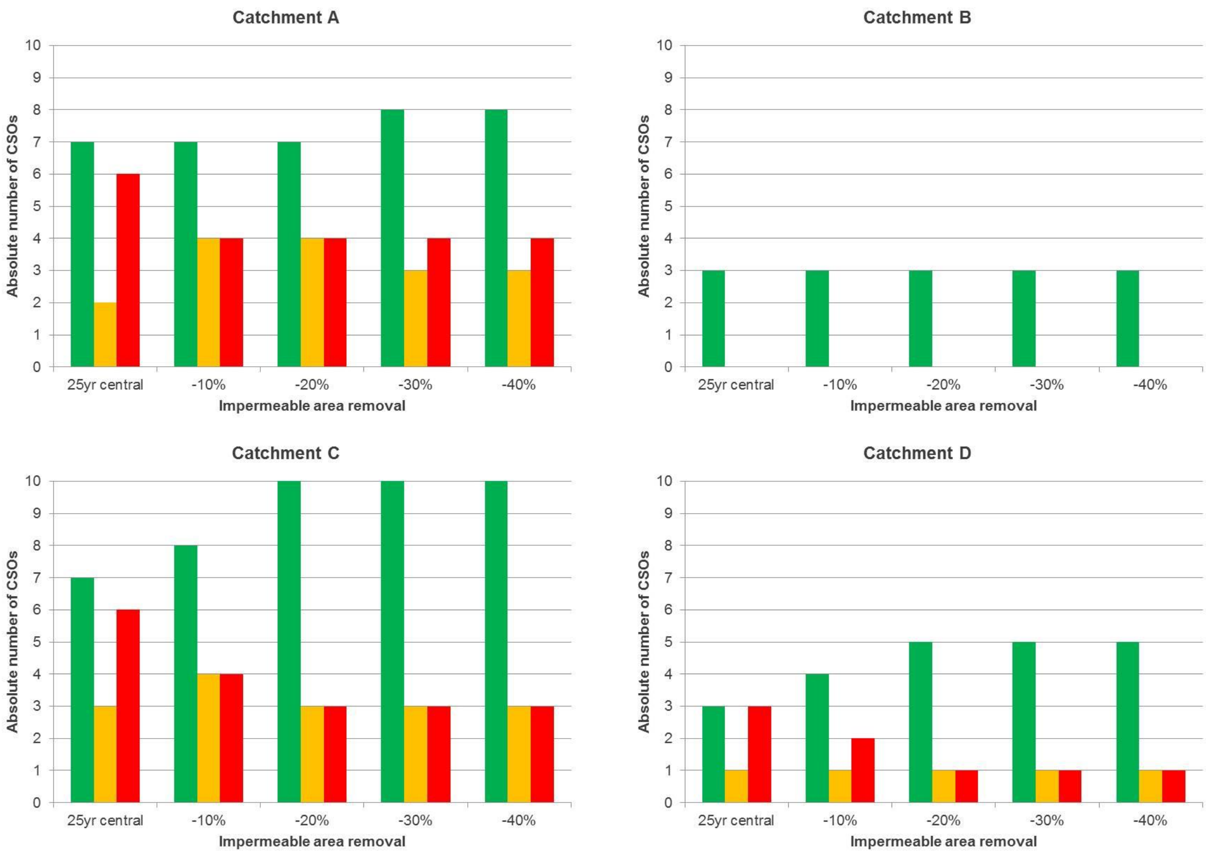


Figure 42 Pilot Catchment A: Enhanced spills / summer aggregate scores - absolute number scoring method – future assessment with interventions

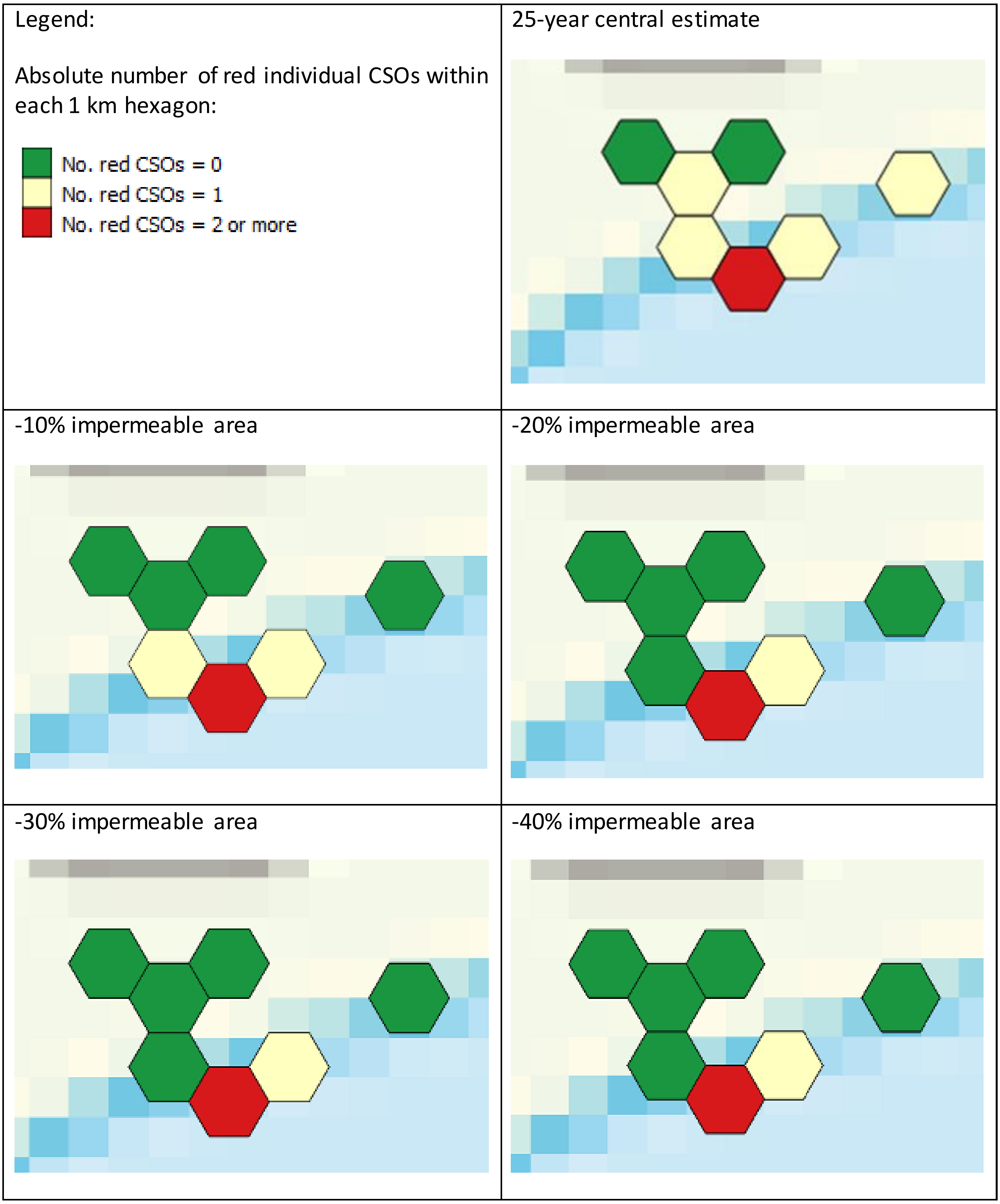
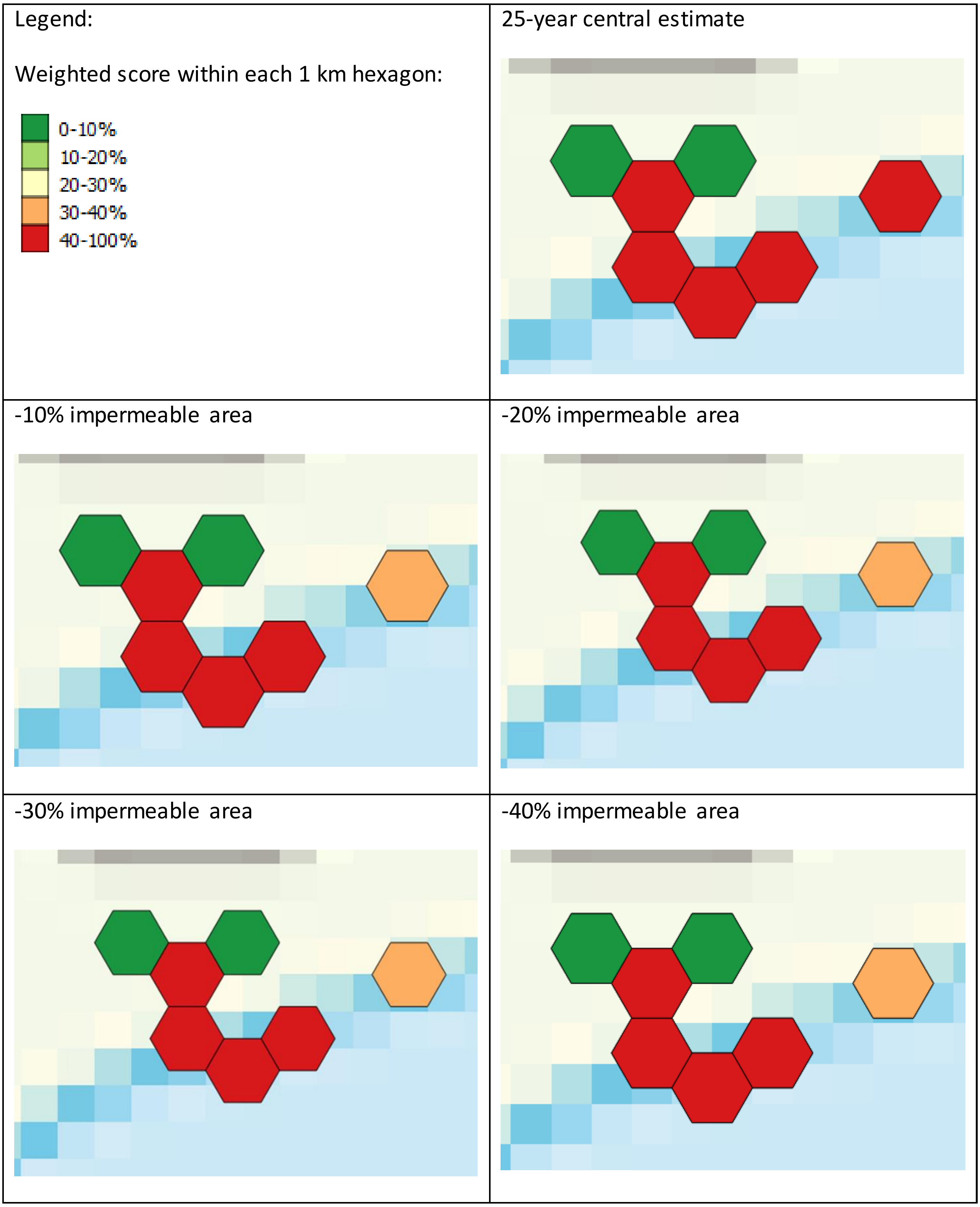


Figure 43 Pilot Catchment A: Enhanced spills / summer aggregate scores - weighted CSO scoring method - future assessment with interventions



7.8.5 Detailed interventions

Figure 44 compares all the pipe metrics for the present-day model with those of the present-day model with the short-term detailed interventions included.

Figure 45 compares all the pipe metrics for the 25-year (central) future model with those of the 25-year future model including the short-term detailed interventions and the 25-year future model including both the short-term and the long-term detailed interventions.

All three metrics, flooding return period metric score, surcharge return period metric and the Initial metric, pipe full capacity / 10 x DWF, show improvement with inclusion of the detailed interventions.

Pilot Catchment B only has three overflows, all of which are EOs at pumps. Therefore, the CSO metrics have not been shown, because they do not show any changes.

Figure 44 Pilot Catchment B: all pipe metrics – present day and present day with short-term detailed interventions

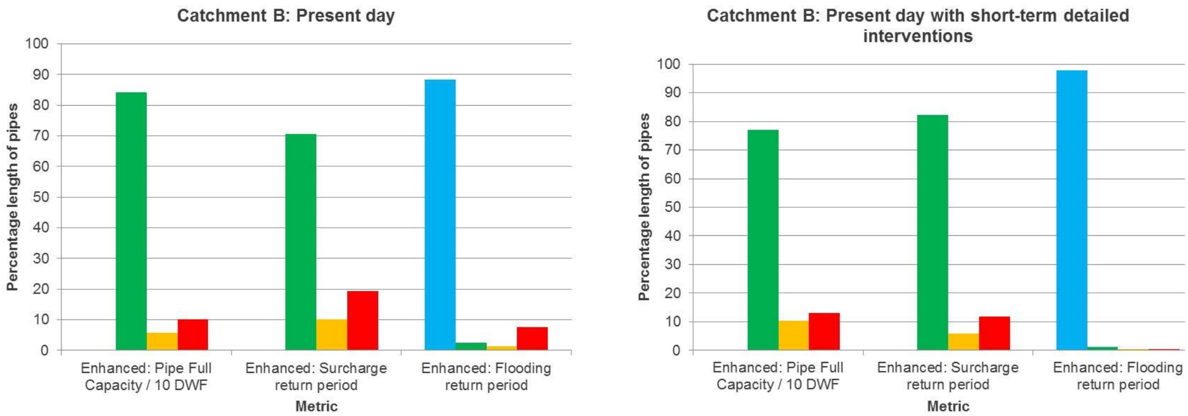


Figure 45 Pilot Catchment B: all pipe metrics – future 25-years and future 25-years with detailed interventions

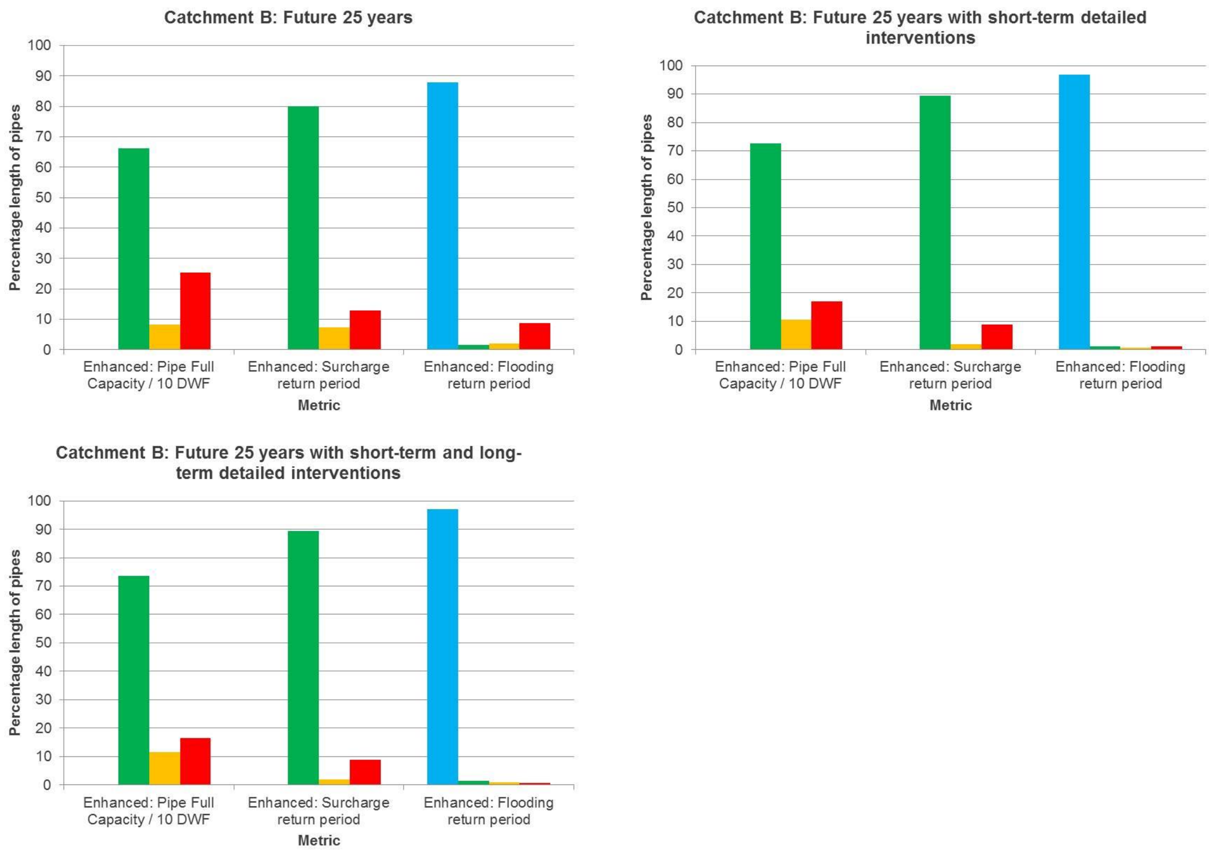


Figure 46 shows how the detailed interventions (see Table 19) compare with the high-level interventions of 10%, 20%, 30% and 40% area removal based on surcharge return period. Figure 47 shows an alternative method for comparing performance of the detailed interventions with the four high-level interventions (10%, 20%, 30% and 40% area removal) based on the Enhanced Method metric - surcharge return period.

Note that the performance of the detailed interventions is phased over five years, as would be expected to implement solutions within a catchment. The score of the green line at the 5-year time horizon is the present-day Framework model with the short-term detailed interventions included. The green line at the 25-year time horizon is the 25-year Framework model with the short-term detailed interventions included. The deterioration of the catchment is approximately at the same rate as the Framework model without any interventions although the percentage length of ‘red’ pipes is lower between the 5-year and 25-year time horizons. The green line at the 30-year time horizon is the 25-year Framework model with both the short-term and long-term detailed interventions included. This shows a moderate improvement to the score.

The threshold performance in Figure 47 has been arbitrarily set at 20%. Below this threshold less than 20% of pipes are in surcharge when the model has been run with the 2-year return period design storms. Based on the proposed scoring thresholds, this covers both the "green" and "light green" categories.

Both of these figures show that the detailed intervention performs slightly better than the 30% and 40% area removal high-level intervention, for the 25 year time horizon.

The 40% area removal for Catchment B (which equates to 2.5 ha) would cost £1.75M, based on the estimated unit capital cost of £500K/ha for the first 10% of area removal (1.6 ha) and £1M/ha for the remainder (0.95 ha) (see Section 5.2). The detailed intervention would have capital costs of approximately £4.2M (see Table 19).

Figure 46 Pilot Catchment B: Enhanced surcharge return period – future 25-years, future 25-years with high-level interventions and future 25-years with detailed intervention

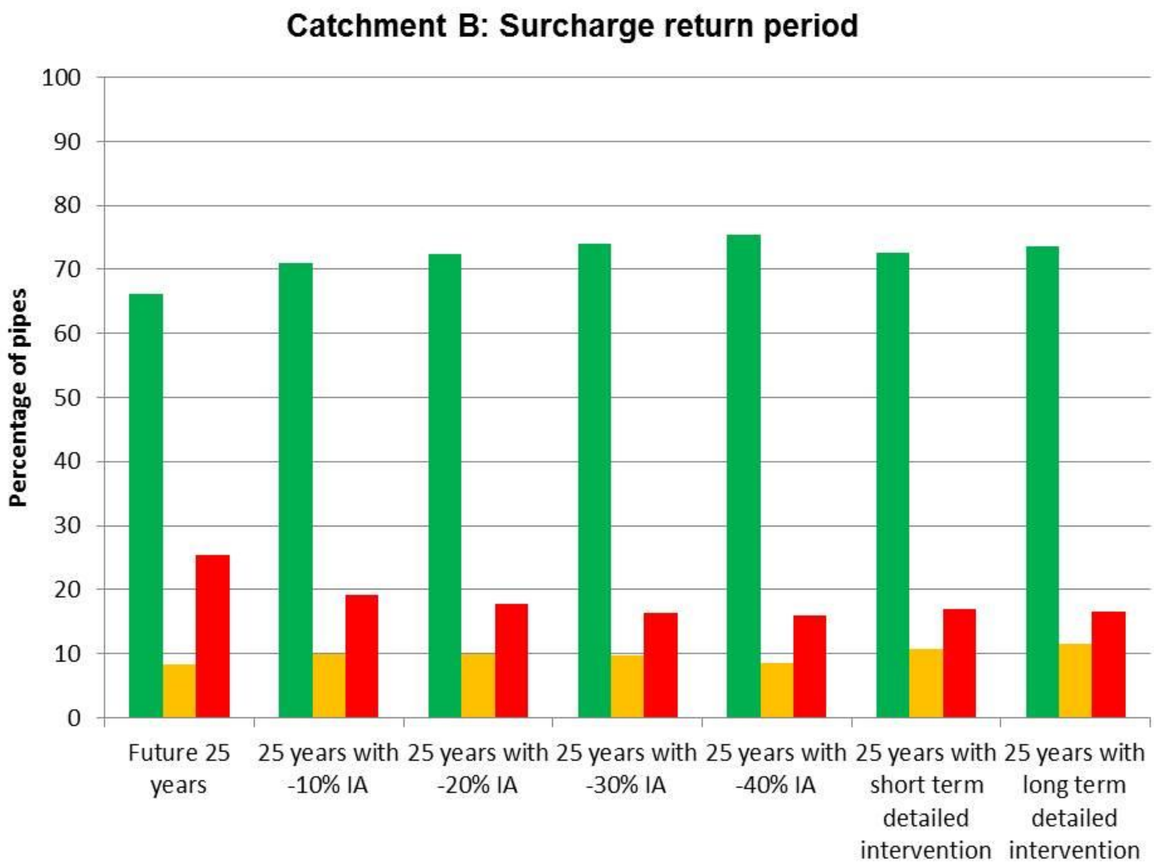
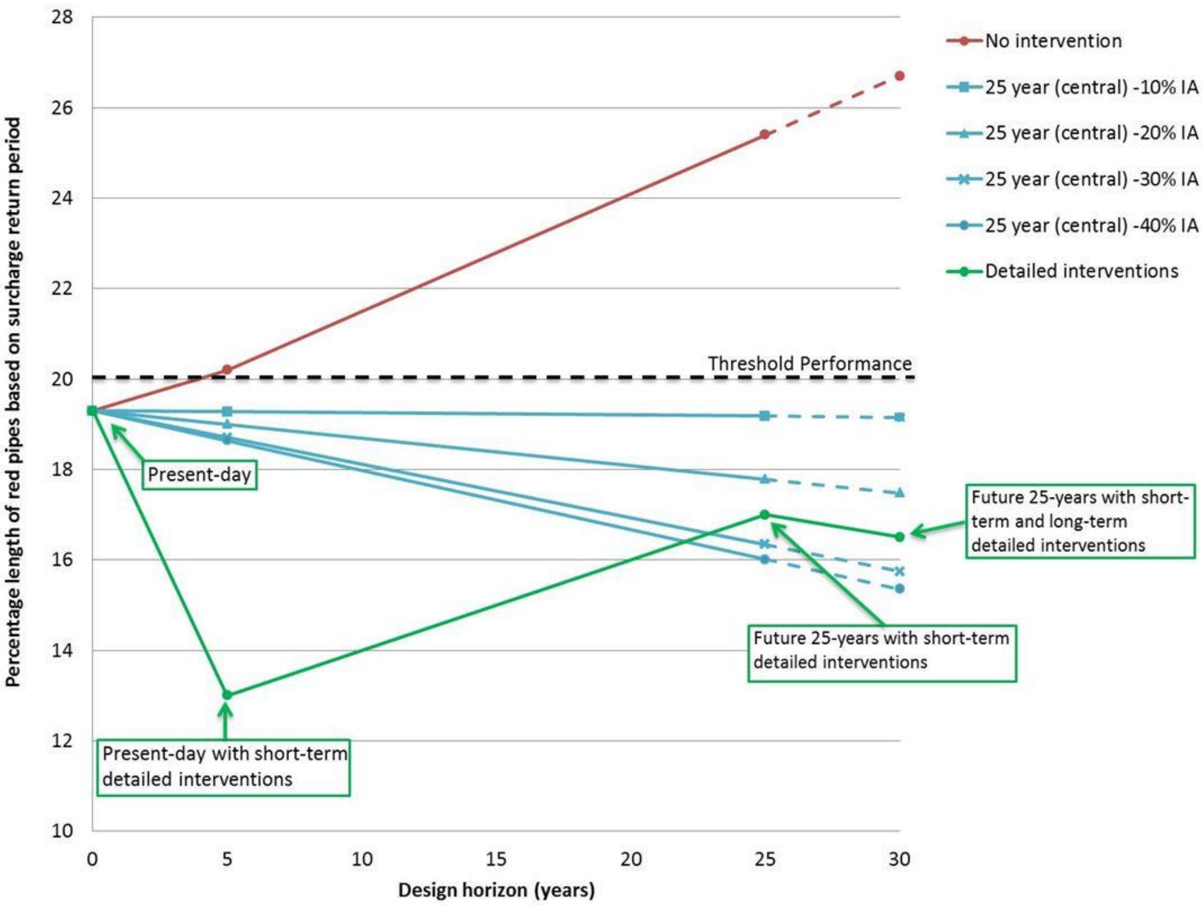


Figure 47 Pilot Catchment B: Threshold performance for alternative interventions (based on surcharge return period)



7.9 Summary of findings

The following points summarise the findings from the testing of the pilot catchments regarding the metrics, scoring thresholds and visualisation.

Pipes

1. Scoring by length of pipe or population equivalent upstream are the preferred individual scoring methods for pipes. Length of pipe gives equal weighting to all pipes, while population equivalent upstream provides weighting and greater emphasis to the larger trunk sewers.

2. Initial metrics based on DWF do not align well with results based on surcharge for Enhanced models.

3. The Initial and Enhanced method metrics do not appear to be sensitive to infiltration.

4. The omission of contributing areas in the Initial Model results in an overestimate of pipe capacity even when using 10 x DWF.

5. The DWF multiplier 10 increases the sensitivity of the analysis for the Initial Method. This factor also aligns with the metric on pass forward flows from CSOs.

6. Surcharge has been demonstrated to be reasonably well aligned to trends based on flooding and, therefore, surcharge is a suitable lead indicator reflecting flooding level of service.

7. Surcharge provides greater sensitivity of analysis than using number of flooding nodes.

8. Aggregate scores can be shown using any tessellating shapes such as hexagons or post code boundaries. Three scales are suggested (1km, 10km, 100km), but this can be varied depending on the detail required. (The largest scale would represent a water company area with between 4 and 8 cells).

9. Five aggregate scoring bands, providing a gradation of 5 colours from 'good' to 'bad', is suggested in preference to three bands, as the change in performance is easier to distinguish spatially and temporally. It also allows the individual pipe and CSO metrics to be shown by three colours (red, amber and green) in visualisation and therefore can be seen to be different information.

10. The Initial Models do not appear to be very sensitive to expected levels of future population change.

11. The Enhanced metric scores and aggregate thresholds for surcharge return period are reasonably sensitive to future pressures.

12. For the pilot catchments, the metrics were found not to be particularly sensitive to the variation in the future pressures (±30% sensitivity) at either the 5-year or 25-year time horizons.

13. There is a reasonable improvement in the Enhanced metric scores between the 25-year baseline scenario and with impermeable area removal, but perhaps not as much as might be expected. The greatest improvements are seen with 10% and 20% removal. Beyond this there is less improvement, probably because of the minimum threshold of impermeable area set for each subcatchment. For almost all of the Enhanced metrics for all pilots the 25-year with 10% removal of impermeable area results in scores that are better than present day scores.

CSOs

1. The Initial metric for CSOs is not sensitive to infiltration for the four pilot catchments.

2. In general, an individual CSO tends to get scored green more often with the Initial metric (continuation pipe full capacity/DWF) compared with the Enhanced metric (number of spills/year). The exception is for EOs and other overflows where there is storage. The Initial metric does not take account of any storage at the CSO and, therefore, is not appropriate for these overflows. Type of overflow should be taken into consideration when calculating and understanding the initial CSO metric scores.

3. The Enhanced metrics - number of spills/year and number of spills/summer - closely align. Which of these metrics is more relevant will vary from catchment to catchment.

4. The predicted number of spills is not sensitive to the spill counting method used. Therefore the EDM spill counting method is preferred, because it is directly comparable with the method of counting spills by EDM spill monitors.

5. There is no significant additional benefit of using a metric based on the population equivalent upstream of a CSO up to the next CSO upstream.

6. Scoring by the weighted approach is the preferred aggregate scoring methods for CSOs. It allows for a greater distribution of scores than a simple percentage number of CSO approach because it increases the number of scores available by using the both the amber and red CSOs to score the boundary. Although use of the absolute number of individual red CSOs is suitable for small numbers of CSOs in a catchment area, it is not suitable where large numbers of CSOs exist.

7. Five aggregate scoring bands, providing a gradation in colours from ‘good’ to ‘bad’, is suggested in preference to three bands, as the change in performance is easier to be distinguish both spatially and temporally.

8. The metric continuation pipe full capacity/incoming pipe full capacity is a fixed parameter and, hence, does not vary with Initial or Enhanced Model, future pressures or interventions. Therefore, it has limited use and is not recommended for the Framework.

9. The Initial CSO metric (continuation pipe full capacity/DWF) is sensitive to future population change, in contrast to the Initial pipe metric.

10. The Enhanced metrics (number of spills per year and number of spills per summer) are sensitive to future pressures.

11. Using a metric for all CSOs on a river reach ensures a better indication of the polluting pressure on the environment than scoring CSOs separately.

12. For the pilot catchments, the metrics were found not to be particularly sensitive to the variation in the future pressures (±30% sensitivity) at either the 5-year or 25-year time horizons. On occasions an aggregate score threshold is crossed, but often the score remains the same.

13. There is a large improvement in the Enhanced metric scores between the 25-year baseline scenario and with impermeable area removal. The greatest improvements are seen with 10% and 20% impermeable area removal. Beyond this there is less improvement because of the minimum threshold of impermeable area set for each subcatchment. For the majority of pilots and metrics the 25-year with 10% impermeable area removal scores are better than the present day scores.

8 Conclusions

The main conclusions from this project are the following:

1. Although the project has proposed methods and metrics that include the use of Initial Models, due to the limited proportion of the network covered by Enhanced Models, the Framework does not extend to the use of the Initial Models information for the assessment of interventions and long-term investment planning. This is because the measured performance using the Initial Models is of limited accuracy and value, and the assumptions needed for assessing future change or possible interventions would be wholly inadequate for investment decision-making.

2. The use of the pilot catchments has provided a useful platform for testing a range of metrics for both the Initial Method and the Enhanced Method. Changes have been made to the originally proposed metrics for pipe capacity and new metrics have been developed for both the assessment of pipe capacities and CSOs performance. These are considered to be the best compromise between providing simplicity of analysis and providing lead indicators of the performance of sewerage assets.

3. The pilot catchments have shown that the metrics used by the Enhanced Method are a good indicator of the Level of Service (LoS) for pipes, which is usually measured in terms of flooding. In fact, it is considered that the use of surcharge is a more sensitive means of assessing the change in performance than the use of flooding.

4. In contrast, the pilots have shown that the metrics used by the Initial Method are not well correlated with the performance measured by the Enhanced Method. This highlights the need to treat the results from the Initial Method with caution. The Initial Method effectively provides little more than confirmation of the availability of sewerage network information.

5. The metrics for CSOs used by the Enhanced Method are closely aligned to Environment Agency current performance measures of LoS. However, the linkage to the Water Framework Directive is minimal to avoid the need to use river hydraulic or water quality information. The metrics used by the Enhanced method cannot be used for assessing the quality of the receiving waters.

6. It was decided that the 'individual scoring' for pipes and CSOs should remain as Red / Amber / Green, while the 'aggregate scoring' needs to be expanded to five bands from Red to Green. This provides an increase in the sensitivity of the performance information available for visualisation.

7. A sensitivity approach to uncertainty has been used rather than the development of ranges based on fundamental assessment of the characteristics of individual parameters. The pilot catchments indicate that changes of +/- 30% have less effect than anticipated. This is thought to be the effect of throttles within the network that protect other parts of the network from change, in the same way that the number of flooding nodes increases by very little when flows are increased significantly (even though the flood volume and flood frequency might increase more significantly). In spite of the limited change performance, it is still considered that sensitivity analysis based on a 30% uplift is useful to show the degree of change that occurs with a change in the loading conditions.

8. The relatively small improvement in performance resulting from interventions is thought to be due to the same reason.

9. Area removal is the only form of intervention being considered for the high-level approach of the Framework. Other methods such as additional storage were considered but found to be impractical to apply without undertaking a detailed modelling study.

10. Analysis of the costs of retrofit SuDS found that the types of SuDS and the assumptions made in the cost breakdown gave a wide range of possible costs. In general, removal of a hectare of hard surface was found to range from £500,000 to £1M. Although this is a wide range, it has been assumed that this is sufficient for the Framework at present, but that more work on this is needed as retrofit data becomes available.

9 Recommendations and next steps

The key next step is for the industry to put into practice the approach, as presented in this report and in the Guidance Document, and to learn from its application, recognising that future iterations of the Framework and guidance may be required.

To facilitate this, this project recommends that a working group of all UK sewerage undertakers is set up to share experiences of applying the Framework. This would enable:

- Identification of any interpretations (or misinterpretations) of the approach that might require further guidance;

- Identification of any useful industry-wide tools that might further encourage use of the Framework and promote consistency of approach;
- Identification of further technical developments required to deliver in full a national assessment of available capacity. This would include the visualisation tool described in Section 6, which would need the development of a centralised system for sharing and processing data;
- Identification of updates required to the guidance as a result of research and other developments in the industry. For example, the guidance on climate change provided in the Guidance Document and in Appendix 6 of this report will need to be reviewed and revised based on the output from UKWIR project CL10 (due to be published in 2017) and UKCP18 (due to be published in 2018). Guidance on the unit cost of area removal should probably also be updated as more data comes available;
- Further promotion of the Framework within each organisation and across the industry as a whole;
- Identification of additional steps required

10 References

Adaption Sub-Committee, Climate change – is the UK preparing for flooding and water scarcity? Adaption Sub-Committee Progress Report 2012, *Adaption Sub-Committee*, (2012)

Allitt, R., Allitt, M. and Allitt, K., Impact Of Urban Creep on Sewerage Systems. *UKWIR Report Ref No. 10/WM/07/14* (2010)British Standards Institution, Rainwater harvesting systems. Code of practice*, BSI* BS 8515:2009+A1:2013 (2009)British Standards Institution, Code of practice for surface water management for development sites*, BSI* BS 8582:2013 (2013)

CIRIA, Overview of SuDS performance, Information provided to Defra and EA, CIRIA (2009)

Defra and Environment Agency, An assessment of evidence on Sustainable Drainage Systems and the Thames Tideway Standards*, Environment Agency* (2013)

Duckworth, C., Assessment of urban creep rates for house types in Keighley and the capacity for future urban creep. *MA thesis. University of Manchester* (2005)

Garside, I. G., WaPUG note 23: Using annual rainfall time series. *WRc* (1991)

Kellagher, K., Wilson, S. and Thomson, R. J. C., Final Surface Water Drainage Report, EDFRA WT1505 (2013)

Kellagher R. and Gorton, E., TSR stochastic rainfall generation for Mallow: 10 year series*. HR Wallingford* (2016)Ministry of Housing and Local Government, Technical committee on storm overflows and the disposal of storm sewage: final report. *London: HMSO* (1970)

Mott MacDonald, Future Impacts on Sewer Systems in England and Wales. Summary of a Hydraulic Modelling Exercise Reviewing the Impact of Climate Change, Population and Growth in Impermeable Areas up to Around 2040. *Ofwat* (2011)

Scottish Water and WRc plc, Sewers for Scotland 3rd Edition - A technical specification for the design and construction of sewerage infrastructure. *Scottish Water* (2015)

Woods Ballard, B., Wilson, S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R. and Kellagher, R., The SuDS Manual*, CIRIA C753* (2015)

Appendix 1 - Bibliography

Adaption Sub-Committee, Climate change – is the UK preparing for flooding and water scarcity? Adaption Sub-Committee Progress Report 2012. *Adaption Sub-Committee*, (2012)

Allitt, R., Allitt, M. and Allitt, K., Impact Of Urban Creep on Sewerage Systems. *UKWIR Report Ref No. 10/WM/07/14* (2010)

Anderton, S., Ledbetter, R. and Prudhomme, C., Understanding the performance of water supply systems during mild to extreme droughts. *Environment Agency Report SC1 20048/R* (2015)

Anglian Water, Towards sustainable water stewardship. Sustainable drainage systems (SUDS) adoption manual. *Anglian Water* (2011)

Arkell, B., Cambridge, A., Darch, G., Jeal, G., Jones, P., Kilsby, C., McSweeney, R., Osborn, T. and Ravnkilde, K., Climate Change Modelling for Sewerage Networks. *UKWIR Report Ref. No. 10/CL/10/15* (2011)

Ashley, R., Stovin, V., Moore, S., Hurley, L., Lewis, L. and Saul, A., London Tideway Tunnels Programme Thames Tunnel Project Needs Report. Potential source control and SUDS applications: Land use and retrofit options. Appendix E Thames Tideway Tunnel Needs Report. *Thames Water Utilities Limited* (2010)

Balmforth, D., Digman, C., Kellagher, R. and Butler, D., Designing for exceedance in urban drainage – good practice. *CIRIA C635* (2006)

Bates, B., McLuckie, D., Westra, S., Johnson, F., Green, J., Mummery, J. and Abbs, D., Revision of Australian Rainfall and Runoff - The Interim Climate Change Guidance. *Floodplain Management Association National Conference* (2015)

Bennett, J., Blenkinsop, S., Dale, M., Fowler, H. and Gill, E., Rainfall Intensity for Sewer Design - Technical Report. *UKWIR Report Ref. No. 15/CL/10/16-1* (2015)

Bilham, E., Classifications of heavy falls of rain in short periods, British Rainfall 1935. *HMSO pp.262-280* (1935)

Bray, B., Gedge, D., Grant, G. and Leuthvilay, L., UK Rain Garden Guide. *RESET Development* (2012)

Brisley, R., Wylde, R., Lamb, R., Cooper, J., Sayers, P. and Hall, J., Techniques for valuing adaptive capacity in flood risk management. *Proceedings of the ICE - Water Management DOI: 10.1680/wama.14.00070* (2015)

British Standards Institution, Rainwater harvesting systems. Code of practice. *BSI BS 8515:2009+A1:2013* (2009)

British Standards Institution, Code of practice for surface water management for development sites. *BSI BS 8582:2013* (2013)

Bruni, G., Reinoso, R., van de Giesen, N., Clemens, F. and ten Veldhuis, J., On the sensitivity of urban hydrodynamic modelling to rainfall spatial and temporal resolution. *Hydrol. Earth Syst. Sci., 19(2) pp.691-709* (2015)

Bujnowicz, M., Dempsey, P. and Murray, D., Modifying Existing Rainfall Design Sets For Climate Change - Final Report. *WRc Report No.:P8100.05* (2010)

Cabinet Office, Keeping the Country Running: Natural Hazards and Infrastructure. A Guide to improving the resilience of critical infrastructure and essential services. *Cabinet Office* (2011)

Chan, S., Kendon, E., Fowler, H., Blenkinsop, S. and Roberts, N., Projected increases in summer and winter UK sub-daily precipitation extremes from high-resolution regional climate models. *Environ. Res. Lett.* 9(8), p.084019 (2014)

Cheng, K., Wei, C., Cheng, Y. and Yeh, H., Effect of spatial variation characteristics on contouring of design storm depth. *Hydrol. Process. 17(9) pp.1755-1769* (2003)

CIRIA, HR Wallingford and MWH, Collating the urban drainage evidence base. *CIRIA C783* (2008)

CIRIA, Overview of SuDS performance, Information provided to Defra and EA. *CIRIA* (2009)

City of Rotterdam, Resilient Rotterdam Program. Future-proofing as a shared responsibility. *City of Rotterdam* (2015).

CIWEM, CIWEM Urban Drainage Group Rainfall Modelling Guide 2015. 4th draft for comment. *CIWEM* (2015)

CIWEM, CIWEM Urban Drainage Group Rainfall Modelling Guide 2015. *CIWEM* (2016)

Consumer Council for Water, Reliable services for customers – consultation on Ofwat's role in resilience. Consumer Council for Water Response. *Consumer Council for Water* (2015)

CONVEX, Convex Extreme Rainfall Workshop: Summary, *Summary of the first CONVEX (CONVective EXtremes) workshop held on the 17th and 18th April 2012 at Reading University*. *CONVEX* (2012)

Copernicus Climate Change Service, End-to-end Demonstrator for improved decision making in the water sector in Europe (EDgE)

edge.climate.copernicus.eu, Copernicus Climate Change Service on behalf of ECMWF for the European Commission, [online]
Available at http://edge.climate.copernicus.eu/ [Accessed 30 Jan. 2017]

Coulthard, T., Frostick, L., Hardcastle, H., Jones, K., Rogers, D., Scott, M. and Bankoff, G., The June 2007 floods in Hull Final Report by the Independent Review Body. *Independent Review Body set up by Hull City Council* (2007)

Defra, Adapting to climate change UK Climate Projections, *Defra* (2009)Defra, Creating a great place for living – Enabling resilience in the water sector. *Defra* (2016)

Defra and Environment Agency, An assessment of evidence on Sustainable Drainage Systems and the Thames Tideway Standards. *Environment Agency* (2013)

Department for Communities and Local Government, National Planning Policy Framework. *Department for Communities and Local Government* (2012)

Dierkes, C., Lucke, T. and Helmreich, B., General Technical Approvals for Decentralised Sustainable Urban Drainage Systems (SUDS)—The Current Situation in Germany. *Sustainability 7(3), pp.3031-3051* (2015)

Duckworth, C., Assessment of urban creep rates for house types in Keighley and the capacity for future urban creep. *MA thesis, University of Manchester* (2005)

Dwr Cymru Welsh Water, Model Build and Verification Specification. *Dwr Cymru Welsh Water* (2014)

Dwr Cymru Welsh Water, Sustainable Drainage Plan Specification. *Dwr Cymru Welsh Water* (2015)

Ellis, C., Cripps, R., Russ, M. and Broom, S., Transforming water management in Llanelli, UK. *Civil Engineering 169(CE1), pp.25-33* (2016)

Entec, Northumbrian Water Wastewater network – Dry weather flow capacity mapping. *Northumbrian Water* (2009)

Environment Agency, Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities. *Environment Agency* (2016a)

Environment Agency, Consultation – Developing Spill Frequency Trigger Permits for Water and Sewerage Company Storm Overflows. *Environment Agency* (2016b)

Environmental Services, City of Portland, Portland Watershed Management Plan 5-Year Implementation Strategy 2012-2017. *Environmental Services, City of Portland* (2012)

Fava-Verde, A., Hickey, K., Jeal, G. and Sutherland, J., Wastewater supply-demand framework. *UKWIR Report Ref. No. 14/RG/08/6* (2014)

Federal Water Act (WHG) 2010

fehweb.ceh.ac.uk. (2016). Home Page - FEH Web Service. [online] Available at: https://fehweb.ceh.ac.uk/ [Accessed 1 Jun. 2016]

Flood and Water Management Act 2010 (c.29). *HMSO*

Flood and Water Management Act 2010 (c.29) Sch3. *HMSO*

Garside, I. G., WaPUG note 23: Using annual rainfall time series. *WRc* (1991)

German Association for Water, Wastewater and Waste (DWA), Standard DWA-A 100E Guidelines of Integrated Urban Drainage (IUD). German DWA Rules and Standards. *Hennef: German Association for Water, Wastewater and Waste (DWA)* (2006)

German Association for Water, Wastewater and Waste (DWA), DWA-A 102. Niederschlagsbedingte Siedlungsabflüsse – Grundsätze und Anforderungen zum Umgang mit Regenwetterabflüssen (Precipitation Conditional settlement outflows - principles and requirements for dealing with rainy weather drains). *German Association for Water, Wastewater and Waste (DWA)* (in preparation)

Gov.uk. (2016). Flood risk assessments: climate change allowances - Detailed guidance - GOV.UK. [online]
Available at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances [Accessed 1 Jun. 2016]

Greater London Authority, London Sustainable Drainage Action Plan - draft for public consultation. *Greater London Authority* (2015)

Greaterdublindrainage.com. (2016). Greater Dublin Strategic Drainage Strategy | Greater Dublin Drainage.
[online] Available at: http://www.greaterdublindrainage.com/gdsds/ [Accessed 1 Jun. 2016]

Halcrow, Drainage Strategy Framework. For water and sewerage companies to prepare Drainage Strategies. Good practice guidance commissioned by the Environment Agency and Ofwat. *Environment Agency and Ofwat* (2013)

Hewes, W. and Pitts, K., Natural Security: How Sustainable Water Strategies Are Preparing Communities for a Changing Climate. *Washington D.C: American Rivers p.112* (2009)

HR Wallingford, SAM - System-based analysis and management of urban flood risks. A new procedure for performance assessment of sewerage systems. *HR Wallingford Report SR700* (2009)

HR Wallingford, Use of spatial rainfall in urban flood modelling. DTI SAM - System Based Analysis and Management of Urban Flood Risks. Technical Note MCS0441-01. *HR Wallingford* (2010)

HR Wallingford, SR736 Developing Stormwater Management using Rainwater Harvesting. Testing the Kellagher / Gerolin methodology on a pilot study. *HR Wallingford* (2012)

HR Wallingford, Assessment of high intensity rainfall for the future based on analysis of warmer Atlantic cities. Initial investigation. *HR Wallingford* (2013a)

HR Wallingford, Using UKCP09 in Sewer Network Modelling. Development of baseline observed rainfall time series for Yorkshire. *Project not published publicly MAR5027-RT003-R01-00* (2013b)

HR Wallingford, Using UKCP09 in Sewer Network Modelling. Applying climate change projections to time series rainfall. *Project not published publicly MAR5027-RT004-R01-00* (2013c)

HR Wallingford, SuDS symbology and data model. Interim report. *UKWIR research project not published* (2015)

HR Wallingford, Urban drainage best practice. A review for Anglian Water. *Project not published publicly MAR5568-RT0001-R03-00* (2016a)

HR Wallingford, Urban drainage best practice review for Anglian Water. Feedback report. *Project not published publicly MAR5568-RT0002-R01-00* (2016b)

Innovyze.com. (2016a). Innovyze - Innovating for Sustainable Infrastructure. [online] Available at: http://www.innovyze.com/products/icm_riskmaster/ [Accessed 1 Jun. 2016]

Innovyze.com. (2016b). Innovyze - Innovating for Sustainable Infrastructure. [online] Available at: http://www.innovyze.com/products/infonet/ [Accessed 2 Jun. 2016]

Institute of Hydrology, Flood Estimation Handbook (five volumes). *Institute of Hydrology (reprinted 2008 by the Centre for Ecology and Hydrology)* (1999)

Jones, P., Harpham, C., Kilsby, C., Glenis, V. and Burton, A., UK Climate Projections science report: Projections of future daily climate for the UK from the Weather Generator. *UK Climate Projections* (2010)

Kellagher, R., Climate Change and the hydraulic design of sewerage systems - Summary Report. *UKWIR Report Ref. No. 03/CL/10/0* (2004a)

Kellagher, R., Drainage of development sites - a guide (X108). *HR Wallingford and CIRIA* (2004b)

Kellagher, R., Audacious - Adaptable Urban Drainage. Comparison on RainSim and TSRsim stochastic rainfall generators benchmarked against observed data. *HR Wallingford Report SR675* (2005)

Kellagher, R., Review of the Flood & Water Management Act: Investigations on flooding. Evidence review of factors contributing to surface water flooding from Section 19 LLFA reports. *Defra* (2015)

Kellagher R. and Gorton, E., TSR stochastic rainfall generation for Mallow: 10 year series. *HR Wallingford* (2016)

Kellagher, R. and Lauchlan, C., Use of SUDS in High Density Developments Guidance Manual. Report SR666, Environment Agency R&D Technical Report P2-261/18. *HR Wallingford* (2005)

Kellagher, K., Wilson, S. and Thomson, R. J. C., Final Surface Water Drainage Report. *Defra WT1505* (2013)

Kjeldsen, T. R., Flood Estimation Handbook Supplementary Report No. 1. The revitalised FSR/FEH rainfall-runoff method. *Centre for Ecology and Hydrology pp.28-29* (2007)

Local Authority SuDS Officer Organisation (LASOO), Non-Statutory Technical Standards for Sustainable Drainage: Practice Guidance. *Defra* (2015)

mcm-online.co.uk. MCM-Online | The Manual. (2016) [online] Available at: http://www.mcm-online.co.uk/manual/ [Accessed 1 Jun. 2016]

Ministry of Housing and Local Government, Technical committee on storm overflows and the disposal of storm sewage: final report. *HMSO* (1970)

Ministry of Housing and Urban-Rural Development of the People's Republic of China, Technical Guidelines for the Construction of Sponge City - Construction of stormwater system based on low impact development (Trial). *Ministry of Housing and Urban-Rural Development of the People's Republic of China* (2010)

Mott MacDonald, Future Impacts on Sewer Systems in England and Wales. Summary of a Hydraulic Modelling Exercise Reviewing the Impact of Climate Change, Population and Growth in Impermeable Areas up to Around 2040. *Ofwat* (2011)

Mott MacDonald, Resilience - outcomes focused regulation. Principles for resilience planning. *Ofwat* (2012)

NERC, Flood Studies Report (five volumes). *NERC* (1975)

NYC Department of City Planning, Coastal Climate Resilience. Designing for Flood Risk. *NYC Department of City Planning* (2013)

NYC Department of Environmental Protection, NYC Green Infrastructure Plan. A sustainable strategy for clean waterways. *NYC Department of Environmental Protection* (2010)

Ochoa-Rodriguez, S., Wang, L., Gires, A., Pina, R., Reinoso-Rondinel, R., Bruni, G., Ichiba, A., Gaitan, S., Cristiano, E., van Assel, J., Kroll, S., Murlà-Tuyls, D., Tisserand, B., Schertzer, D., Tchiguirinskaia, I., Onof, C., Willems, P. and ten Veldhuis, M., Impact of spatial and temporal resolution of rainfall inputs on urban hydrodynamic modelling outputs: A multi-catchment investigation. *Journal of Hydrology, 531, pp.389-407* (2015)

OFWAT, Output from the Resilience Task & Finish Group. *Ofwat* (2015)

Pall, P., Allen, M. and Stone, D., Testing the Clausius–Clapeyron constraint on changes in extreme precipitation under CO2 warming. *Clim Dyn*, *28(4), pp.351-363* (2006)

Phillywatersheds.org. Green City, Clean Waters, *Philadelphia Water Department* (2016) [online] Available at: http://www.phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan [Accessed 2 Jun. 2016]

Pitt, M., The Pitt review: learning lessons from the 2007 floods. *An independent review by Sit Michael Pitt* (2008)

Portlandoregon.gov. Green Streets, *The City of Portland, Oregon* (2016)
[online] Available at: https://www.portlandoregon.gov/bes/45386 [Accessed 2 Jun. 2016]

PUB, Singapore's National Water Agency (2016)
[online] Available at: https://www.pub.gov.sg/drainage [Accessed 2 Jun. 2016]

Raingain.eu. (2016). *Four cities gain rain | École des Ponts ParisTech - Site RainGain - Site RainGain.* [online]
Available at: http://www.raingain.eu/en/four-cities-gain-rain [Accessed 1 Jun. 2016]

Rotterdam Climate Initiative, The Rotterdam Challenge on Water and Climate Adaptation - 2009 Adaption Programme. *Rotterdam Climate Initiative* (2009)

SEPA, Water Use Regulatory Method (WAT-RM-07) Sewer Overflows. Version 3.1. *SEPA* (2014)

Scholz, M., Corrigan, N. and Yazdi, S., The Glasgow Sustainable Urban Drainage System Management Project: Case Studies (Belvidere Hospital and Celtic FC Stadium Areas). *Environmental Engineering Science*, *23(6), pp.908-922* (2006)

Scottish Water and WRc plc, Sewers for Scotland 3rd Edition - A technical specification for the design and construction of sewerage infrastructure. *Scottish Water* (2015)

Scottish Water Working Group, Sewers for Scotland 2nd Edition - A design and construction guide for developers in Scotland. *Water UK/WRc plc* (2007)

Sewerage (Scotland) Act 1968 (c.47). *HMSO* (1968)

srm.wrcplc.co.uk. Home - Sewerage Risk Management (2016)
[online] Available at: http://srm.wrcplc.co.uk/ [Accessed 1 Jun. 2016]

Starr, M., An Improved Definition of Sewage Treatment Works Dry Weather Flow. *Tynemarch Systems Engineering Ltd* (2006)

Stewart, E., Jones, D., Svensson, C., Morris, D., Dempsey, P., Dent, J., Collier, C. and Anderson, C., Reservoir Safety – Long Return Period Rainfall. *R&D Technical Report WS 194/2/39/TR Volume 1 (Part 1). Defra* (2013).

Stovin, V., Moore, S., Wall, M. and Ashley, R., The potential to retrofit sustainable drainage systems to address combined sewer overflow discharges in the Thames Tideway catchment. *Water and Environment Journal, 27(2), pp.216-228* (2012)

Sustainable Urban Drainage Scottish Working Party, Water Assessment and Drainage Assessment Guide. *SUDS Scottish Working Party* (2016)

svs.gsfc.nasa.gov. (2016). *SVS Archived Story: /svs/db/stories/Landsat/atlanta heat background.html.* [online] Available at:
https://svs.gsfc.nasa.gov/stories/Landsat/atlanta_heat_background.html [Accessed 1 Jun. 2016]

Technical Committee CEN/TC 165, Draft of the Hydraulic Design Standard submitted to TC165 for approval of a new work item and if approved for CEN enquiry. Formerly Annex E of EN 752. *BSI* (2015)

Thameswater.co.uk, (2016). Counters Creek - Tackling sewer flooding. [online] Available at: http://www.thameswater.co.uk/about-us/9344.htm [Accessed 2 Jun. 2016]

The City of Copenhagen, Cloudburst Management Plan 2012. *The City of Copenhagen* (2012)

The Source, (2016). Copenhagen unveils first city- wide masterplan for cloudburst. [online] Available at: http://www.thesourcemagazine.org/copenhagen-unveils-first-city-wide-masterplan-for-cloudburst/ [Accessed 1 Jun. 2016].

The Water Environment (Controlled Activities) (Scotland) Regulations 2011, SSI 2011/209. *HMSO* (2011)

UKWIR, The use of Active System Control (ASC) when designing sewerage schemes – a guide. *UKWIR Report Ref. No. 13/SW/01/5* (2013)

UKWIR, Real-time Integrated Modelling, Monitoring and Control. *UKWIR Report Ref. No. 15/SW/01/12* (2015)

Welsh Government, Recommended non-statutory standards for sustainable drainage (SuDS) in Wales – designing, constructing, operating and maintaining surface water drainage systems. *Welsh Government* (2016)

Wisdish, A. and Barnes, J., Strategic Growth Planning – Proactively Managing Uncertainty. *CIWEM UDG Autumn conference* (2016)

Woods Ballard, B., Wilson, S., Udale-Clarke, H., Illman, S., Scott, T., Ashley, R. and Kellagher, R., The SuDS Manual, *CIRIA C753* (2015)

WRc plc, Sewers for Adoption - A Design and Construction Guide for Developers - Small Developments Version - September 2013. Taken from the Seventh edition. *WRc plc on behalf of Water UK* (2013)

Appendix 2 - Consultations - Meeting with Welsh Water

Mapping Welsh Water's Sustainable Drainage Plan onto 21st Century Drainage

Venue: Millennium Room, Welsh Water, Baglan, Port Talbot

Date: 07/12/2016 Time: 11:00 – 15:30

Attendees

Paul Grabham – Welsh Water	Andrew Power - Mouchel	Rhona Kirkham - RPS
Tom Boichot - Atkins	Richard Kellagher – HR Wallingford	Lizzie Gorton – HR Wallingford

Apologies

Tony Harrington – Welsh Water	Amy Shoesmith – Welsh Water	Helen Udale-Clarke – HR Wallingford

1. 21st century drainage – project overview

Project objectives:

- National and regional reporting of the status of the drainage infrastructure (pipe networks & CSOs) using appropriate metrics;
- Forecasting the future status of the systems taking into account future pressures: climate change, urban creep, infill and new development;
- Taking into account uncertainty;
- Methods & metrics can be used within a framework to prioritise investment, considering possible interventions and costs and time;
- Key delivery of the information is visualisation.

3 pilot study networks to test the methodology

2. Methodology for assessment of drainage capacity – 'initial'

Where there is network data only

Scope metrics – pipes capacities. Summarised in terms of performance in the catchment.

- Pipes: Flow rate (constant) v Pipe-full capacity
    - Flow rate = DWF + I + E
    - Green: <30%, Amber: 30% – 50%, Red: > 50%
- Catchments – Number of pipes
    - Green: < 5%, Amber: 5% – 10%, Red: > 10%
    - Length of pipe would be more representative than number of pipes (otherwise scaled in favour of the many 150mm pipes)

There is no areal (rainfall response) related information in this method. This means that creep and climate change etc. have no influence.

- An automated optimisation tool could be used to distribute area – but this is likely to be a recommendation of 21st CD project rather than suggest it as a current approach to take.
    - Tool would use spatial rainfall, flow hydrograph at treatment works and GIS network data to allocate area to each pipe. Flow hydrographs at pumps and telemetry data could also be used.
    - Anglian Water have an area distribution tool/technique (to discuss with James Hale and other Anglian staff at workshop on 15th December).
- A simpler approach is to apply approximate area to each pipe. 5m2 per address point in foul only areas and 50m2 per address point in combined areas is considered typical.
- Another recommendation of 21st CD project could be to undertake a project to determine if there is a correlation between proportion of flow in foul / combined pipes that is DWF, and proportion that is storm. It could examine factors such as type / age of house, area of upstream catchment or impermeable area upstream etc. If there was a universal procedure it would be simpler than using an optimisation tool.

Scope method includes commercial and industrial flows.

It is proposed to use recorded data from WwTW (and PS) to calculate infiltration within the catchment. Distributing this infiltration requires assumptions to be made.

- There would be seasonal variation in infiltration, it is proposed that the Q80 infiltration flow rate for the year is probably used, though this would be less than the Q80 for winter which might be significantly different.
- Could distribute infiltration evenly per m length, but would this add too much to 150mm pipes?. The feeling was that this would be the simplest method and wouldn't result in substantial surcharge in the small pipes, but may result in slightly more (but not highly unrealistic) 'red'/'orange' further up the network than in reality.

- A method to distribute infiltration based on literature research as a function of size, length and depth of pipe could be an alternative.
- This method assumes all WwTW are monitored and Q80 can be derived.

Other issues with scope method:

- A GIS based system would not capture backwater effects and throttles.
- What constitutes a useful catchment size? Some small networks may need aggregating whilst large ones sub-dividing. Water companies should decide.

3. Methodology for assessment of drainage capacity – 'Enhanced'

Where there is well verified models or Poor / Old / Partial verified models

Scope metrics - pipes surcharge. Summarised in terms of performance in the catchment.

- Pipes – surcharge return period
  - Run multiple return periods and durations
  - Green: > 10 years, Amber: 2 – 10 years, Red: < 2 years
- Catchments – Number of pipes
  - Green: < 5%, Amber: 5% – 10%, Red: > 10%
  - Length of pipe would be more representative than number of pipes (otherwise scaled in favour of the many 150mm pipes)

Not all models are well verified, at least for all branches. Some models will not have their catchments defined. Even if well verified, models may have been verified with limited data in one season and not capture the variability of infiltration through the year. But if there is a model it will be used, and if there are multiple models for seasons etc. The most appropriate one is best chosen by the water company.

4. Methodology for assessment of CSO capacity – initial

Proposed metrics:

- Using Formula A (DWF + 300P + 2E g.p.d (1360P SI units)) and 8 times dilution for Q95 of receiving stream
- Each CSO can get assigned a Q95 value once and this can be used for all assessments into the future. The understanding is that the Q95 won't be affected too much by climate change. We are focused CSO performance and the rivers information is secondary. However Q95 rivers is being included because this is linked to current EA focus on CSOs and the fact this metric is being used in another project in the 21st Century Drainage Programme

- Individual CSOs
  - Green: >F'A and >8 Dilution,
  - Amber: > F'A and <8 Dilution,
  - Red: < F'A
- Catchments – Failed (Red) CSOs
  - Green: <10%, Yellow: <20%, Red: >20%

Should Formula A be adjusted at WwTW and emergency overflows at pumping stations, to 3 x DWF, as this is often used as the requirement before storm tanks start to be utilised?

It was thought we should make use of consented information for CSOs. This would be simple Pass / Fail. However as flows will be incorrectly (under) estimated, should Consented CSOs only be used for 'Enhanced' analysis?

Non-consented / deemed to consent CSOs spilling into the sea or lake will always meet the Q95 dilution test, so as long as they pass F'A they will always score Green. Is this reasonable?

5. Methodology for assessment of CSO capacity - enhanced

Proposed metrics:

- Formula A (DWF + 300P + 2E g.p.d (1360P SI units))
  - Pass forward F' A at 10:1 yr rainfall for 60 minute event
  - Plus 8 times dilution for Q95 of receiving stream (either inflow pipe capacity, or inflow – outflow pipe capacity). Alternatively actual maximum or mean spill rate could be used.
- TSR analysis:
  - Run 3 years
  - Spill frequency based on EDM EA reporting? The view was that this was too coarse and another agreed measure was needed.
- Individual CSOs
  - Green: > F' A and >8 Dilution and <20 spills,
  - Amber: > F' A and <8 Dilution, or 20 – 40 spills,
  - Red: < F' A, or 40+ spills
- Catchments – Failed (Red) CSOs
  - Green: <10%, Yellow: <20%, Red: >20%

Should Formula A be adjusted at WwTW to 3 x DWF, as this is often used as the requirement before storm tanks start to be utilised? Also should Formula A be applied to emergency overflows at pumping stations?

But these proposed metrics do not make use of consented CSOs.

- Most CSOs consents are equivalent to Formula A, others have more strict consents (bathing waters / shellfish) and others are more 'relaxed'. The 'relaxed' consented CSOs won't meet Formula A and/or 8 times dilution and therefore would score 'red' despite meeting their consent.
- Therefore it is proposed to have two measures:
  - If CSO is consented:
    - Green: meets consent, Red: failing consent
    - To show CSO meets/fails consent, run model with 10:1 year event and check if flow exceeds pass forward flow before CSO spills.
  - If CSO is not consented / deemed to consent:
    - Revert back to previously proposed metrics using Formula A, 8 times dilution and spill frequency but still using 10:1 year event to ensure Formula A is met.
- We would need EA feedback to use consented values for RAG scores. It may be that the EA do not want to score CSOs based on their current consents because they are likely to now aspire to tighter limits. It also results in two standards of performance measurement. Both methods can be tested with the pilot catchments.

CSOs spilling into the sea or lake (which are not consented) will always meet the Q95 dilution test, so as long as they pass F'A they will always score Green. Is this reasonable?

The definition of a 'spill' needs to be carefully defined, as NRW, SEPA and EA may have different definitions, but it will be most useful to have a consistent approach across water companies. The data can always be reprocessed with a different definition if needed for different authorities.

It is also typical to have a minimum spill volume before it is counted as a spill to account for model uncertainty.

6. Visualisations

Threshold levels of RAG will control what the maps look like. The proposed thresholds will be checked to make sure they are reasonable during the pilot catchments.

'Initial' & 'Enhanced' reporting

- Score RAG based on number of red pipes/CSOs.
- Lines, grid or full colour to represent catchment performance accuracy.

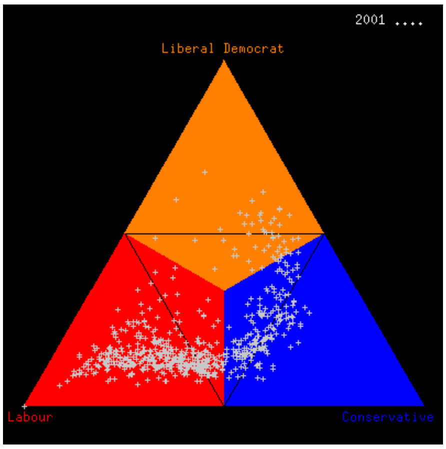
- Vertical height/bars on map can represent population served or length of sewers.
- Bars or pie chart on map can show proportion of RAG.
- Show a snapshot for each time horizon

Future trends

- Map could show two colours for each catchment – present and future score (possibly including grading in colours)
- Variations of adding population and / or pie chart (for both Present and Future) for 3 pipe performance categories as before – getting busy!
- Could show rate of change / change, but this is dependent on the accuracy of the pressures much more. There are potential difficulties in measuring improvement or deterioration when having three ranges of performance.

Non-catchment alternatives

- Overlay postcode/population grids on top of network and assign each pipe/CSO to a grid square, to produce a regular gridded RAG map.
- Triangle, with Red, Amber Green at each corner, and catchment plots in the triangle based on proportion of each score. Shows clustering/spread of catchments in a region/nationally and can show the movement of the point(s) over time.



7. Future pressures

To include development growth, urban creep/infill, climate change

Time horizons: 5 years, 25 years and 2080s

Climate change

- Need adjustments for design events and TSR
- Design storms
    - Limited consensus in industry for design storms.

- Science tends to support general EA guidance, which would be a 40% uplift for 2080s (high emissions, P50). The feeling was that if this was used the consequence on WaSC network impact would be significant, although Welsh Water use 26% for 2050s which is comparable and therefore 40% would not be a concern to them.
- Clasius-Clapeyron is a way of characterising the relationship between temperature increase and % increase in rainfall. Research shows there is a 7% increase for each 1ºC increase which aligns well with the P50 high emissions scenario increase (1.07^4.5ºC = 36%). Australia is the only country that has a climate change policy which use this relationship, but uses a 5% factor as the humidity levels in Australia may not remain as they are.

- TSR
  - No consensus or method by industry on TSR development and use for climate change.
  - A generic methodology based on HR Wallingford for Yorkshire could be produced, but method needs acceptance by the PSG.

Development growth

- Planned development is hard to forecast into the future. We know a growth rate from Local plans for 5 years, but we don't know where exactly it will be placed. In the longer term growth is considerably more uncertain.
- Development growth could either be placed within existing urban areas (i.e. increased density), or it could be placed on the fringes of a network (which may require extension of trunk sewers or new WwTW as it is unlikely they connect into existing 150mm pipes at the fringes).
- We can't represent networks that are yet to be built so we can't assess developments on the fringes of networks. It could also be argued that new developments should have no detriment on the existing network and that new networks would all score Green!
- We can account for increase in developments inside the existing urban areas (assuming that most of the existing network will be the same). Growth rate will actually vary across the catchment, but at a national approach, it is likely that a uniform uplift approach would probably be applied. This can be integrated with the application of urban creep by increasing both populations as well as impermeable area across the catchment.

Urban creep / infill development

- Most WaSC have an approach, but they don't all agree on % increase in impermeable areas, and even if they do, they don't agree on the division between foul systems and surface water systems.
- Often a capping limit of 10% is used.

- It would be preferable if a consensus on current WaSC practice is used for the project recommendations, but the project must not get too prescriptive on procedures, allowing individual WaSCs to use their own defined methodologies. It should preferably be based on a set of simple rules.

Uncertainty

- If all combinations of uncertainty for each pressure was considered, there would be many results which would be too much for anyone to look at and probably not add much value.
- An option would be to use a relatively arbitrary sensitivity range to be applied to all pressures to limit the uncertainty to a single pair of runs of say +/- 30%.

8. Interventions

Types of interventions that could be seen to be feasible to model globally were limited to impermeable area removal/disconnection(/SuDS) or additional storage (online/offline). The later might require a tool in ICM to be developed to automate it.

Should interventions be focused at: a) no detriment, b) development of a Pareto front of cost / benefit, or c) aimed to limit RED categories to a target limit? Compare this to the Do Nothing scenario.

Area removal could be tested by removing 5, 10, 20% etc. of impermeable area. Alternatively areas with greatest area could be targeted as a priority. £1 million / hectare was considered an approximate cost of removal of impermeable area and can be used to create a cost function. If area is assigned to the initial method this intervention can be used on both initial and enhanced methods, otherwise this form of intervention cannot be used for assessment of Initial networks.

To test storage, 30-year storm event for multiple durations could be run and the maximum flood volume calculated (total or each node). Storage that is needed could be modelled using the flood volumes at each node using a cost of £1000 / m^3.

How to show an improvement (reduce number of red pipes) for a storage solution is more difficult because the pipes will still be shown as surcharged unless a method of representing generic storage in a model is.

2012 Mott MacDonald for Ofwat study is worth looking at on how they assessed requirements to meet future pressures.

Time (when interventions need to be applied) is even trickier. Only certain amounts of area can be removed/storage added at one time and so any increases will occur gradually. We need to have a method where those networks which are deteriorating the fastest are targeted first. Interpolation of Present and Future 'Do nothing' scenario could find trigger based on a threshold based on RED categories.

9. Framework

We need a framework that uses the catchment scale metrics to drive the correct interventions.

Much of the success of a framework depends on whether intervention modelling is feasible at a catchment scale to understand cost and timescales. Otherwise the ‘national framework’ may potentially need to ‘drop down’ into a more detailed framework to understand cost, investment and interventions before feeding back into the ‘national framework’. As there would be 1000 catchments within the country this is not feasible (WaSC prioritise the highest risk) and if there were results for a catchment they would not be produced at the same time and would be drip fed back into the ‘national framework’

The National Framework might end up with contradictions between the results of prioritised target catchments and intervention costs compared to WaSC strategies already in place and which use far more detailed metrics. However, this project has the opportunity to define the ‘national framework’ and drive real change, in the UK water industry and potentially further afield. The national framework has the opportunity to define best practice, so we are all working towards the same goal, with the same methodology.

Behind all the visualisation images there would need to be tables which would help in ranking and prioritising catchments / investment.

Appendix 3 - Consultations - Knowledge gathering workshop

Full details of this workshop are provided in the Workshop Report issued in January 2017. A summary of the event is provided below.

Summary details

Date: Thursday 15th December 2016

Time: 9:30am to 3:30pm

Venue: Austin Court, Birmingham, UK

Workshop objectives

The purpose of the workshop was to gather knowledge and opinions from sewerage undertakers in the UK and Ireland, plus other key stakeholder organisations, regarding the scope and proposed approaches being developed as part of this project.

In particular, the project team asked participants to:

1. Review the project team's current understanding of what was needed and proposed approaches, including
    a. Have we missed any important issues?
    b. Are there any surprises?
    c. Do you agree/disagree with what we are proposing?
2. Provide suggestions, specifically
    a. How would you do it and why?
    b. Do you have supporting information that you can share with us?
    c. What should be our priorities?

Participants

The aim was to have representation from all of the sewerage undertakers in the UK plus Irish Water. Participants were identified on the basis of their expertise in one or more of the following areas:

1a – Pipe capacities

1b – CSO performance

2a – Urban creep

2b – Infill growth

2c – Climate change

2d – Strategic growth

3 – Framework for intervention strategies

4 – Intervention modelling

5 – Visualisation/dissemination to stakeholders

Representatives from all but one UK sewerage undertaker were able to participate, supported by some of their consultants.

In addition to this, representatives from other key stakeholder organisations were also invited. Those that were able to attend included the Environment Agency, Defra, Natural Resources Wales, OFWAT and the CIWEM Urban Drainage Group.

In total there were 34 participants in the workshop, plus three members of the project team from HR Wallingford. The full list of participants is provided in the Workshop Report.

Workshop format

The workshop was broken down into four separate topics:

1. Performance assessment methods and metrics
    a. How should models be built?
    b. How should capacity be assessed?
2. Future pressures
    a. How should future pressures be applied?
    b. How should future uncertainties be added and used?
3. Visualisation
    a. How should capacity be visually represented?
    b. How should change in capacity be shown?
4. Interventions and decision-making
    a. How should interventions be modelled?
    b. How can timings and costs of interventions be estimated?
    c. How can interventions and catchments be prioritised?

Topics 1 to 3 were initially discussed in groups and each group then shared the key messages from their discussion with the other groups for further comment. Topic 4 was only discussed in plenary. Details of these discussions are provided in the Workshop Report.

Appendix 4 - Literature review - Urban Creep

Overview

"Urban Creep" is any increase in the impermeable surface of a developed area, subsequent to the original development and not including re-development (adapted from Duckworth, 2005). This additional impervious area will be drained to the existing drainage system, generally without any consideration of whether the capacity of the receiving sewerage system can accommodate the resultant increase in flow rates and volumes. For example, the construction of patios, conservatories, small extensions, paved driveways etc. all result in impermeable surfacing, which increases surface water runoff. Although the focus of this project is primarily standard residential areas, urban creep is also associated with commercial and industrial estates.

Urban creep is of concern due to the contribution of additional surface water runoff to sewerage systems – increasing the risk of flooding (due to capacity exceedance of any sewer type) and pollution (from foul or combined system flooding), or increased spill frequencies of CSOs. Urban creep also represents a significant risk to the sewer network's capacity to cope with both future housing growth and climate change (Mott MacDonald, 2011).

Urban creep is inherently unpredictable and difficult to manage because of the lack of rigorous controls on the paving of driveways and gardens. Urban creep varies in its effect as property extensions result in direct connections to either the surface water or foul/combined systems, whereas driveways and other forms of paving may or may not result in runoff being directly connected to the sewerage system.

The reasons why urban creep takes place is that improvement of a property is often easier and cheaper than moving, so where the property allows an opportunity for a useful change to be made, then changes will occur subject to having the income to do it. It is important to note that each of these elements (opportunity and finance) directly influence the changes that occur. Terraced properties and small gardens have limited opportunity to add paved surfaces or extensions. Similarly, the distance between the pavement edge and the house frontage is also an important parameter. This points to the fact that economic conditions along with planning requirements on property layouts are very influential on how urban creep takes place. Finally, there are the cultural changes that take place, such as the trend to enlarge kitchen and dining areas and reduced commitment to gardening.

From the perspective of drainage impact, there are a few key issues that need to be noted. Runoff from extended driveways will often not be actively drained, but runoff will often pass directly to road drainage. Patios in the rear garden will also rarely be positively drained, but as the waste pipe from the kitchen sink is often found in these locations, there is a good chance that in heavy rainfall a patio might drain to this location. In contrast to this, extensions to the property, including conservatories will tend to be positively drained to whatever drainage system they can be connected to.

Therefore, although remote sensing of urban creep is very effective in quantifying the rate of change of hard surfaces, the implications of urban creep on the sewerage system is still very uncertain without supporting evidence obtained using measurement of flow response during rainfall.

Research and available guidance

Urban creep in the UK has been studied a number of times in the last 20 years. It is a difficult topic to study for several reasons:

- Access to accurate information has historically required visits to properties in order to see what has taken place. However, access to back gardens is always difficult. This problem is now much reduced with the improvement in mapping and aerial drones/quad-copter technology.

- A change in surfacing does not necessarily indicate an increased contribution to sewer flows. This can only be established by either on-the-ground field visits looking at connectivity or accurate flow measurements.

- Historic rates of urban creep may not be representative of current or future rates.

The degree of change of impermeable surface has been shown to be linked to a range of factors – including development density, development type, socio-economic status and economic activity. None of these are static in time and developments change in their use of land and their design. Modern developments tend to be more intensively developed, in line with recent planning guidelines, such as Planning Policy Statement 3 on housing densities (which required developments to provide property densities of 50 houses per ha), though this has now been revoked. In 2008 regulations were implemented that required planning permission for any increase in paved areas for properties that are drained directly to the sewer. It is not known how influential this has been in curtailing urban creep or misconnections.

Although there is national guidance on urban creep recommended by key documents such as Sewers for Scotland (Scottish Water, 2015) (10% of the paved area), BS8582 (BSI, 2013), and the SuDS Manual (Woods Ballard *et al*, 2015), it is important to look to the evidence for what has actually been measured.

The primary and most recent research on urban creep is a study by Richard Allitt Associates for UKWIR in 2010 (Allitt *et al*, 2010). In general sewerage undertakers seem to be aware of this research and it appears to be commonly applied in developing design capacity allowances. However, although the same reference is being followed by most sewerage undertakers, the application of values of urban creep to each sewer type varies considerably. The details of this study and its findings are briefly summarised in this appendix.

The UKWIR guidance provides a literature review of other research on this topic. Four studies are noteworthy in that they quantify the amount of urban creep that had taken place over specified timescales and used various parameters such as housing density to derive correlation equations for predicting future urban creep.

The studies are:

- A postgraduate dissertation on urban creep by Caroline Duckworth, Manchester University 2005 (Duckworth, 2005);

- A study by Ewan Associates on Derby in 2003;

- As part of a Defra pilot study, Newcastle City Council carried out an urban creep assessment on 11 sites of 1 ha each;

- A study carried out by Richard Allitt Associates for Wessex Water in 2008.

This last study breaks down the findings in terms of foul and surface sewerage creep influence as being 0.38m^2 / year per property for foul and 0.70m^2 / year per property for surface water. This was based on an assessment of 30 areas.

The UKWIR study makes no mention of two of the principle references in the Duckworth study; Whitehand (1999) which looked at Birmingham and London and a study by Ealing Council.

WRc carried out a study for UKWIR in 2012 on foul misconnections to the surface water system. Although this information is not of direct interest here, there may be aspects about the findings associated with urban creep behaviour which could provide useful lessons. However, time has prevented consideration of this as part of this project.

A brief summary of the 2005 study and the UKWIR creep study is provided here. A review of the specific details of the other references has not been carried out.

The UKWIR urban creep study

The UKWIR urban creep study was commissioned to:

- Develop a methodology to identify the degree of urban creep within urban areas in England and Wales;

- Produce evidence and numerical values for the degree of urban creep within England and Wales;

- Find (if possible) a factor which can be used to determine the likelihood of urban creep;

- Develop a methodology for adding an allowance for urban creep in hydraulic models of drainage systems.

This was a very comprehensive study analysing aerial images of 100 km by 100 km square areas representing 2,000,000 properties across several cities in England; Leicester, Maidstone, Chester, Newcastle-upon-Tyne and Norwich for periods ranging from 3 to 7 years (between 1999 and 2006). This allowed the estimation of the change in roof and paved areas for the period of assessment.

The study was limited to this short recent period due to the recent improvements in mapping, in particular land cover classification maps, and related information.

The study found reasonable correlated relationships with a range of parameters that could be used to make future predictions of urban creep. The study developed four possible methods for predicting urban creep. Specific correlations were found with property density and property type. In addition, there was strong correlation with the depth of front gardens. It was found that, where distances were less than 4 m between the property and road, urban creep was minimal in the front of the property.

The four methods were:

- Statistical regression tree based on the area postcode which implicitly captures variables such as property density, footprint area, property type etc.
- Whole area sampling of the study (giving a mean of 0.738 m^2/property/year)
- Property type correlation
- Property density correlation.

It is important to note that these methods estimate urban creep in terms of the increase in impermeable surfacing within property curtilages (patios and driveways, and also extensions and conservatories). There is no breakdown of these categories provided.

The headline figures were that creep ranged between 0.4 m^2/property/year and 1.1 m^2/property/year.

The study provided a clear distinction between growth and urban creep, where growth is classified as re-development or new development. It is worth noting that growth can range from one to four times the value determined for urban creep for an urban area.

The Duckworth urban creep study

Although the Duckworth study is now over 10 years old, it has particular value in augmenting the UKWIR study for two reasons. Firstly, it looks at an earlier and much longer period for measuring change in hard surfaces in the urban environment and, secondly, it differentiates between the contribution of hard ground surfacing and property extensions to the measurement of urban creep.

Four categories of housing were defined; low, medium, and high density, and also social housing. These were classified using the Urban Morphology Type area classification. The analysis was carried out over two periods of time; 1971 – 1989, and 1989 – 2002. A number of blocks of 20 houses were selected. It is unclear how many blocks were selected. The analysis carried out statistical ‘t’ tests to assess whether the results were statistically significant in their differences. In most cases this was found to be true.

The following are the findings of the study:

- For low density housing there was an increase in impervious flat area of 15.2% and increase in impervious pitched area of 2.2% between 1971 and 2002.

- For medium density housing there was an increase in impervious flat area of 12.3% and impervious pitched area of 9% between 1971 and 2002.

- For high density housing there was an increase in impervious flat area of 5.3% but impervious pitched surface cover remaining more or less the same between 1989 and 2002. (The 1971 image was not analysed for high density housing).

- For social housing there was an increase in impervious flat area of 12.4% and increase in impervious pitched area of 2.8% between 1989 and 2002.

- For medium and low density housing, the changes that occurred during the study period were greater between 1971 and 1989 than between 1989 and 2002. This indicates a decreasing rate of urban creep toward the end of the study period. This may be a function of saturation or other factors such as the state of the economy.

- For social housing, the changes that occurred during the study period were higher between 1989 and 2002 than 1971 and 1989. This indicates an increasing rate of urban creep toward the end of the study period.

Table 30 Duckworth study - Urban creep rates

Property density	1971 – 1989	Rate of change /year	1989 – 2002	Rate of change /year	1971 – 2002	Rate of change /year
Low – Ground	11.0%	0.61%	4.0%	0.31%	15.2%	0.49%
Low – Property	1.1%	0.06%	1.1%	0.08%	2.2%	0.07%
Medium – Ground	11.4%	0.63%	3.3%	0.25%	12.3%	0.40%
Medium – Property	8%	0.44%	3.5%	0.27%	9.0%	0.29%
High – Ground	-	-	5.3%	0.41%	-	-
High – Property	-	-	0.0%	0.0%	-	-
Social – Ground	2.8%	0.16%	10.4%	0.80%	12.4%	0.40%
Social – Property	0.7%	0.09%	4.1%	0.32%	2.8%	0.09%

From this, it is evident that extensions to properties are a smaller proportion of the total urban creep contribution in residential areas, but that this proportion varies widely with property type. The results also indicate urban creep rates being slightly greater in the past than more recent changes, which may reflect a relationship between urban creep rate and development density, with more modern developments tending to be built at higher densities.

Comparison of the Duckworth figures with the rates proposed by the UKWIR study is difficult as of the study does not use property density, property type or area (as used in the UKWIR study). However, to provide some comparison, example property sizes can be used. If 250 m^2 is assumed to be the mean size of the curtilage of medium density housing and 500 m^2 for low density housing, then application of the Duckworth relationships would give mean creep rates for the whole period of 33 years of 0.33 m^2/year for the low density property extensions and 0.68 m^2/property for medium density dwellings. These figures, though arbitrary, provide a comparison with the UKWIR study. It is important to note that extensions only represent about a third of total additional hard surfacing within curtilages.

Sewerage undertaker practices

The UKWIR urban creep study recommends four possible methods of making an allowance for urban creep, although method 1 (regression tree) was only mentioned by one organisation, while methods 2 and 3 appear not to be used.

Sewerage undertakers generally apply a consistent approach, in that most of them use the UKWIR report on urban creep based on Method 4. It is understood that this uniformity stems from an OFWAT study in 2011 on urban creep carried out by Mott Macdonald (2011). However, the actual creep values used and the allocation of area to different sewer types varies significantly between sewerage undertakers. Even though this would imply some consistency in the method of approach used, values of 2%, 5% and even 15% have been applied. In addition, sometimes areas rather than percentages have been used such as 1.3 m^2 per property.

Appendix 5 - Literature review - Growth and Development

The Planning Inspectorate supports the Government's aim for every area in England to have an adopted Local Plan. A local plan sets out local planning policies and identifies how land is used, determining what will be built where. Adopted local plans provide the framework for development across England.

Local plans are produced with a 15 year horizon by the local authority with due consultation with the local community. Many local parish communities are also producing Neighbourhood Plans to try and ensure that local development growth is appropriately located to minimise the impact of negative elements such as traffic, while trying to achieve government target for housing in the area.

The official demographic projections for local authority areas are usually published every other year, based on the Office for National Statistics Mid-Year estimates (MYEs) for two years earlier, and run for 25 years from the base date. This timetable is sometimes disrupted by additional releases in response to important new data such as census information; the last of which took place in 2011. This information is used by the Department for Communities and Local Government to inform the government projections for the 25 year housing projections.

Growth in greenfield areas

Growth targets set by government for many parts of the country, particularly in the south of England, are high. At present, due to changes in the government targets where housing numbers have been increased by up to 100% for some regions, Local Plans are not compliant with government rules with having a 5 year land availability plan in place. In this situation developers can submit planning applications for additional areas not included in the local plan, and the government often rules in their favour even where the local authority objects.

This current situation means that local communities and those providing services to them such as sewerage undertakers, have difficulty planning for potentially large areas of additional development taking place where not reflected in current planning documents. This is less of a problem where local plans are in compliance with government requirements, but all areas marked as being potentially available for development may not get developed at all and the timescales for each site are not usually known.

Growth in greenfield areas implies the construction of new drainage systems, which will be built in accordance with current design criteria. In many case the surface water system is adopted by a management company, as the SuDS schemes they are encouraged to build will not be adopted by the sewerage undertaker.

In terms of this project, these additional surface water sewers (and SuDS) systems cannot be considered as they do not exist as yet, and in principle, they should be designed to have suitable capacity to serve the community. However, the foul sewage generated will normally be passed (often by pumping) to an existing treatment works. This is likely to be connected to the existing sewerage system at some point and hence drain to the treatment works, though in some instances a new treatment works may be created. The impact on sewer capacity may be significant in terms of additional foul flows for a limited section of the network.

Growth within the urban conurbation

Local plans also make assumptions with regards to infill growth and redevelopment within the existing urban developed areas. For large towns and cities there can be a substantial component of the growth in the area. This may be focused at key locations or assumed to be an uplift across the town or city.

The growth in the urban area may result in an increase in paved surface as well as an increase in population. However, any planning associated with development is likely to attempt to control the rate and volume of runoff. Therefore, the impact in terms of direct runoff is likely to be limited.

Appendix 6 - Literature review - Climate Change

This is provided in a separate document.

Appendix 7 - Best practice - Time series rainfall

Time series rainfall is the term given to a collection of rainfall events over a period of time. This can be continuous data (dry and wet periods) or a selection of separate relevant rainfall events. A rainfall time series can be data that has been recorded by rain gauges or generated by a stochastic rainfall tool.

Time series data has a number of advantages over design event rainfall, but there are also a few drawbacks.

Time series rainfall advantages over design storms

Time series rainfall is more useful than design storms for a number of reasons including:

1. The seasonal characteristics of rainfall, such as duration and intensity, along with other important characteristics, such as antecedent conditions and evaporation, are all captured in a rainfall series. There is no need to consider design wetness factors, seasonal corrections on rainfall depths and storm profiles.

2. Runoff models often have catchment wetness parameters and these are automatically calculated appropriately for the start and through the event being modelled.

3. The joint probability issues of antecedent dry periods and previous rainfall events and event characteristics are addressed automatically.

4. The joint probability issues of rainfall taking place over a site and the catchment of the river into which the development discharges and concerns over appropriate design river levels can also be automatically addressed if models of both systems can be used.

5. Time series rainfall captures rainfall shapes. Therefore, the attenuation of less intense periods of rainfall and runoff volumes in sewers with spare capacity can be captured, enabling a more accurate volumetric and frequency analyses of system performance, such as spills from CSOs or flooding. In some networks reverse flow takes place and spills can be affected. In such instances design rainfall events cannot be used to accurately analyse CSO performance, whereas time series captures these behavioural aspects.

6. Time series rainfall assists in more accurate water quality modelling of sewage pollutant concentrations, as the mass build-up of sediment in dry periods and washoff can be modelled.

7. The use of series rainfall enables the development of RTC rules, which design rainfall cannot be used for.

Time series rainfall disadvantages over design storms

However, there are some disadvantages of time series rainfall over the use of design storms including:

1. Many more events have to be run than a limited matrix of design storms (even though design storms usually require several return periods and multiple storm durations to be run). This means that computational times can be significantly longer.

2. Although time series rainfall provides more information, outputs need to be analysed appropriately to make best use of them, which can be time-consuming.

3. Time series rainfall events, as with design storms, are usually applied as uniform rainfall across the whole catchment. As the areal characteristics of rainfall through the seasons varies significantly, the use of an aerial reduction factor (ARF) is much more difficult to determine, and there is limited guidance available on this aspect. Normally time series events are not applied with an ARF value.

4. Extreme rainfall is difficult to record – gauges need to be in place for many years to provide a useful series for recording extreme events. Even when these happen, the accuracy of rainfall recording instrumentation can be reduced by conditions, such as hailstones and wind, that can occur in unusual events. Fortunately, stochastic rainfall tools can produce reasonably accurate series including extreme events from periods of rainfall of only 7 to 10 years (although 20 years is desirable).

Producing a rainfall time series

Time series rainfall must not be inappropriately used. Some examples of misuse include:

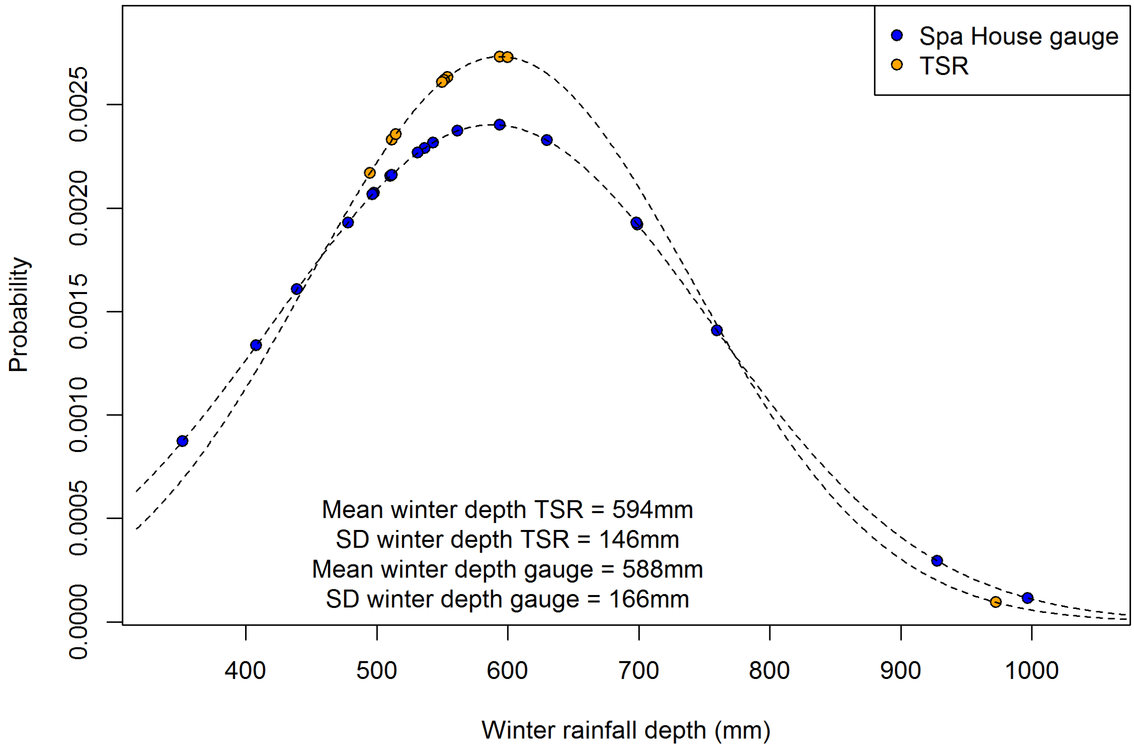
1. Use of a "typical" year by basing the selection on SAAR and/or the number of events or other annual average metric;

2. Selection of a few events as being 'typical' based on a measure of its effect on particular parts of the drainage system, or its depth and average intensity;

3. Use of an inter-event dry period which is too short (such as one hour) to divide up storms as earlier rainfall will still be having an effect in larger systems with long travel times.

Rainfall that takes place in any month of any year will tend to be very different from that month in the subsequent two or three years. The variability of rainfall each year is now recognised in many regulatory requirements such as the Bathing Waters or Water Framework Directives. Assessments of compliance to some Directives specifically cater for an analysis based on several years. In general, the normal approach is to use at least 10 years of information, and there is trend towards this becoming 20 years. Therefore, the representation of rainfall in a series should reflect this and a suitable period of time be used in capturing this variability. This means that the mean and distribution of high and low rainfall years for depths, numbers of events etc. (annual / seasonal / monthly) should all be considered. Figure 48 illustrates this aspect and in this case it also shows a comparison between a gauge and a stochastically generated rainfall series. This approach is very useful in demonstrating the adequacy of a stochastically generated rainfall series in replicating the gauge on which it was calibrated or another location.

Figure 48 10 year period mean winter depth normal distribution vs Spa House gauge



Source: HR Wallingford (2016) Courtesy of Irish Water

Shorter periods than 10 years can be acceptable where there is a high degree of frequency. For example, three years is probably sufficiently representative for CSO spill analysis where a structure spills frequently (say more than 20 times a year or 20 times in the months of interest). However, where CSOs have only a few spills a year, a longer series is advisable.

This does not mean a selection of relevant rainfall events cannot take place. In many instances events are of no relevance and need not be run. CSOs may never spill where events are less than 4 mm and events in excess of 15 mm might be necessary for flooding to start from sewers where there are restrictions in the system. Selection of relevant events from a series can significantly reduce the computational effort needed without losing any accuracy in the analysis of the system. For example, the largest 200 or 300 events with event peak intensities that exceed 10 mm/hr from an extreme 100-year series would probably provide the same answers as running all 15,000 rainfall events, which would typically take place over a period of 100 years.

Summary of the stages for producing a rainfall series

The production of a stochastic series is very similar to producing a series based on recorded data, as recorded data is an input needed for training/calibrating the tool parameters.

The stages of producing a stochastic series of rainfall are:

1. Obtain a relevant hourly or sub-hourly recorded data set;

2. At least 10 years of gauge data is advisable to calibrate a stochastic model for creating an extreme series, while an observed data set of more than 3 years and at a temporal resolution of 5 minutes or less may be suitable for direct use for assessing the performance of a sewer system;

3. If the recorded data set is long enough for direct use, but is only hourly resolution, then a stochastic analysis is still needed in order to create a 5-minute resolution series;

4. If the data has not been quality checked (and even if it has) the data sets need to be reviewed for missing data and other possible data anomalies;

5. A useful check is to compare the monthly rainfall depths against another local gauge, if this is available, and check that depth difference ratios are consistent (taking into account the differences in seasonal rainfall characteristics and the distance between the gauges);

6. Assuming the data set appears to be largely robust, where data is missing or thought to be incorrect, days or weeks of data from another year (from the same gauge or another gauge) should be substituted;

7. Carry out an annual and seasonal rainfall depths and variability analysis and compare to national hydrological information;

8. Carry out an extreme analysis check on the data where larger events are important by analysing the low frequency rainfall depths for a range of specific durations and compare the findings for that location against design event depths;

9. Carry out calibration of the stochastic tool using hourly data;

10. Produce between one and ten 100-year series depending on how extreme a data set is needed;

11. Carry out extreme value analysis to check on the most appropriate series for the low frequency return periods, which best reflects the design event rainfall depths for the area;

12. Use the selected 100-year series to produce a disaggregated 5-minute 100-year series;

13. Take the whole series or select a 10-year series from the extreme series using a rolling period and use relevant metrics to check and compare the results with observed or design event data. Metrics might include: mean annual and seasonal rainfall depths, annual variability, numbers of events in broad depth range categories, extreme event depths for durations from 30 minutes to 6 hours.

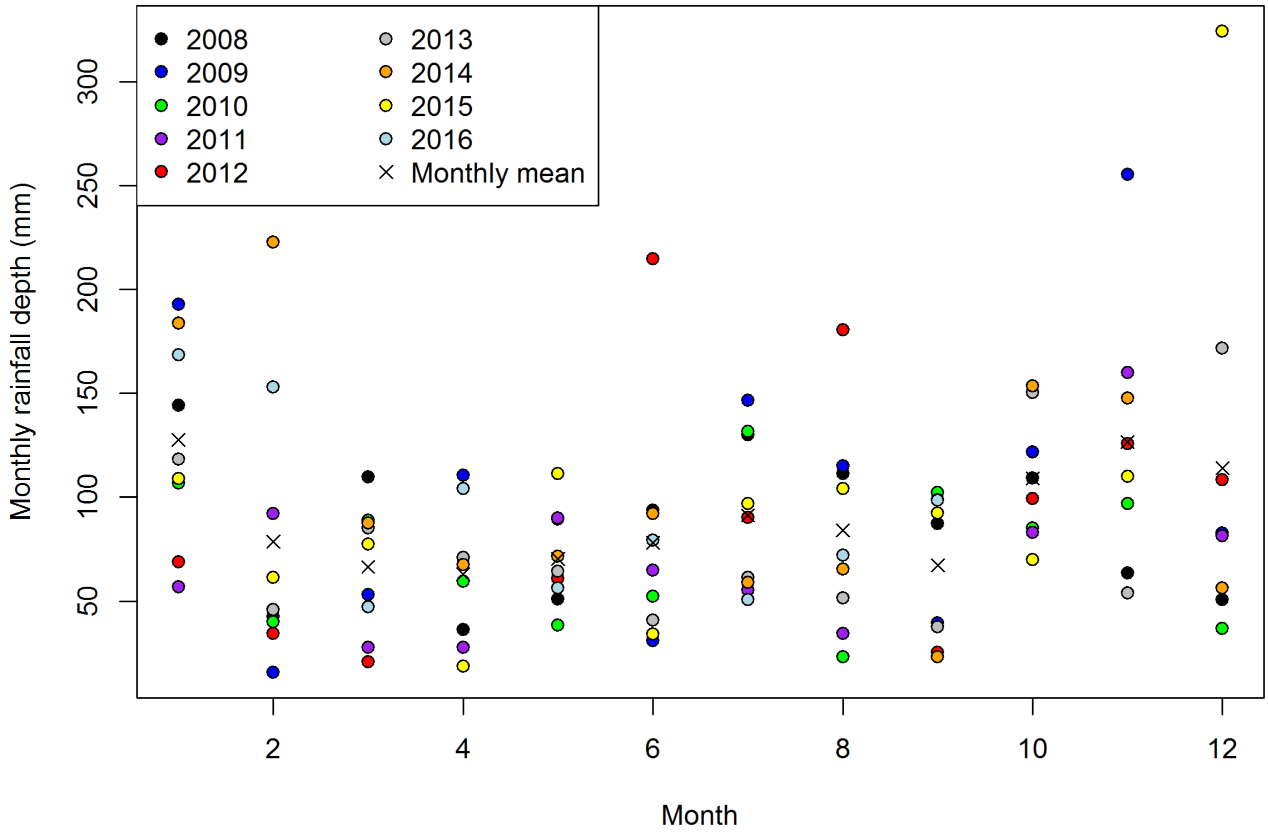
In theory, an observed series is more accurate than a stochastic series, as not all the relationships between rainfall events through the years will be captured exactly by these tools. The main reason for using these tools is their ability to generate extreme series and high temporal resolution data where this is not available from recorded information. It is important to note that where observed data is being used there needs to be greater care taken in checking for incorrect event data, which would tend to get smoothed out by a stochastic tool during the calibration process.

The use of a stochastic tool to produce sub-hourly data can be particularly useful where 5-minute data is either unavailable or particularly expensive, or perhaps too difficult to check for anomalies.

Checking the appropriateness of the data sets produced

Figure 49 illustrates the importance of not just checking annual variability in Figure 48, but also looking at seasonal and monthly rainfall behaviour. Certain months in a period of years will have a high level of variance in the rainfall depth.

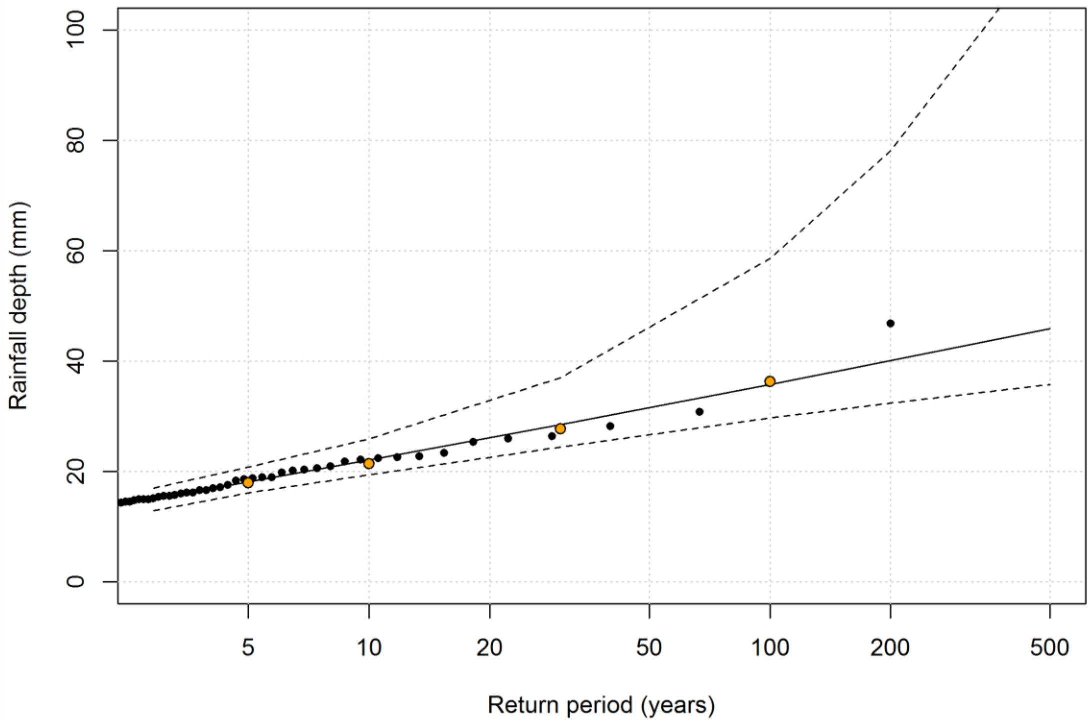
Figure 49 Monthly depth for each year and monthly mean for Moore Park 1 minute gauge



Source: HR Wallingford (2016) Courtesy of Irish Water

Figure 50 illustrates the check made for assessing representation of extreme events for a stochastically generated series plotted against design event rainfall depth for the same location.

Figure 50 General Pareto Distribution fitted to 1 hour extreme value analysis of 100 year TSR and compared to FSU rainfall depths



Source: HR Wallingford (2016) Courtesy of Irish Water

Table 31 illustrates the check made for the top 5 events from three possible suitable 10-year series (based on metrics such as annual depth, number of events etc.) where it is considered to be important to have a realistic representation of the likely biggest events in a 10 year (or 3 year) period. The top 5 events need to consider the event duration, so four durations have been checked. It can be seen that there is considerable variation with the brown coloured set having significantly greater depths than the purple and light blue 10 year periods selected.

Table 31 Top five rainfall event depths (mm) for three chosen 10 year periods, ranked for 1, 6, 12 and 24 hour event durations

1 hour	6 hour	12 hour	24 hour
26	62.4	72.8	107.4
25.4	51.2	68.2	103
21.8	42.6	62.6	94.4
21	42.4	60.6	64.8
20.4	40.2	59.2	63.4
18.6	37.2	57.6	62.8
16.2	36.6	53.6	62.6
16.2	36	52.6	61.8
15	35.8	47.8	59.4
14.6	35	46.4	53.6
14.4	30.8	40.6	51.4
14.4	29.8	39.8	49
13.8	29.6	38.8	48.4
13.6	27	35.8	46.6
13.2	26.4	34.6	43.8

Source: HR Wallingford (2016) Courtesy of Irish Water

Adjustment of rainfall series and adjustment of results

Calibration against gauge data depends on good and sufficient gauge information being available at the location of interest. Although there are many gauges scattered across the UK, there will always be locations where gauges do not exist and where the hydrological characteristics are not quite the same as a location with gauge information. This means that adjustments might need to be made to either the generated series or to the results of the analysis to take account of these differences.

An alternative, theoretically, is the use of radar rainfall which is available at 1 or 2 km resolution at any point across the whole of the UK. The length of record is now long enough for stochastic calibration purposes. The same process of checking the quality of the data would still be needed, though the Met Office does carry this out on all their data.

Assuming a gauge is used which is not at the site of interest, there are three simple measures for assessing the difference in the hydrology between the locations. These are:

- SAAR (Standard Average Annual Rainfall depth);
- M5_60 (the 5-year 1-hour rainfall depth);
- 'r' (The ratio of the 5-year 1-hour rainfall to the 5-year 2-day rainfall).

Although the FSR is now obsolete as rainfall data, these parameters are easily established and there are no equivalent simple indicators available for use from FEH13 data. These and other values, however, can be derived, if FEH13 information is obtained for the two sites.

The simplest approach is to use the ratio of SAAR for the two locations to modify all intensity values by a constant factor. In general this is thought to be sufficient for most purposes and no further adjustment is recommended. This is considered to be a conservative approach where there is an increase in SAAR which would result in higher intensities, whereas it is often the case that higher annual rainfall takes places in regions where intensities diminish (with lower values of M5_60). However, adjusting the intensities of a series downwards where SAAR values are lower is, therefore, conversely non-conservative.

An alternative scaling approach is to modify the intensities of the rainfall series based on the difference in M5_60 values. Which is the better option is best assessed for each specific instance. Post-processing of spill frequencies and volumes of discharge by the ratio of the SAAR values might be appropriate if the uplifts on SAAR and M5_60 are very different. However, in this case there would be some concern over using a gauge data set for such a location.

Although there is scope for investigating which scaling approach should be used for modifying the rainfall and the model outputs, in general it is thought that in most cases gauges will be suitably located such that the differences in results of the two methods is unlikely to be of great significance.

Appendix 8 - Literature review - Unit cost of SuDS

Design criteria for SuDS application

The cost of the design of a SuDS element depends very much on the design criteria. For example, SuDS that are designed for the 100-year event with additions of up to 40% for climate change and with throttle rates that are related to the greenfield runoff rate require very large storage volumes. Depths of rainfall can range from 100 mm up to 150 mm for the critical duration events. These criteria are aimed at providing flood protection downstream of these developments.

However, there are many reasons why the design criteria at a specific location might be different. Firstly, the focus for intervention might not be flooding, but aimed at minimising spills from CSOs or even improvement of flows to the treatment works. Other reasons include relaxation of criteria to encourage redevelopment of brownfield land and stimulation of the local economy, or the management of local flooding where a significant reduction in frequent flooding at a location can be achieved without necessarily meeting standard criteria.

New build versus retrofit SuDS

There can be considerable differences in the costs between retrofit SuDS and new build drainage systems. The most significant is probably that of rainwater harvesting, where new build costs are likely to be of the order of £1500 per dwelling, while retrofit may be as high as £4500.

Another SuDS element which potentially has widely different costs in retrofit scenarios is permeable pavements. In new developments permeable pavements provide not only the necessary attenuation storage but the road surface too. If permeable pavement was not used then a road would need to be constructed along with the drainage system and a separate attenuation storage unit. Therefore, new-build permeable pavement costs are often very attractive forms of providing storage. Retrofit costs may need to include removal of an existing pavement and associated kerb and drainage systems prior to installation of the new system, so the difference in these costs would be very large. An intermediate position is that of a road or car park that needs attention and is replaced with a permeable pavement.

Whole life costs of SuDS

In assessing costs it is important to decide whether the costs are just capital costs, whole life costs (construction and operating costs) or whether any added value (i.e. cost offsets) is included for other benefits such as water resource reduction, water quality treatment, air quality or heat island mitigation. Then there is the need to purchase land or easements if there is a need to build on land not owned by those building the SuDS units. There is growing emphasis on valuing natural capital and for some SuDS there are considerable additional benefits provided, though some benefits are more difficult to value than others. For this project cost of SuDS can be considered to be the capital value of whole life cost of retrofit SuDS. The uncertainty range of costs is probably broader than trying to differentiate between whole life costs and capital costs. Both land costs and added value is ignored, as this depends on the value attributed to benefits such as air quality. All SuDS unit costs vary greatly due to a range of issues. For example, groundwater protection may require liners to be used, or high voids cellular storage may be chosen over the use of stone media. Rainwater tanks designed for surface water storage control as opposed to conserving water for non-portable use can require tanks of twice the size.

A further complication is that SuDS are often designed to manage rainfall runoff in a series of units, so that impermeable areas are served by more than one SuDS element. This means that the whole site cost has to be assessed in terms of the whole drainage system design and cannot be broken down in terms of the constituent elements.

There are the additional constraints of existing services in constructing retrofit SuDS. Gas and water are laid at relatively shallow depths, and these, together with existing sewers and other infrastructure, often impose considerable constraints on the design and construction of SuDS elements.

In addition to the cost of constructing and managing SuDS, there is the cost of their design. Where local retrofit SuDS schemes are individually designed, the added costs of the design as well as difficulties with access to the site may significantly increase the cost of the SuDS units.

Sources of data

Data on cost of SuDS has been of interest for many years and has proven to be very difficult to ascertain. As new development has been the predominant source of data, there is very little evidence for retrofit SuDS construction. Even for new developments SuDS construction costs have been difficult to obtain, because costs are often absorbed within landscaping costs and not provided separately.

Sources of information include:

- The Defra report produced by WSP with support from HR Wallingford, EPG and WRc, "Final surface water drainage report" (2013). This project was aimed at producing a cost comparison and justification of the benefits of using SuDS for new developments.

- The climate change report "Climate change – is the UK preparing for flooding and water scarcity?" by the Adaptation Sub-committee (2012) which included an assessment of costs effectiveness of sustainable drainage schemes.

- A small development at Lamb Drove, Cambridge which incorporated a number of different SuDS was monitored for cost and its hydraulic and water quality performance. A Defra report (Defra and Environment Agency, 2013) was produced summarising this information.

- A CIRIA report "Overview of SuDS performance" (2009) for Defra and the Environment Agency was produced by a consortium led by HR Wallingford. In it there were estimates made of the global costs of SuDS.

- HR Wallingford led an UKWIR / WERF joint USA / UK project on SuDS "Post project monitoring of BMPs/SuDS to determine performance and whole life costs" (2005) which resulted in the first full production of a cost model for SuDS.

- Defra also commissioned five individual pilot studies (2010) to assess their drainage costs comparing the use of SuDS with traditional drainage schemes.

- Defra and the Environment Agency produced a paper on the Thames Tideway "An assessment of evidence on Sustainable Drainage Systems and the Thames Tideway Standards" (2013) which included some SuDS costing values for producing an equivalent performance for protecting the Thames from spills greater than 4 times a year.

- Thames Water, as part of its studies into the Thames Tunnel, commissioned a SuDS analysis by Sheffield University "London Tideway Tunnels Programme: Thames Tunnel Project Needs Report - Potential source control and SUDS applications: Land use and retrofit options" (2010). This made a detailed analysis of the potential to use SuDS on three catchments in London for disconnection of areas and costed them.

- A high profile retrofit SuDS scheme at Llanelli was implemented in 2014-15. An ICE article in the Civil Engineering proceedings (Volume 169 Issue CE1 2015) "Transforming water management in Llanelli" refers to 15.2ha of impermeable area being served by retrofit SuDS. Although the article mentions that it was more cost effective than the use of traditional solutions, it does not provide the total cost of the scheme.

- An assessment of SuDS cost commissioned by the Welsh government was carried out by Environmental Policy Consulting Ltd and produced in 2017. The document "Sustainable Drainage Systems on new developments: Analysis of evidence including costs and benefits of SuDS construction and adoption" was focused at the relative costs between SuDS and traditional drainage systems and the findings were similar to that of the WSP study in that SuDS were universally less expensive to use in new developments except for very small developments. However, information on costs were not provided in a form that allowed a cost per unit area to be clearly gained.

- There are two sources of costing tools which are available for costing new SuDS these are:

    - The www.UKSuDS.com SuDS costing tool which was created from the results of the UKWIR / WERF project;

    - The SuDS for Roads spreadsheet which can be found on scotsnet.org.uk is a very detailed quantities based tool.

As part of the consultation for this project, it was suggested that the cost of area disconnection was of the order of £1M per hectare. This is thought to originate from the Llanelli project, though evidence for this project has not been possible to obtain.

The Defra/EA statement on SuDS costs for addressing CSO spills is based on the assumption that 50% of the impermeable area was effectively disconnected from the combined sewerage by the use of SuDS. The value stated was £13B for a catchment area of 550km^2. On the basis that 40% of the whole catchment area is some form of drained hard surfacing, this amounts to 20% of the impermeable area being disconnected. This approximates to a cost of £1.2M/

impermeable ha. Although a very rough cost estimate, it is in the same ball park as the value stated earlier.

Sheffield University carried out a study using the whole life costing tool produced by HR Wallingford for estimating the cost of SuDS. A cost of £580,000/ha was estimated for 12.5ha of disconnected impermeable area for one of the Thames Water catchments being analysed. The SuDS used was dominated by the use of permeable pavements. It is not known what premium was added to the costs for addressing retrofit conditions. However, it is important to note that the majority of the area was given to the use of permeable pavements and it is believed that no allowance was made for the additional area that could be served by the storage created within permeable pavements. As many permeable pavements are used for parking, but the road way between the parking bays remains impermeable, these areas can be drained to the bays. This approach can also be taken by passing runoff from roofs into the permeable pavement storage. The ratio of impermeable area to permeable pavement area that can be used varies depending on throttle rates and whether the permeable pavement is lined or not, but a ratio of 2 or 2.5:1 can often be assumed. If this was applied to this catchment perhaps 25 ha could be served for the same cost thus reducing the total cost to around £300,000/ha.

The detailed analysis carried out by the WSP study looked at three scales of typical residential developments with detailed design for actual developments that have taken place. Different criteria were used to investigate the range of costs, but in round numbers the total costs for small, medium and large sites respectively were found to be £45K, £100K and £640K. The total catchment area for each site was ~0.2ha for 8 properties, 0.7ha for 32 properties and 4.4ha for 210 properties. The costs per site area and by impermeable area based on 60% impermeable surface range from £140K - £225K / ha for the sites and £240K - £375K / impermeable ha.

The WSP study took into account the provision of basic SuDS, the use of more enhanced SuDS and also soil conditions. Rainwater harvesting was considered in terms of both communal systems as well as individual property units. Detailed consideration was also given to management and operational costs.

It can be seen from these initial figures that there is a considerable range in the broad brush approach to SuDS costs, so it is worth exploring the individual costings of various SuDS elements. The three most likely types of SuDS that could be applied across a heavily urbanised landscape are small bio-retention systems, rainwater harvesting and permeable pavements. The use of swales, basins and ponds are possible, but are more likely to be applied in new residential developments.

Rainwater harvesting unit costs are very cost-sensitive to whether they are retrofit or not. In addition, the layout of roof pitches and whether the systems are designed for stormwater management also influences the cost. However, in round numbers the cost of a retrofit rainwater harvesting unit for stormwater management is likely to be of the order of £5000 and might serve a roof of $50m^2$. This amounts to a capital cost of £1M/ impermeable ha.

Permeable pavements using stone media that approximate to around £100/m^2, but because they have capacities in excess of 100mm of storage, they can serve adjacent areas of between one and two times the area of the pavement. This effectively means that the unit cost of permeable pavements (not including land costs or details such as linings), is of the order of £400,000/ha. The use of high voids plastic cellular storage systems is less accepted by many organisations for adoption, but cost per unit volume reduces significantly where these units can be used.

Infiltration systems are very much cheaper than most other forms of SuDS, but their use is often constrained by the existing built environment. An assumption of disconnection based on the general use of infiltration is not considered to be appropriate.

Other SuDS components, such as swales and basins, can be applied in certain urban areas where parks and other green space are available. These units are considerably less expensive where they can be used. Green roofs have benefits for reducing CSO spills, but in most cases they have limited benefits in reducing flood risk. They have significant benefits associated with enhancing the environment. They can be widely applied across a city and in some cases used in conjunction with rainwater harvesting. The Llanelli system used a significant number of small bioswale units to capture road runoff. Although the component elements of bioswales are not costly, because they are small, their unit costs for disconnecting area is quite high.

Conclusions

For the purpose of this exercise in exploring costs for disconnecting impermeable surfaces, it is considered that the simple assumption of using a 2:1 split between permeable pavements and rainwater harvesting without reflecting any additional benefits (such as water saving) associated with their use represents a conservative approximation of disconnection costs. The assumption of 2:1, although relatively arbitrary, does approximately reflect the ratio of paved area to roof area in built up environments. This means that a cost of the order of £500K/ha is probably a reasonable estimate for use for this project. This cost would escalate if ambitious targets of area disconnection are set, as some areas will be more difficult to remove than others.

This estimate is approximately twice that of the detailed WSP study, but this was an assessment for new developments and costs of the permeable pavements were off-set for the provision of the road and the associated drainage system. However, the cost estimate is very much in line with the detailed assessment carried out by Sheffield University for Thames Water in 2010, though it is unclear what premium was made for retrofitting SuDS.

It is suggested that £500,000/ impermeable ha would be a reasonable assumption for widescale application of an intervention policy of disconnection of contributing area for sites where solutions are relatively easy to implement, and this might rise to £1M/ impermeable ha if a large proportion of impermeable surfaces were to be disconnected.

Appendix 9 - Pilot catchments - Selection method

21st Century Drainage - Capacity Management

Method for selecting test catchments

As part of the above project, we are looking for suitably representative foul/combined sewerage systems from across England, Wales, Scotland and Northern Ireland that we can use to test the potential metrics and associated methods for assessing system capacity.

Testing will be carried out on 3 test catchments with well verified hydraulic models of the sewerage system, but we are looking for around 6 to 8 models that meet our requirements, so that we have some options should difficulties arise with obtaining all of the information/data needed.

The models need to meet the criteria listed below.

1. The sewerage system should include foul, partially-separate and/or combined sewers and can be a mix of all three. We are not looking for foul only systems, although parts of the sewerage system can be foul only. Models with separate surface water network elements in them can be provided, but the separate surface water sewers that do not drain into the combined system will be removed or ignored in the network analysis.

2. The sewerage systems should include a number of CSOs. A range of CSO sizes and hydraulic characteristics would be useful.

3. The sewerage systems should represent typical performance/capacity issues, such as:

    a. CSOs with a range of spill characteristics including operating with reverse flow from downstream; or

    b. Foul systems with a rainfall-runoff response and evidence of infiltration during wet periods.

4. The sewerage system receives flows from a range of land use types (typically urban, suburban, industrial, commercial).

5. The modelling software used must be InfoWorks CS or ICM.

6. The model should preferably be a detailed, “all nodes” model.

7. The model must be well verified for both dry weather and rainfall events.

8. All data associated with the verification process (rainfall files, depth and flow hydrographs etc.) is available should we require it.

9. Subcatchments must be geospatially defined with a GIS-based area take-off method.

10. Roof and paved areas for each subcatchment must have been determined using a suitable impermeable area take-off method and these need to be represented in the model separately.

11. All data associated with the area take-off process (such as OS MasterMap) is available for use and access/permission to use this data is provided.

12. The DWF component of the modelled flows has been represented using population, trade flows and infiltration flows, specified for each subcatchment.

Selection will be based primarily on the above, with additional considerations also being:

a) Manageable run times (we will want run times to be as short as possible).

b) If the model is large, it is possible to divide the model into hydraulically independent systems for use in this project.

c) The catchment has the potential for significant new development in the future (we would ideally like one of the three test catchments to fall into this category).

d) If the model has been used to develop a DAP, that the DAP reports are available should we require them.

A questionnaire is provided separately that, once complete, will enable us to check whether a the proposed catchment meets our requirements and will also allow us to compare the potential benefits of different catchments.

Appendix 10 - Pilot catchments - Questionnaire

21st Century Drainage - Capacity Management

Test catchment submission questionnaire

If you believe that you have a sewerage system model that meets our requirements, please complete the following details as fully as possible and send it by email to Helen Udale-Clarke at HR Wallingford - h.udale-clarke@hrwallingford.com. You can also contact Helen if you have any queries.

We will review all of the forms submitted and then ask for around 6 to 8 models to be sent to us for more detailed review. **Do not send any models or data until asked to do so.**

Please note that the model must be available in InfoWorks CS or ICM.

Contact details

Contact name (for future correspondence)	
Contact email	
Contact phone number	

General information

Name of catchment	
Location	
Water Company	

Why is this model a good example to use for this study?

When was the model built and verified?	

Details of the model

Number of nodes	
Is the model an “all nodes” model?	Y/N
Does the model include any dual manholes?	Y/N

Total number of subcatchments	
Total modelled catchment area (ha)	

Number of foul only subcatchments	
Total area of foul only subcatchments (ha)	
Number of foul only sewers/links	

Number of combined subcatchments	
Total area of combined subcatchments (ha)	
Number of combined sewers/links	

Number of partially separate subcatchments	
Total area of partially separate subcatchments (ha)	
Number of partially-separate sewers/links	

Number of CSOs	
Number of hydraulically independent groups of CSOs	
Number of hydraulically independent groups of CSOs with the potential for reverse flows during storm conditions	

Total modelled population	
Total modelled trade flows (m^3/day)	
Total modelled base flow infiltration (m^3/day)	
Has variable infiltration been modelled?	Y/N

Runoff models used	

Model build

How were the subcatchments defined? *(e.g Thyssen polygons, area take off from OS mapping)*	
Are connected paved, roof and pervious areas represented separately?	Y/N
How were paved roof and pervious areas estimated? *(e.g. area take off from OS mapping)*	
How was the connected population estimated? *(e.g. census, address point data x occupancy rate, flow survey)*	
How were trade flows estimated? *(e.g. consented flows, flow survey)*	
Is OS MasterMap data available for use in this study?	Y/N

Model verification

When was the flow survey carried out?	Start date: End date:
How good was the flow survey data?	Good / Moderate / Poor
How good is the DWF verification?	Good / Moderate / Poor
Number of rainfall events successfully used for storm verification	
How good is the storm verification?	Good / Moderate / Poor

Is the digital flow survey and rainfall data available?	Y/N

System performance

Does the sewerage system suffer from frequent flooding?	Y/N
Does the sewerage system suffer from frequent CSO spills?	Y/N
Does the sewerage system suffer from infiltration?	Y/N

Details of the above and any relevant additional information can be provided in the box below.

Modelling future pressures

Has the model been used for assessing future system performance?	Y/N
If yes, is there documentation explaining what future pressures were applied and how?	Y/N
Was climate change accounted for in the assessment of future system performance?	Y/N
Was urban creep accounted for in the assessment of future system performance?	Y/N
Was infill development accounted for in the assessment of future system performance?	Y/N
Was “strategic” new development accounted for in the assessment of future system performance?	Y/N

Modelling interventions

Has the model been used to assess interventions to improve system performance?	Y/N

If so, what types of interventions were modelled?	

Are there any other characteristics of the catchment worth highlighting? *For example:*

- *Are the sewers generally steep or flat?*
- *Does the sewerage system have boundary conditions?*
- *Does the catchment include highly urbanised areas, industrial or commercial areas, mostly suburban residential areas, etc?*

Please provide any additional information in the box below.

Thank you. This is the end of the questionnaire

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Appendix 11 - Pilot catchments - Model descriptions

The following tables detail the networks provided for each pilot catchment. A description of each network and the differences between the networks has been provided.

Table 32 Description of networks provided for Catchment A

Networks provided	Description of networks
Verified model	• As-verified design state • Verified for 2012 flow survey

Existing system - 2013	• Baseline for 2013
	• As 'verified model' with:
	  ○ abandonment of a number of CSOs;
	  ○ implementation of a scheme;
	  ○ silt levels set as identified by a 2013 CCTV survey (varies from 0-67% of pipe height), and
	  ○ blockages included as identified by a 2013 CCTV survey .
	• 53 of 3742 pipes (1.4%) have silt level greater than 10% of pipe height
	• No change to roughness values. They vary from Ks = 0.15 – 30mm Colebrook-White. 31 of 3742 (0.8%) have (either top or bottom) roughness ≥ 15mm.
	• There are 15 orifices representing blockages.

2030 future scenario model	• Time horizon 2030
	• As 'existing system – 2013' model with:
	  ○ observed changes to residential development since 2013,
	  ○ an allowance for strategic development (see Note 1 below)
	  ○ no allowance for urban creep

Networks provided	Description of networks
2040 future scenario model	• Time horizon 2040 • As '2030 future scenario model' with: o A population uplift between 2030 and 2040 (see Note 2).

Note 1:

The 2030 time horizon model was updated with any observed changes to residential development (and population) since the 2013 model, and also with all proposed development approved by the planning service.

As well as using planning applications and the Area Plan, walk over surveys were carried out, and if any of the identified developments had no construction being carried out the development was classed as "proposed", and was applied to the model as follows:

- If the number of properties was not stated in the planning application, it was assumed 25 houses/ha and 3 people per house.
- Areas for proposed development were added to the model in line with population projections.

A percentage annual population uplift was calculated from census data and was applied to the 2015 existing modelled residential population to calculate the projected population in 2030. This was compared against adding all of the strategic development to the 2015 population. School populations were added to both estimates and the higher figure from the second estimate was taken forward and distributed across the areas which were zoned for prospective development.

Similarly for the 2040 time horizon model, the projected population was calculated from the percentage annual population uplift. The additional population since 2030 was distributed across the new development catchments on a pro-rata basis. This can be considered as growth as opposed to strategic development.

Note 2:

Growth (population increase) has been applied for the 2040 time horizon model. The projected population was calculated from the percentage annual population uplift (calculated from census data) using 2015 as the base year. The 2030 time horizon model was used as the starting point and additional population since 2030 was distributed across the new development subcatchment on a pro-rata basis.

Table 33 Description of networks provided for Catchment B

Networks provided	Description of networks
Verified model	• As-verified design state • Verified for 2013 flow survey

Existing system - 2013	• As 'verified model' with:
	  o all silt removed from pipes, and
	  o implementation of new pipes/nodes (assumed to be a new scheme since verification).
	• No change to roughness values. They vary from Ks = 1.5 – 20mm Colebrook-White. 1 of 1959 (0.05%) have (either top or bottom) roughness ≥ 15mm.

Current scenario	• As the 'existing system - 2013' model with:
	  o uplift for present day conditions, 2014;
	  o includes the 'planned' schemes for 'now'. i.e. committed sewerage schemes and quick-win solutions (including capital schemes and identified SuDS opportunities), and
	  o increased base flow for some subcatchments

Short term future scenario	• As the 'current scenario' with:
	  o uplift for 5 years, approximately 2020;
	  o committed sewerage schemes where there is a level of confidence in a scheme going ahead within the timeframe, and
	  o proposed catchment developments confirmed within this planning period (see Note 1 below)
	  o no allowance for urban creep

Long term future scenario	• As the 'short term future scenario' with:
	  o uplift for 25 years, approximately 2040;
	  o committed sewerage schemes where there is a level of confidence in a scheme going ahead within the timeframe, and

Networks provided	Description of networks
	○ catchment developments that have not been allocated to the medium term model are included (see Note 2 below).
Existing system - 2016	• The most up to date 'cleaned' model from the 2013 verification • As the 'existing system – 2013' model with: ○ some minor updates from CCTV applied

Note 1:

All confirmed or proposed development sites which are in Local Plans or are known by the water company were included within the model.

The short term scenario includes development sites where they are known by the sewage undertaker's developer services through growth data from council, local plan for the area, and 'committed to' schemes. The development projection in number of units for these sites is based on the projected build rates.

The short term growth was added to the model at specific nodes. New developments were added to the model based on the projected population of the development and as a single subcatchment representing the development site. A population multiplier of 2.5 was used per dwelling and the population checked against any projected growth totals. It was assumed that there will not be any additional impermeable area loading on the foul/combined system, so the flow components are domestic only.

Note 2:

The long term scenario includes the all development sites within the short term scenario plus all of the other Local Development Plan allocations. The long term scenario is more strategic and includes longer term strategies outside of the current local plan information.

The long-term growth figures (number of people and number of properties) are added to all nodes in the model as a general increase.

Note 3:

Climate change was included in the analysis for the long-term scenario. An uplift for climate change has been applied as a multiplying factor within the summer and winter design rainfall generated for the catchment. An uplift of 20% was used.

Table 34 Description of networks provided for Catchment C

Networks provided	Description of networks
Verified model	• As-verified design state • Verified for 2014 flow survey
Existing system - 2014	• As 'verified model' with: ○ pumps at design rates; ○ blocked screens are cleaned etc. , and ○ silt is reduced to 10% of pipe diameter where it is greater than this. 149 of 5320 (2.8%) pipes have a sediment depth > 0mm. • No change to roughness values. They vary from Ks = 0.03 - 60 mm Colebrook-White. 48 of 5320 (0.9%) have (either top or bottom) roughness ≥ 15mm.
2026 future scenario model (future developments)	• As 'cleaned' model from the 2014 flow survey with: ○ an allowance for new developments applied (see Note 1 below).
2026 future scenario model (future developments and urban creep)	• As 'cleaned' model from the 2014 flow survey with: ○ an allowance for new developments applied (see Note 1 below) ○ an allowance for urban creep (road and roof impermeable areas increased by 4% in residential developments and 1% in commercial areas, and decreasing the permeable area accordingly. Changes have been made to combined and storm subcatchments).

Note 1:

The Local Development Plan (LDP) was used to determine future developments. The sewerage undertaker examined all of the sites identified within the LDP and decided which committed and proposed development sites would be included in the future model based on their own specifications.

Five committed development sites and three proposed development sites were included in the future model.

The following were applied in the model to the new developments:

- The daily contribution to the foul network has been increased from the existing consumption rate of 165 l/hd/day to 175 l/hd/day.
- The population for residential areas has been determined from the number of proposed units in the LDP and a multiplier of 2.4 people per household.
- The future commercial sites have been modelled using a factor of 20 m^3/ha/day.
- An allowance for infiltration has been made in the future development areas which equates to 40% of population or trade derived flows for each subcatchment.

Note 2:

An uplift for climate change has been applied as a multiplying factor within the summer and winter design rainfall generated for the catchment. An uplift of 8% was used.

Table 35 Description of networks provided for Catchment D

Networks provided	Description of networks
Verified model	• As-verified design state • Verified for 2013 flow survey
Existing system - 2013	• As 'verified model' with: o a number of operational issues (blockages, restrictions etc.) removed. o No change to sediment depth in pipes (varies from 0-33% of pipe height) • 21 of 2863 pipes (0.7%) have silt level greater than 10% of pipe height • No change to roughness values. They vary from Ks = 0.1 – 15 mm Colebrook-White. 4 of 2863 (0.1%) have (either top or bottom) roughness ≥ 15mm.
2025 future scenario model (with creep)	• As 'existing system' model with: o average water consumption rates reduced by 8.33 l/hd/day o an allowance for urban creep applied (see details in Note 1).
2025 future scenario model	• As 'existing system' model with:

Networks provided	Description of networks
(with new developments)	○ average water consumption rates reduced by 8.33 l/hd/day ○ an allowance for new developments applied.
2025 future scenario model (with new developments and creep)	• As 'existing system' model with: ○ average water consumption rates reduced by 8.33 l/hd/day; ○ allowance for urban creep applied (see details in Note 1) ○ allowance for new developments applied (see Note 2 below).
Existing system with low velocities	• Model used to review the velocity performance of the network • As 'existing system' model with: ○ all silt removed from model and roughnesses updated to clean pipe (i.e. bottom roughness changed to 3 mm Colebrook-White), and ○ baseflow parameters reduced to allow shallower baseflow.

Note 1:

The future scenario model was updated for creep following the sewage undertaker's specification. Of the four different methods for estimating the amount of urban creep in the UKWIR document method one was selected (regression tree approach). This was because it could be applied to the model with relative ease and the approach has been produced by statistical analysis and is shown to fit to all the UKWIR sample catchments to an acceptable degree. Therefore determining which of the UKWIR sample catchments most relates to Catchment D was not required as it would have been for one of the other methods.

Using the regression tree approach, urban creep was calculated for each modelled contributing area using the contributing area for the catchment size and the seed count for the number of properties within each contributing area.

The calculated amount of urban creep per year was then factored up based upon the number of years between model verification and the design horizon. The value calculated for urban creep for each subcatchment is the overall total value. Some of this area may not contribute flows to the modelled network and discharge elsewhere (e.g. un-modelled surface water system). Therefore, the amount of urban creep finally applied to the future model was adjusted based upon system type. The following adjustments were used:

- For combined drainage areas, the whole of the calculated value was applied.

- For separately drained areas, 50% of the calculated value was applied to the foul system and 50% of the calculated value was applied to the surface water system.
- In partially separate areas, 50% of the calculated creep area was applied to the combined subcatchments and 50% was applied to the storm subcatchments.
- For new contributing areas added into the model for areas of future development, it is generally unknown when this development will occur and therefore a nominal 10% of the calculated value was applied.

Note 2:

Proposed development data was obtained from the Unitary Development Plan (UDP) and applied to the model. In total 36 new developments were added to the model.

The following assumptions were used when modelling the new developments:

- If no surface water discharge to a public sewer network is likely (i.e. soakaway/ watercourse) or development is in a separately drained area, it was assumed that there would be no contributing impermeable area to the foul network.
- Runoff contribution for developments considered to discharge to the combined public sewer system was applied as a percentage of the total area. This contribution was assigned to a dummy storage node with flows throttled to the greater of 10% of the runoff (2.78Ai with i=50 mm/hr) or 7 l/s.
- An address point multiplier of 3 people per property was assumed, to calculate populations in new developments.
- DWF allowance for new employment sites assumed to be 150 l/day per 100 m^2 warehouse floor space, 300 l/day and 550 l/day per 100 m^2 commercial and manufacturing floor space respectively.

The AMP5 water consumption rates identified that the average consumption rate would reduce by 8.38 l/hd/day between the verification period and the design horizon in 2025. Therefore, the consumption figures were reduced by this figure.

Note 3:

No uplift for climate change has been made in the future scenarios.

Note 4:

No uplift for climate change has been made in the future scenarios. Climate change is to be assessed by the sewerage undertaker in AMP6.