Storm Overflow Evidence Project

Final Report

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November 2021

Revision	Description	Author	Quality Check
001	Draft	EJG	CJD
002	Final	EJG	CJD
003	Final with updated Executive Summary	EJG	CJD

Sign-off Sheet

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Executive Summary

Background

Storm overflows[1] are used in combined sewer systems[2] to spill a mix of wastewater and rainwater into rivers and the sea. Their purpose is to provide a ‘release valve’ that reduces the risk of overloaded sewers causing flooding during rainfall, especially in people’s homes. Storm overflow spills are normally dilute compared to wastewater, with a very high rainwater content, and they may also be screened to remove litter. However, they are also untreated, introducing contaminants and pathogens directly into the water environment.

Storm overflows are a legacy of sewer design and construction practices until the second half of the twentieth century. They were a pragmatic and affordable means of draining towns and cities. Their use is consistent with practice throughout Europe, which has some 650,000 overflows across the continent[3]. There are 15,000 storm overflows in England and 13,350 discharge to inland rivers.

Overflows are designed to operate infrequently and as the result of heavy rainfall and this is the basis of their environmental permits. However, in practice spills can also be caused by blockages, operational issues and ‘infiltration’, where pipe joints and cracks in sewers allow groundwater to enter taking up capacity. More recently, as population growth and the paving over of green space have continued and rainfall patterns have changed, it has become increasingly difficult for the capacity of sewers to keep pace. Many storm overflows therefore operate more frequently than is acceptable to the public and other stakeholders in the community even though they are a relatively small contributor to water quality standard failures overall.

A government-led Storm Overflow Taskforce has been established to tackle the issue in England. Their work includes representatives of the water industry, regulators (Environment Agency and Ofwat), environmental groups, and CCW representing customers. Their remit is to explore policy options that reduce the occurrence of storm overflow spills and any harm that is caused.

The Taskforce has commissioned this report authored by Stantec, known as the Storm Overflow Evidence Project (SOEP), to provide a more detailed understanding of the

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[1] Storm overflows is a general term and includes combined sewer overflows (CSOs) and storm tank discharges at wastewater treatment facilities. They are sometimes referred to as intermittent discharges.

[2] Combined sewer systems carry both wastewater (sewage) from homes and businesses, and stormwater generated by rainfall falling on the built-up area. They also carry infiltration from groundwater.

[3] https://www.eureau.org/resources/position-papers/4955-position-paper-on-overflows-from-collecting-systems-1/file

public’s priorities on the issue, and the costs and benefits of different policies and scenarios that respond to those priorities.

Policies and scenarios include limiting the annual average number of spills (the spill frequency) of 13,350 storm overflows discharging into inland rivers in England to 40, 20, 10, 5 and 0 , as well as differentiating between universally applied national limits and more targeted ‘sensitive catchment’ ones. For each of the above policies, three delivery scenarios are considered; storage, storage with a low uptake of sustainable drainage (SuDS) and storage with a high uptake of SuDS. The frequency-based approach is contrasted via case studies with approaches based on configuring improvements to protect river health and addressing the special case of infiltration in sewers.

This is a national assessment to understand the typical investment required to meet a range of policy outcomes. A modelling approach has been used to estimate the scale of solutions. To evaluate the water quality benefit a national scale water quality assessment was undertaken and compared with available national data. The cost of solutions (implemented over a 25-year period), bill impacts (annual) and benefits in this executive summary and report should be considered indicative reflecting the available data and, the technical approach and assumptions necessary for a national assessment.

The costs, bill impacts and carbon described in the executive summary apart from those for full separation relate to the options for storage and storage with SuDS (assuming significant uptake). The different policy options provide a significant range in the costs for different delivery scenarios, these include a low estimate for the lowest cost scenario, and a high estimate for the highest cost scenario. The costs, bill impacts and carbon included in this summary have been increased by 30% to account for overflows with permits that could not be included in the analysis.

It is the first assessment of its kind ever conducted.

Key findings

Costs and bill impacts

- The complete separation of wastewater and stormwater systems (eliminating storm overflows) would cost between £350 billion and £600 billion. This could increase household bills between £569 and £999 per year and is also highly disruptive and complex to deliver nationwide.
- The costs of retaining storm overflows discharging to inland waters but limiting their operation vary widely depending on how frequently they operate. We have modelled nationally applied policies and scenarios costing between £5 billion (40 spills average) - £280 billion (0 spills average). The equivalent benefits are £2 billion and £39 billion. The impact on annual household bills could be between £9

and £495 respectively. The ranges depend on how policies are delivered and reflect uncertainties.

- A refinement mixes the requirement for spill control depending on river type. A general limit of 40 spills on average per year, reduced to 10 spills in sensitive catchments would cost between £18 billion and £110 billion. The impact on annual household bills could be between £30 and £208 per year. This 40/10 spill policy is similar in cost and bill impact to the policy of 20 spills on average per year.
- A policy focused on achieving 10 spills per year on average in sensitive rivers (such as chalk streams) would cost between £16bn and £82bn. The impact on annual household bills could be between £26 and £150 respectively. A policy focused on achieving 10 spills per year on average in rivers where storm overflows are observed to be the reason for not achieving good ecological status would cost between £13bn and £59bn. The impact on annual household bills could be between £22 and £108 respectively.
- A policy focused on improving rivers known to be used for bathing to achieve an average spill frequency of five per year would cost between £8bn and £26bn. The impact on annual household bills could be between £13 and £48 respectively. However, this policy ignores the costs of dealing with other sources of microbial and other contamination, which may be more significant and difficult to deliver.

Environment

- Over a third of the public surveyed in May 2021 rank pollution related to sewage as a ‘top three’ environmental issue. The overwhelming majority (70%) would like remedial action focused on river ecology (including its plants and animals) rather than its aesthetic (13%) or to support safe swimming (8%).
- If we do nothing new on storm overflows, we estimate that up to 83 additional water bodies could fail to achieve good ecological status by 2050 because of their impact; an increase of 13% from today’s baseline. This estimate could increase further for the overflows with permits not analysed. This deterioration is due to reduced river flows, population growth, urban creep and changes in rainfall due to climate change. For the same reasons, rivers currently used for recreation will see around a quarter of their length become unsuitable for swimming.
- All policies and scenarios assessed in this report carry a significant cost in carbon. Achieving a national average of 10 spills per year would emit five times the amount of carbon involved in constructing the Thames Tideway project – a

£5bn "super sewer" and largest ever project undertaken by the UK water industry. Getting to zero spills would emit 33 times the amount of Thames Tideway.

Discussion

Key findings show that nationally, wastewater network upgrades will tend to be cheaper without the addition of SuDS schemes. Even with the highest ambition for SuDS (for example, retrofitting blue-green infrastructure in every street), this is unlikely to reduce spills to 40 per year or fewer on its own. However, SuDS will still be a much more favourable and cheaper solution in specific locations; bring important additional benefits (e.g. amenity, health and reduced flooding) that mean their inclusion can significantly improve the overall economic case for investment; and could see costs reduce significantly if a major deployment programme incentivised the supply chain to invest, innovate and achieve better economies of scale. Another source of savings is from co-delivery with aligned infrastructure improvements.

This research has found that taking into account social, public health and ecological benefits, none of the policies and scenarios examined are cost-beneficial when assessed nationally. This emphasises that additional evaluations at local scales will be important to get a more accurate view of long-term costs and benefits. However, this does not preclude cost beneficial solutions that may be viable locally (and also reflects uncertainty about how the public values reduced spills as opposed to environmental or other outcomes). Investment in spill-based approaches should therefore also take into account the opportunity cost and equivalent benefits that would derive from targeting alternative environmental drivers.

Recommendations

As this is the first comprehensive piece of research of its kind, there are still many unknowns and uncertainties in deriving these numbers. The report identifies a number of recommendations for further consideration and analysis; in particular on the need for common approaches to valuing benefits, for improving understanding of water company customers' willingness to pay for reductions in storm overflow harm, and the effect of operational aspects on overflow performance. Further analysis at both a local and national level could identify more efficient solutions and a greater understanding of benefits.

Glossary

B£ST	A tool published by CIRIA for estimating the benefits arising from SuDS and other green infrastructure
Drainage and wastewater management plan (DWMP)	A planning process undertaken by water companies in partnership with others to establish the long-term needs for investment in sewers and wastewater treatment. The Environment Bill 2021 makes provision for DWMP to become statutory and equivalent in status to Water Resource Management Plans.
Equivalent Ecological Status	Developed for this research to describe the harm to river health caused by storm overflows in water bodies.
Event Duration Monitor (EDM)	A device installed at storm overflows by water companies to report the frequency and duration of their operation. Water companies report data to the Environment Agency.
Harm	This research is concerned with reducing the harm caused by storm overflows to inland rivers. This includes harm to river health and public health and a social response.
Policy	In this research, it is the application of an average annual spill frequency limit. This is either 40, 20, 10, 5 or 0.
Rainwater	For the purposes of this research, it is rainfall-runoff generated from impermeable surfaces entering combined sewers. It is synonymous with stormwater.
Reasons for not achieving good (RNAG)	Where water bodies fail to achieve Good Ecological Status the Environment Agency attribute a reason – the RNAG. It is relevant in this research where the reason is storm overflows.
Scenario	The engineering approach taken to achieving policy goals. In this research, it is either wastewater network storage alone or in addition to different levels of SuDS.
Sewer Overflow Assessment Framework (SOAF)	An approach to prioritise improvements in frequently operating storm overflows based on reduced harm to river health.

SOEP	Storm overflow evidence project
Storm overflow	Where a combined sewer discharges a dilute but untreated mix of wastewater and rainwater into a water body during rainfall. The term is synonymous, for the purposes of this research, with the terms combined sewer overflow, intermittent discharge and storm tank overflow.
Urban Pollution Management (UPM)	A planning approach developed first in the 1990s to match investment in storm overflows with river needs. Its principles underpin current historical investment priorities to reduce harm from storm overflows, including SOAF.
Volume Weighted Spill Frequency	A single value characterising the frequency of all storm overflows discharging to a water body. It is used in this research to calculate harm caused by storm overflows to river health, public health, and the social impact.
Water body catchment	In this research, it is an area of land from which all surface run-off flows through a series of streams and rivers to a particular point in the watercourse such as a river confluence.
Willingness to pay (WTP)	A term used by water companies to understand the preferences of their customers to pay for different improvements in water services. It is used to evaluate the benefits of improved service – for example, a reduction in river pollution.

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1.0 Introduction

Water UK commissioned Stantec to complete the Storm Overflow Evidence Project (SOEP), referenced here as ‘this research’. The project was undertaken in the period January to October 2021, with the main assessment completed between January and August, with subsequent refinement, review and report writing through to October.

A project steering group was chaired by Water UK (Stuart Colville) and included representation from the Environment Agency (Keith Davies), Ofwat (Nicholas Adjei, Ian Pemberton and Kirelle McManus), Defra (Simon Scanlan), the Intermittents Task and Finish Group (James Maclean), the Drainage and Wastewater Management Plan (DWMP) Steering Group (Yvette de Garis) and Blueprint for Water[4] (Amina Aboobakar). John Spence was the programme manager for Water UK. Further to the work of the project steering group, CIWEM provided feedback and input during the drafting of the report. The authors acknowledge the guidance and challenge of Prof David Balmforth and Dr Paul Metcalfe during the project and the writing of the report.

This research provides evidence to the Storm Overflow Taskforce[5], a joint industry-government group established to tackle river pollution from storm overflows.

This research presents a rapidly delivered, first of kind, national scale, and strategic level analysis, and because of this, certain assumptions and limitations were necessary. As such, the of cost of solutions (implemented over a 25-year period), bill impacts (annual) and benefits in this report and executive summary should be considered indicative. The scope and context for this research should be noted when quoting conclusions on capital investment needs and benefits. This research is not a substitute for locally specific wastewater network and catchment water quality planning processes being undertaken by water companies as part of Drainage and Wastewater Management Plans (DWMP) and other investment planning processes.

1.1 Project Scope

The project scope is to:

1. Quantify the harm storm overflows cause inland rivers[6] in England today and estimate the impact in 2050, taking account of climate and population changes. It is assumed, for the purposes of this research, that storm overflows and sewers are properly maintained and operating in accordance with their environmental permits.

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[4] https://www.wcl.org.uk/blueprintforwater.asp

[5] https://www.gov.uk/government/news/taskforce-sets-goal-to-end-pollution-from-storm-overflows

[6] The Storm Overflow Evidence Project considers the impact of storm overflows on inland rivers only. This excludes the impact on coastal and estuarine water bodies

2. Estimate the costs and benefits of imposing alternative policies to reduce harm from storm overflows, including an estimate of how new investment might affect customers' water bills. The policies explored are limited to the consideration of different annual average spill frequency limits such that could be included within permits once all overflows have event duration monitoring (EDM) installed.
3. Compare the strengths and weaknesses of different engineering approaches to reducing harm from storm overflows, including network storage, separation, treatment and blue-green infrastructure. This research tests the costs and benefits of two approaches only: network storage and blue-green infrastructure or sustainable drainage (SuDS).
4. Undertake surveys of the public to better understand why river pollution caused by storm overflows is causing elevated levels of concern.
5. Use case-studies to illustrate different storm overflow improvement projects.

1.2 Report structure

Section 2 describes the project background and some context about storm overflows.

Section 3 describes the methodology developed and followed to quantify harm and calculate costs, benefits and outcomes of different storm overflow control policies. It establishes the assumptions and uncertainties that should be understood when interpreting results.

Section 4 presents the projects' principal results on the costs, benefits and outcomes of different policies and impacts on water bills. Section 4 forms the basis of a stand-alone slide-pack of analysis highlights.

Section 5 is a discussion of how the evidence could be improved through greater precision, accuracy, and reduction of uncertainties.

Appendix A presents supplementary information on the features of different engineering approaches to reducing the occurrence of storm overflow.

Appendix B contains supplementary data for calculations made to calculate storage volume and impermeable area reductions.

Appendix C presents a summary of survey work undertaken by Stantec's partners Blue Marble into public attitudes towards storm overflows and river quality

Appendix D presents supplementary results to those included in Section 4, addressing policy options suggested by Defra that limit storm overflow improvements to certain river types.

Appendix E presents selected case studies which highlight real-world storm overflow projects and recently implemented or planned solutions.

Appendix F presents uplifted cost values to account for overflows with permits that could not be included in the analysis.

2.0 Context

2.1 What are storm overflows?

Storm overflows are structures in sewer networks or at wastewater treatment works where capacity is limited and a mix of wastewater (from households and industry) and storm water (from rainfall runoff) is released, with little or no treatment, into rivers, estuaries or the ocean. Often these releases are screened to remove obnoxious litter and sometimes stored first so that solid matter settles in tanks and is retained for treatment. In dry weather, all polluting loads from households and industry should be conveyed to treatment, but in wet weather a proportion of this polluting load is released to the environment. The Environment Agency has published an informative video[7] describing the basics. There are 15,000 storm overflows in England discharging to either inland water bodies, estuaries or the coast.

Storm overflows were constructed because single sewers carrying wastewater and storm water (combined sewers) could never affordably be large enough to convey all flows to originally crude sewage outfalls and later treatment plants. A ‘release valve’ was needed to prevent homes and businesses flooding. Storm overflows were originally designed to only operate during times of heavy rainfall without causing significant harm to water bodies.

However, overtime, as new development has occurred upstream, housing densities have increased, impermeable surfaces have been paved over, rainfall patterns may have changed and ingress from groundwater has increased as sewers age, some overflows now operate too frequently causing harm to water bodies and concern from the public. Overflows may also operate because of operational problems such as blockages or equipment failure and because of capacity issues downstream. Furthermore, our sewer system has not been consistently upgraded or managed differently to keep up with these changes in inflows or customer behaviours.

England and the whole United Kingdom have a high prevalence of combined sewers because this approach was standard until the mid-twentieth century and our large urban areas were established in this period. More recent development in new towns and urban extensions have separate foul and surface water sewer systems, although sometimes the separated surface water systems flow into combined sewers. Some sewers are officially classified as combined sewers in sewer records, but many foul sewers

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[7] https://www.youtube.com/watch?v=7Hg12F-0jsM

(notionally carrying only wastewater) also receive rainwater and other inflows and also have storm overflows within networks or at wastewater treatment works inlets. The classification of sewers by type is hence complex and not a reliable indicator of storm overflow risks. This research project addresses all types of storm overflow that have environmental permits, allowing wet weather discharges to rivers.

There are 13,350[8] storm overflows in England, discharging to rivers. Measurements from 9,240[9] storm overflows indicate that in 2020, these overflows operated 342,346 times. Data indicate that for the United Kingdom, 2020 was a wetter than average year compared to the 1981-2010 average[10].

Storm overflows' intended mechanism for operating is through rainfall generated runoff (rainwater), in excess of sewer capacity, entering sewers from roofs, roads and other hard surfaces in towns and cities. This type of storm overflow mechanism is the one addressed in this research in its review of costs and benefits of different policy options for reducing harm. In this research, it is assumed that storm overflows and sewers are properly maintained and operating in accordance with their permits.

The overflows are legal, under environmental permits issued by the Environment Agency and are increasingly monitored[11] with devices which measure the frequency and duration of spills. Permits are only issued where the overflow causes no harm but many permits are historical and the cost of revising them heavily (for example by implementing spill frequency standards) is significant, as this report will show.

However, other mechanisms do also influence the frequency, duration and volume of storm overflow discharges and may sometimes be the dominant cause:

- Incorrect settings at storm overflows or at wastewater treatment works inlets can cause storm overflows to operate more frequently than allowed for in environmental permits issued by the Environment Agency.
- Sewer blockages or mechanical/electrical failures in sewer networks can limit flow being passed forward. This can result in discharges from storm overflow structures during periods of light or no rainfall. A contributing and significant factor behind blockages is customers misusing sewers by flushing away fats, oils, greases, wet wipes and nappies.

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[8] This is an estimate provided by the Environment Agency. In total there are 15,000 storm overflows of which 89% discharge to inland rivers, the remainder discharge to coastal or estuarine waters (10%) or groundwater (<1%).

[9] The subset of storm overflows which are monitored and discharge to inland rivers

[10] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/summaries/uk_monthly_climate_summary_annual_2020.pdf UK average rainfall in 2020 was 1308mm which is 114% of the 1981-2010 average. It was the wettest February on record and all summer months were wetter than average. North West England was especially wet relative to average but some eastern coastal fringes were drier than average.

[11] https://environmentagency.blog.gov.uk/2021/03/31/event-duration-monitoring-lifting-the-lid-on-storm-overflows/

- The presence of groundwater or rainfall induced infiltration in sewers can vary seasonally and in wet winters sewer capacity is sometimes consumed with these flows causing storm overflows to operate more frequently and sometimes for prolonged periods. Infiltration can enter the public sewer through privately owned lateral connections on customers' properties. Sewers can also receive inflows from watercourses and land drainage, which take capacity which would otherwise be available to convey flow generated from storm runoff from paved surfaces. The special case of groundwater infiltration and its effect on storm overflows is discussed in Case Study 3 in Appendix E.

Furthermore, screens at storm overflows can fail to retain solid material, resulting in aesthetic impact on the receiving watercourse.

In this report, the term 'storm overflow' is synonymous with the terms Combined Sewer Overflow (CSO), Storm Tank Overflow and Intermittent Discharge. It is used as a noun to describe the physical structure and the nature of the discharges from it. These discharges (sometimes referred to as 'spills') are characterised here by their volume and frequency. Whilst the pollutants in storm overflow vary by place and through time, this variable has not been accounted for in this research.

2.2 How storm overflows cause harm

Harm caused by storm overflows can be considered in three categories (defined in the project scope), each of which is addressed in this research:

- Harm to river health: where storm overflows prevent the achievement of Good Ecological Status principally because river water chemistry is worsened by intermittently low levels of dissolved oxygen and high levels of ammonia. The Environment Agency estimates that approximately 402 inland river water bodies fail to achieve Good Ecological Status because of intermittent discharges through storm overflows. Storm overflows can introduce other chemical and biological pollutants into water bodies such as microplastics, pharmaceuticals, excessive nutrients, heavy metals and bacteria organisms (see next bullet). They can also pollute with visible litter, rags, and plastics.

- Harm to public health: where storm overflows prevent safe river bathing or other recreational water uses because of high levels of bacteria.

- Social impact: where knowledge and visibility of storm overflows causes public concern about river health, public health, aesthetics and the proper operation of wastewater infrastructure.

Storm overflows which operate infrequently and are designed to capture sewer litter (plastic and rags) and take of account of the assimilative capacity and nature of the receiving water body may cause harm when they operate.

The reduction of harm is the objective of policies considered in the project and, whilst a desirable outcome alone, it can also be assigned a monetary value used to weigh the costs and benefits of different policy choices.

Storm overflows cause harm to rivers, but there are many other causes. Significant pollution sources include:

- Contaminated runoff from agricultural areas (non-urban diffuse pollution)
- Final effluent from the wastewater treatment process
- Contaminated runoff from roads entering rivers through surface water sewers and highway drains (urban diffuse pollution)
- Illegal connections of wastewater into surface water sewers discharging directly to rivers.

2.3 Public opinion about storm overflows

Stantec worked with the market research company Blue Marble to characterise press and public opinion about storm overflows and river quality in general. Outputs from this research are included in full in Appendix C. The survey’s key findings of 2096 adults in May 2021 are:

- Despite a heightened media spotlight in 2020/21, the issue of storm overflows did not ‘break through’ to the public consciousness in quite the same way as an issue like plastic pollution has.
- But when prompted, sewer pollution did have recognition as an issue with 36% of the population putting it in their top three environmental issues affecting the UK and 8% citing it as their most concerning issue.
- Almost two-thirds of the population expect it to be safe to swim in rivers.
- 28% of river users (as defined by those that have in mind a river they know) noted that a river they know sometimes contains visible sewer residues.
- 41% of the population are aware that water companies use storm overflows and these individuals are three times more likely than others (35% vs 11%) to attribute river pollution to water company practices. 58% of those aware of storm overflows are conscious of unpermitted discharges being an issue.
- 70% of the population wants improvements in rivers to ensure healthy ecological habitats. 13% want improvements to river aesthetics and only 8% want improvements to ensure rivers are safe for swimming. This final point possibly

contradicts expectations on it being safe to swim and reflects a possible gap in the expectations of the general public and those passionate about river swimming.

2.4 Reducing harm from storm overflows

Reducing the volume and frequency of storm overflow results in less harm to rivers and reduced societal concerns.

To do this either more collected rainwater and wastewater must be retained in the system and provided with treatment at a wastewater treatment works. Or the quantity of rainwater entering sewers must be reduced, enabling a higher proportion of all flows to receive full treatment. Reducing the volume and frequency of storm overflow to zero eliminates this harm completely, although it does not address other risks (see section 2.2).

A variety of engineering approaches can be used to reduce the volume and frequency of storm overflow discharges or reduce harm in other ways, and these are described fully in Appendix A. In summary, engineering approaches either:

- Separate the combined sewer system into independent foul and surface water systems
- Add capacity to (or mobilise capacity within) combined sewer systems to store, convey and fully treat more
- Manage storm runoff differently, so that it does not all enter the combined sewer, using partly or wholly nature-based solutions such as sustainable drainage systems and/or blue green infrastructure
- Treat discharges from storm overflows *in situ* to a standard where harm is avoided by conventional or nature-based methods

In practice, there will be an optimum mix of approaches appropriate to specific locations and wastewater catchments. Where spills are caused by operational issues in sewers, then solutions are linked to improved asset management by water companies and changing public behaviour, but these issues are out of scope in this research.

The first three approaches are considered in this research, but only the nature-based solution approach (using SuDS) provides opportunities to deliver additional benefits to communities alongside the benefits which reduce harm to rivers.

Policies to control harm from storm overflows vary and can be characterised as:

- Those controlling the performance of storm overflow structures (e.g., specifying the multiple of dry weather flow[12] which should be passed forwards without overflowing)

- Those specifying an outcome[13] in the receiving water body (e.g., achieving water quality standards developed to assure good river or public health). Appendix E describes two case studies where this approach has been adopted recently to establish the improvements necessary in urbanised catchments in northwest England.

- Those specifying the frequency[14] of storm overflow occurrence usually as an annual average but sometimes limited to only bathing seasons. In Appendix D options are tested which consider controlling spill frequency on only certain types of water body.

The scope of this research was limited to considerations of storm overflow spill frequency policies because of the transparency with the public and other stakeholders they provide. Policies using spill frequency were also more straightforward to assess nationally. Policies which introduce spill frequency conditions in permits are only recently possible because of the implementation of EDM monitoring programmes, which will soon cover virtually all storm overflows.

Policies targeting river quality outcomes have not generally maintained a high level of public support because spill frequencies can remain high and social acceptability low even though river health outcomes can be proven through modelling and tested by long term monitoring. Most recent inland storm overflow improvements have taken this approach and it is integral to the current Storm Overflow Assessment Framework (SOAF) programme of investigations and improvements. Case studies 1 and 2 in Appendix E illustrate examples of this type of targeted improvement.

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[12] Such as the Formula A method used to set many historical environmental permits - (1970) Technical Committee on Storm Overflows and the Disposal of Storm Sewage
[13] Using the Urban Pollution Management (UPM) approach which sets an appropriate pattern of storm overflow spills for the nature of the receiving water (www.fwr.org/UPM3/)
[14] Currently used in the UK to protect bathing and shellfishery waters

3.0 Methodology

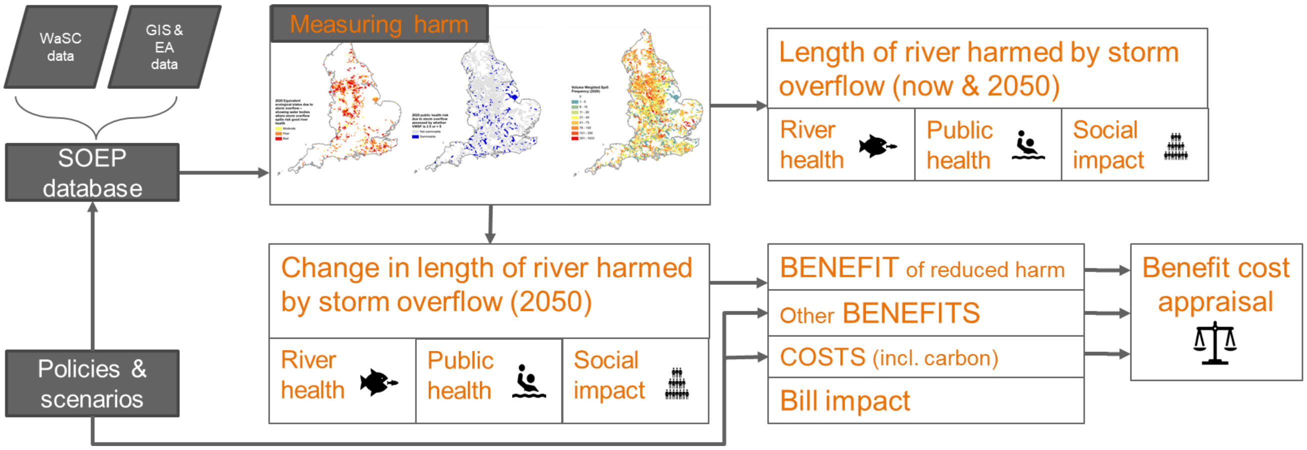
3.1 Introduction

This section describes the approach taken to meet the project's analytical objectives around quantifying harm and testing the costs and benefits of different policies. Results are presented in full in Section 4.

The approach is illustrated in Figure 3-1. Water company data on storm overflows and other information about the river network are combined in the SOEP database. This is processed to model and quantify harm caused by storm overflow in three categories: river health, public health and social impact. Different policies and scenarios are initially defined and tested to calculate changes in harm. Information on costs and benefits is combined to complete a benefit-cost appraisal.

An important point is that these assessments have been made for the whole of England and in the main with existing data only and over a short period. Whilst meeting its ambitious goals as a first of its kind analysis, the approach has many assumptions and a number of limitations, which are summarised in each sub-section. Section 5 contains a number of recommendations on how the project's outputs could be improved.

Figure 3-1 SOEP approach indicating key stages



3.2 Characterising current and future storm overflow discharges

3.2.1 Approach

Water companies build and maintain sewer network hydraulic models used for planning and design purposes. They are calibrated to replicate observed levels and flows throughout sewer networks and can be used to predict the occurrence of sewer flooding and storm overflow spills. Although accurate design and planning tools they are unsuitable for use at a national scale for the questions addressed in this project. Data requirements and simulation times would be too onerous.

This research uses results from simulations with these models to characterise current and future storm overflow discharges. Water companies are currently completing a large sewer network modelling exercise in support of their own long-term planning programme – the Drainage and Wastewater Management Plan (DWMP[15]). Results from the risk assessment phase of DWMP have been used for this research.

For each storm overflow, which has been modelled, water companies have provided the average annual spill volume and frequency[16] for current day populations and rainfall, resulting from simulations with time series rainfall inputs of 5-10 years duration. This research uses these data, in preference to recorded EDM data, because the estimate of spill volume is a necessary input to subsequent calculation of river impact, network storage and controlled impermeable area runoff outputs. These outputs are central to costing and benefits estimation and would not have been calculable from EDM captured spill frequency and duration data alone.

Figure 3-2 shows the location of 6,872 storm overflows modelled by companies which have a current day (2020) spill frequency greater than zero times per year. There are a further 2,376 overflows which are modelled but have no predicted spills in 2020, although some (146) commence spilling in 2050. Water company network hydraulic model results data hence account for 9,248 (in 2020) and 9,394 (in 2050) overflows overall.

The shortfall between 9,248 (9,394) and the 13,350 overflows known to discharge to inland waters is because not all drainage catchments are modelled, not all overflows in drainage catchments are modelled and some data have been omitted by companies because of uncertainties about data quality and reliability.

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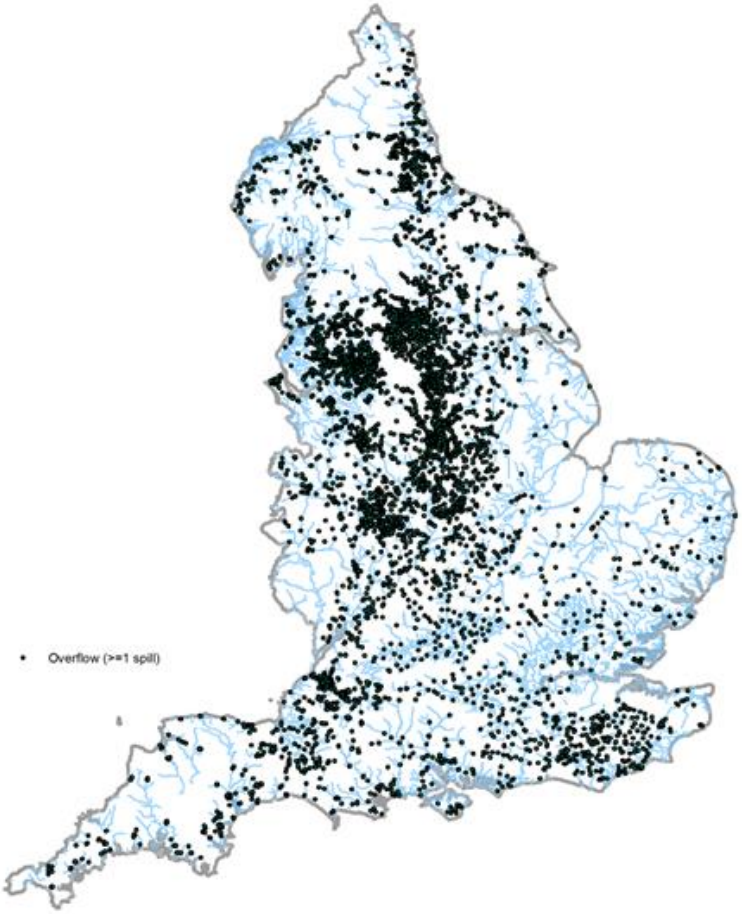
[15] https://www.water.org.uk/policy-topics/managing-sewage-and-drainage/drainage-and-wastewater-management-plans/

[16] One company combined modelled spill volumes with measured spill frequency

The regional pattern of overflows in Figure 3-2 is as to be expected given the historical development of combined sewers but the pattern may also reflect some regional differences in geology, as well as in the extent to which water companies have modelled networks and storm overflows within them.

Figure 3-2 SOEP storm overflows with greater than zero spills in 2020



Water companies have also provided (in most[17] circumstances) equivalent results for 2050 which differ because of different rainfall[18], different populations and water consumption[19], and allowances for 'urban creep'[20].

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[17] Where 2050 predictions were not available then the 2020 pattern was assumed to apply

[18] Historical rainfall time series were perturbed for climate change following an established approach published by UKWIR https://ukwir.org/rainfall-intensity-for-sewer-design-stage-2-0

[19] Water consumption by households is forecast to reduce significantly from c. 140 litres/person/day currently to c. 125 litres/person/day in the 2050s. This reduces the quantity of wastewater which is generated and hence the 'dry weather flow' present in sewers.

[20] The progressive paving over of permeable surfaces, such as gardens, so that they become impermeable and start contributing runoff to sewers

3.2.2 Uncertainties and limitations

The coverage of sewer network hydraulic models is not 100% and some storm overflows are not hydraulically modelled and hence not included in this research. There are 13,350 permitted storm overflows discharging to inland rivers in England and this research represents 9,248 (69% in 2020) and 9,394 (70% in 2050) using data from hydraulic models representing networks draining between 77% and 99% of the sewered population, depending on the water company. The total number of spills per annum for the current day in this research is 251,808, with an average number of spills per overflow of 27. The average number of spills from overflows operating at least once per year is 37. The results from this research therefore exclude the investments (and benefits) associated from improving approximately 30% of storm overflows and it is recommended that results are considered in this light and adjusted by 30% (±10 percentage points) to account for this uncertainty. Adjusted capital cost estimates are included in Appendix F.

Water companies monitor storm overflows using Event Duration Monitors (EDM) and in 2020 reported results[21] to the Environment Agency for 13,102 storm overflows (discharging to all types of receiving water body) of which 9,250 discharge to inland rivers. The total number of spills monitored as discharging to inland rivers in 2020 was 342,346, with an average number of spills per overflow of 37.

The number of modelled overflows in this research (9,248 in 2020) is very similar to the number of inland overflows for which there is EDM monitoring (9,250 in 2020). However, the number of spills represented in this research is 26% lower (251,808 vs 342,346). Note these will not necessarily be the same overflows (modelled and EDM) as some are monitored and not modelled and *vice versa*.

Sewer network hydraulic models have been developed over a long period and differ in terms of their accuracy at predicting the occurrence of storm overflow today. They do not generally represent these causes of storm overflow: highly seasonal groundwater infiltration problems, mechanical/electrical failures and ephemeral sewer blockages. They do represent the original and intended purpose of storm overflow: rainwater runoff from paved surfaces entering combined sewers of finite capacity. They also represent storm overflow structures (orifices, weirs, screens, etc.) and can be reliable at predicting storm overflow volumes, which are important for considering river dilution and impact.

Whilst it is not possible to attribute the exact mix of causes of overflow at each location in this research, the most common cause is rainwater entering sewers of insufficient capacity. This is the mechanism represented in hydraulic network models which, overall, can explain approximately 74% of measured spill incidents. The remaining

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[21] https://environment.data.gov.uk/portalstg/home/item.html?id=045af51b3be545b79b0c219811d3d243

measured overflows are attributable to a combination of other causes (linked to asset health) and unmodelled inflows (e.g., groundwater inundation).

Whilst this research's estimate of storm overflow activity will not be the same as that measured by EDM, it has the advantage of estimating the spill volume. This is necessary to draw conclusions about river dilution and water quality. Its disadvantage is that it does not represent storm overflows operating for a variety of reasons, such as blockages, inflows, mechanical/electrical failures and illegal permit breaches. Whilst they can be significant causes of overflows and harm, they do not result from strategic under capacity issues in sewer networks and treatment systems. This research's approach has been developed to address these strategic needs.

Water company modelling coverage and results of storm overflow operations are incomplete. Not all overflows are modelled and those which are might not be modelled accurately accounting for all mechanisms causing storm overflow. To account for these uncertainties, it is recommended that this research's costs and benefits for the control of spill frequency (not full separation) could be inflated by 30% (± 10 percentage points) because approximately 70% of known overflows are included but it is appreciated that the 'missing' overflows are likely to be less significant in terms of spill volume and frequency. This would not, of course, alter the relative balance of costs and benefits, only the absolute numbers. Inflated capital cost estimates for different polices and scenarios are included in Appendix F.

3.3 Characterising storm overflow harm

3.3.1 Approach

The challenge in making a national assessment of storm overflow impact is considerable. The approach developed for this research is the first of its kind and is tailored to programme and data availability constraints.

Storm overflow harm is considered in three ways: river health, public health, and social impact. Harm is quantified to characterise current and future levels of harm and to test the effectiveness (and hence benefits) of different policy interventions designed to reduce harm.

Underpinning the approach is a map of inland river water body catchments in England. These areas are published by the Environment Agency[22] and defined for Cycle 2 of the implementation of the Water Framework Directive (WFD) as "an area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point in the water course such as a river confluence". The average length of

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[22] Available under Open Government Licence from data.gov.uk WFD River Waterbody Catchments Cycle 2 - data.gov.uk

river water bodies in catchments containing an overflow (regardless of spill frequency) is 14 km. There are 1663 (2020) and 1667 (2050) water bodies in this research's assessment, which receive discharges from storm overflows.

3.3.1.1 River health

The purpose of this assessment is to evaluate the effect storm overflows have on Ecological Status in rivers and to consider how the status changes under different control policies.

Each storm overflow in England is assigned a receiving water body if this is an inland river. Storm overflows to estuarine or coastal waters were excluded from the analysis. Allocation to water body was done from either the grid reference of the storm overflow outfall or on a nearest river basis from the grid reference of the storm overflow (sometimes some distance from the river).

The frequency of storm overflow from each overflow impacting on a water body was combined into a single volume weighted spill frequency (VWSF) value by dividing the sum of the product of annual spill volume and annual spill frequency by the sum of the annual spill volumes. The VWSF is used to characterise the overflow frequency patterns for each water body:

$$VWSF = \frac{\sum(Volume \times Frequency)}{\sum Volume}$$

From estimates of the average and 95 percentile low flow[23] in each water body, the values of other percentile flows were calculated using a standard assumption that river flow held a log normal distribution[24]. This provided estimates for river dilution of storm overflow discharges.

The approach draws a comparison between WFD's assessment of Ecological Status and the dilution that river flow provides to a storm overflow discharges. There are published 99 percentile water quality standards[25] (Table 3-1) designed for assessing the impact of storm overflows in wet weather and these were used to assess the risk that a water body exposed to storm overflows would have its water quality sufficiently compromised such that it did not achieve Good Ecological Status. A simplification of the approach is that the assessment does not take account of other influences on achieving Good Ecological Status, only the influence of storm overflows.

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[23] Extracted with permission from the Environment Agency's national SAGIS-SIMCAT model

[24] A standard assumption used in water quality planning when using tools such as the Environment Agency's RQP and SIMCAT

[25] See Table 6 (page 16) of the Storm Overflow Assessment Framework http://www.water.org.uk/wp-content/uploads/2018/12/SOAF.pdf

The approach is corroborated by analysis of a large number of results from a detailed Urban Pollution Management (UPM) modelling investigation which are summarised in

Figure 3-3. It shows how BOD concentration (Y-axis) varies with dilution ratio (X-axis) and delineates the simulations which resulted in a pass or fail of the dissolved oxygen fundamental intermittent standard[26] which is considered a requirement for Good Ecological Status. The data show that once the dilution ratio is >0.5 (and in-river BOD concentration is >20 mg/l) nearly all simulations show a failure and that when dilution is <0.2 (and in-river BOD concentration is <20 mg/l) then all simulations show a pass.

By assuming an event mean concentration for BOD in storm overflow and a ‘clean’ river quality the resultant mixed concentration of BOD can be equated to first 99 percentile values and then a simple dilution ratio (spill volume: river volume) as indicated in Table 3-1. Subsequently, this dilution ratio is used as a means of assigning an Equivalent Ecological Status to the water body as a consequence of the operation of storm overflows alone. It should be stressed that this assessment precludes other factors determining ecological status and can be considered as the impact of storm overflow into an otherwise clean water body.

To calibrate this assessment method the quantity of river flow used in the dilution calculation was varied by selecting a suitable percentile river flow and duration of river flow and comparing the resultant Equivalent Ecological Status for each water body to Environment Agency assessments of where intermittent discharges (storm overflows) are considered one of the reasons for failure to meet actual Good Ecological Status.

Through experimentation, the optimum parameters selected were:

- the 70-percentile river flow (exceeded for 30 percent of the time); this is a higher an average flow reflecting that overflows are more likely to occur when river flow has responded to rainfall.
- the 2020 VWSF multiplied by the average duration of modelled spills (4 hours)

Table 3-1 Equivalent ecological status and corresponding BOD 99 percentile values and spill to river flow dilution ratios

Equivalent Ecological Status	BOD (mg/l)	Dilution ratio (spill:river)
High	9	≤0.10
Good	11	≤0.15
Moderate	14	≤0.20

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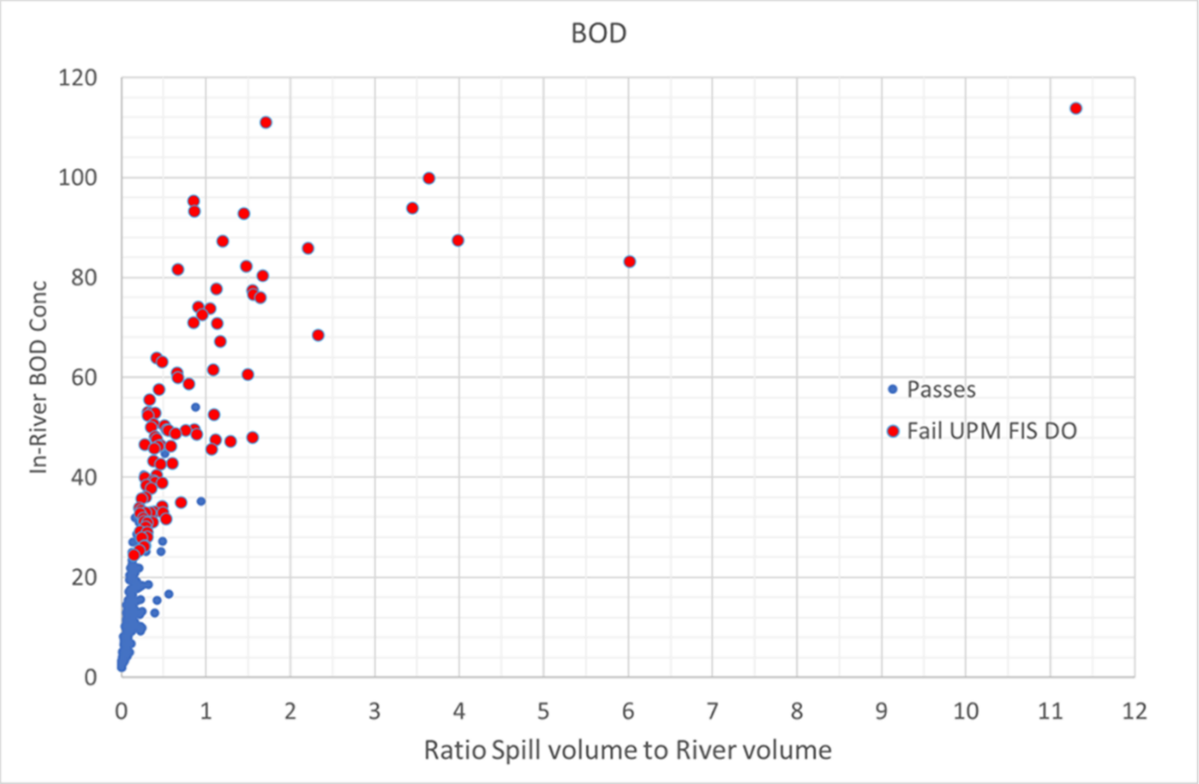
[26] See Table 2.3 of the UPM Manual http://www.fwr.org/UPM3/Section2.pdf

Equivalent Ecological Status	BOD (mg/l)	Dilution ratio (spill:river)
Poor	19	≤0.30
Bad	N/A	>0.30

Figure 3-3 Dilution ratio, in river BOD concentration and UPM Fundamental Intermittent Standard compliance (DO)



For validation of the method Figure 3-4 shows a map (left) of how harm to river health is evaluated in this research for the 2020 baseline (current day) using Equivalent Ecological Status. It includes 628 water bodies achieving moderate, poor or bad storm overflow classification. The figure also shows (right) the latest Environment Agency assessment[27] that 402 water bodies do not achieve good status as a result of storm overflows.

Although not wholly independent, the validation shows that this research is assessing a similar order of problem as the one reported by the Environment Agency, noting that the latter is likely to under-report. The spatial pattern is similar too; it is an important

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[27] Water Framework Directive reasons for failure reported here Environment Agency - Catchment Data Explorer

validation and gives confidence that the current level of harm to river health is captured appropriately and that the assessment method is a sound basis upon which to test changing patterns of storm overflow discharge.

This research's assessment of river health was also independently validated against SOAF outputs. The SOAF process is detailed in the Storm Overflow Assessment Framework guidelines[28]. The process uses a combination of aesthetic surveys, invertebrate surveys and water quality modelling to determine the level of environmental impact from storm overflows. This provides an impact classification. Water bodies which displayed failing SOAF impact classifications were identified and this research's outputs for these water bodies interrogated. Of the sample 17 river water bodies that were detailed as containing failing WFD SOAF assessments, 11 were found to have a worse than 'good' Equivalent Ecological Status. It can be speculated that the difference here is due to characteristics of the actual overflows which are not captured through modelling, such as their operation due to causes other than hydraulic capacity such as blockages, permitting issues or asset maintenance. Overall, the validation was considered appropriate for the purposes of this research.

As well as an England wide view, water bodies with the following designations are identified in this research so that polices can be tested which prioritise them:

- Rivers defined as or passing nearby to Sites of Special Scientific Interest (SSSI)
- Rivers defined as or passing nearby to Special Areas of Conservation (SAC)
- Rivers designated as Sensitive Areas Eutrophic
- Chalk streams

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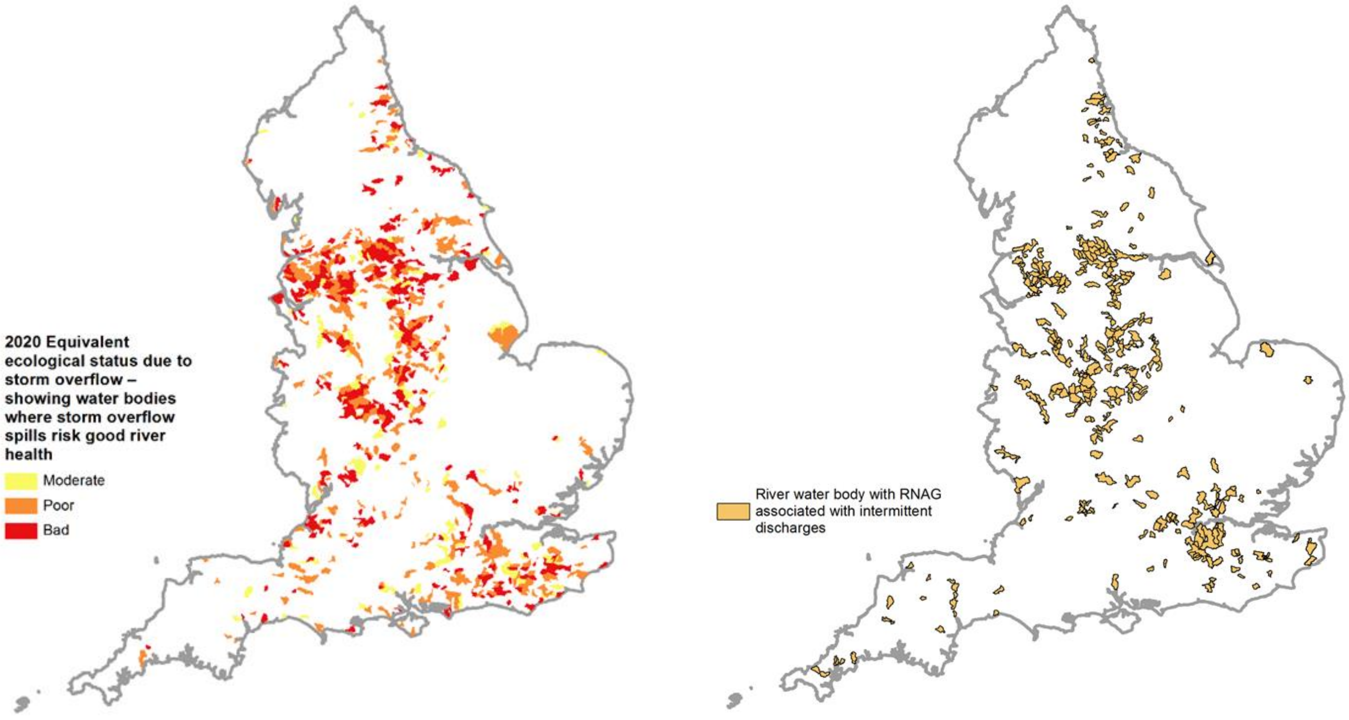
[28] The SOAF process is detailed in the SOAF guidelines and summarised in Figure 1 of the guideline document (Environment Agency, June 2018, Version 1.6, Storm Overflow Assessment Framework). SOAF.pdf (water.org.uk)

Figure 3-4 SOEP evaluation of storm overflow impact on river health for 2020 (left) and current RNAG due to storm overflow (right)



3.3.1.2 Public health

Public health is at risk where there is bathing (or immersive recreational use), and bacteria levels are in excess of thresholds established for safe bathing and tested through regular sampling in the bathing season. The standards[29] for inland waters are summarised in Table 3-2 showing the two faecal indicator organisms used to assess whether there is faecal matter and hence dangerous bacteria in the water.

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[29] Bathing Water Quality https://environment.data.gov.uk/bwq/profiles/help-understanding-data.html

Table 3-2 Classification water quality thresholds for inland bathing waters

Classification	Concentration thresholds for 3.19scherichia coli (EC). Colony forming units (cfu) per 100ml – 95th percentile	Concentration thresholds for intestinal enterococci (IE). Colony forming units (cfu) per 100ml – 95th percentile
Excellent	≤500	≤200
Good	≤1000	≤400
Sufficient	≤900 (90th percentile)	≤330 (90th percentile)
Poor	Worse than sufficient	

Storm overflow discharges are not biologically treated or disinfected and hence are a significant source of faecal matter. However, rivers are also at risk from other sources, including treated wastewater effluent (where this has not been disinfected) and contaminated runoff from roads and agricultural livestock.

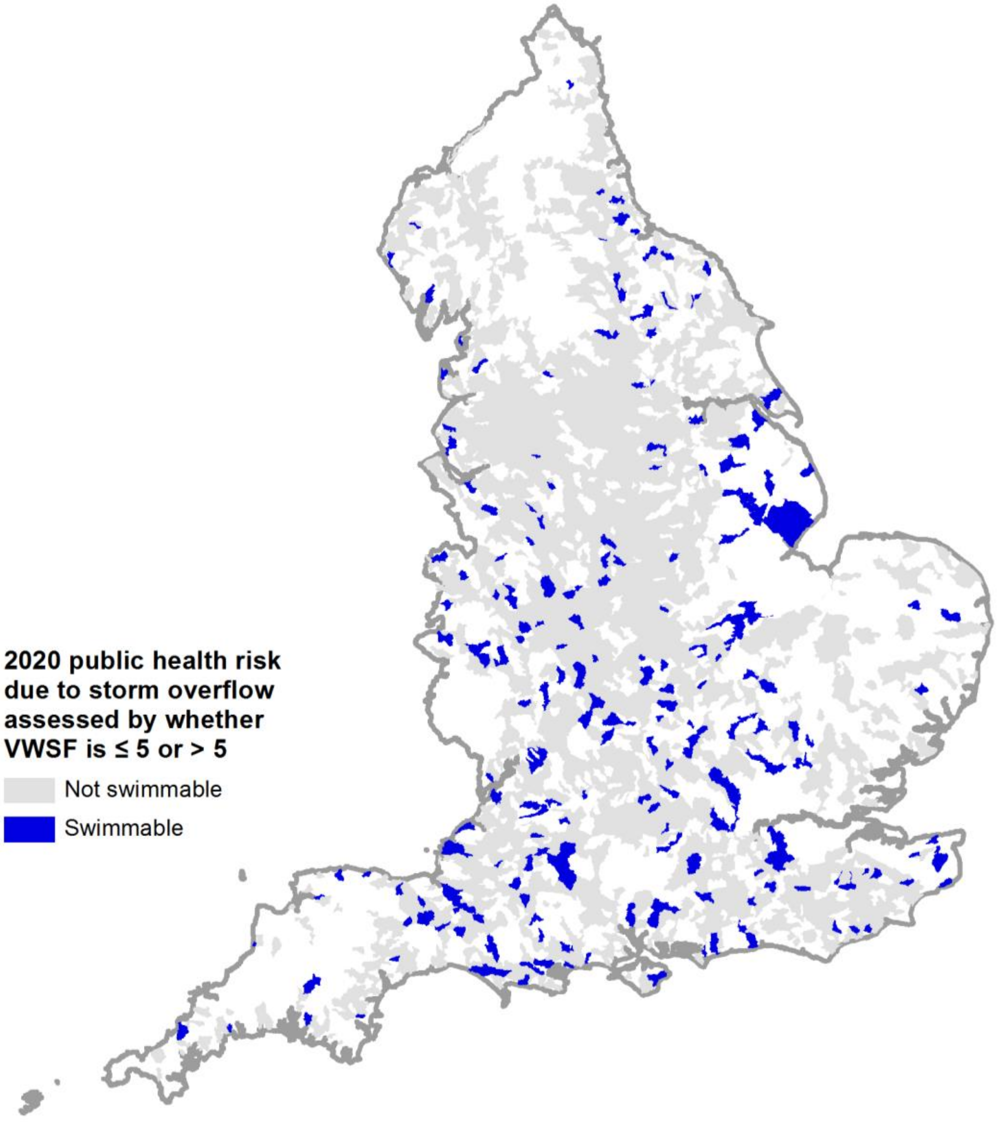
The sources and fate of bacteria in rivers is complex and difficult to model on a national scale so, on advice from the Environment Agency during the project development, a spill frequency limit of up to one per bathing season (May-September) was deemed the maximum average annual discharge from storm overflows consistent with achieving good bathing water quality. This advice is still under development and no spill frequency limits for inland bathing water have been agreed and finalised. Even with very low spill frequencies, bathing in receiving water bodies during or shortly after overflow discharges will still present a public health risk. Any control of storm overflows does not preclude the presence of faecal contamination from other sources.

In this research, the working assumption of one spill per bathing season is interpreted as a maximum VWSF per water body of five per year, recognising that most spills occur in wetter months outside the bathing season. Five spills per year (F5) was also a policy which had been developed and tested so investment needs had already been calculated. Data from analysis of 500 overflows for one water company in a wet region of the UK show that the percentage of spills occurring in bathing seasons varies between 15% and 50% with high frequencies at 15% and in the range 30%-45%. An assumption that one spill per bathing season is equivalent to five spills per year is hence not unreasonable as a national level average.

Because other sources of bacteria are not represented, this assessment is for the risk that storm overflows alone are a risk to public health and their control can make a river ‘swimmable’. This assumes that other sources of bacteria have been eliminated, for example, through the disinfection of treated sewage effluent or implementation of good management practices in agricultural runoff. Hence, the assessment of ‘swimmable’ in this context does preclude the situation that the river might still be unsafe for swimming because of other causes.

Figure 3-5 shows the water bodies in England which receive storm overflow and divides them into swimmable (VWSF ≤ 5) and not swimmable (VWSF > 5), indicating how risk to public health varies. A subset of rivers has been identified where bathing and recreational use is already commonplace and is used in a variation on the main tested policies and presented in Appendix D.

Figure 3-5 SOEP evaluation of public health risk due to storm overflow for 2020 (current day)



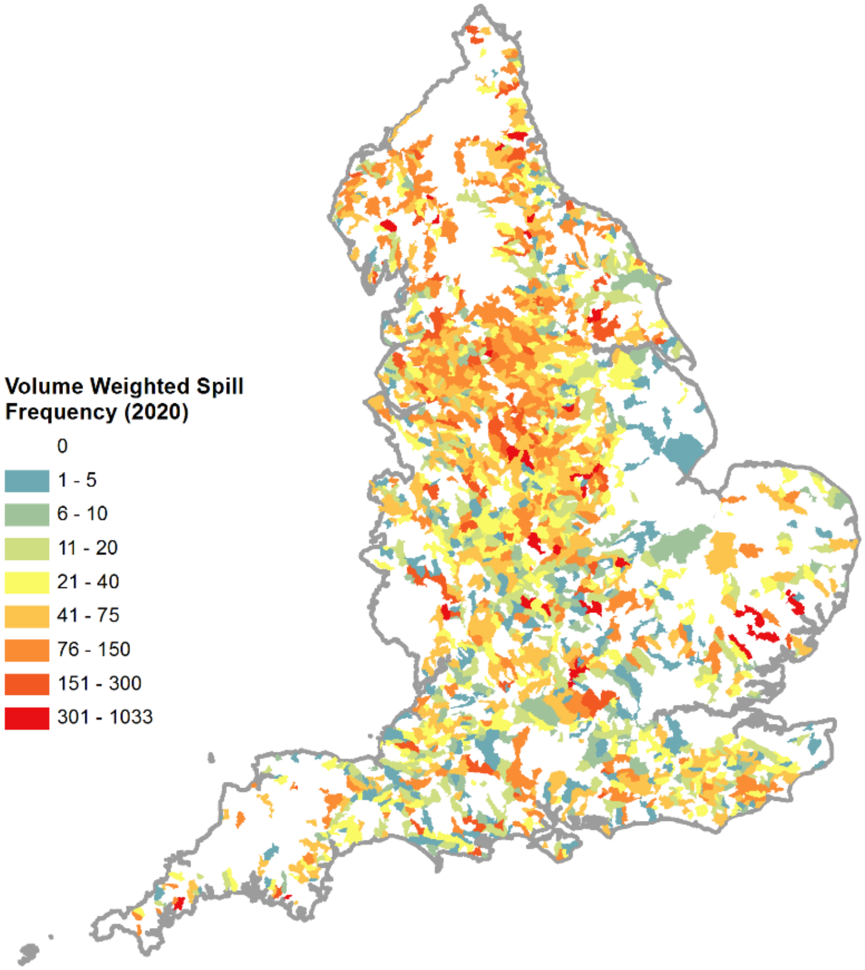
3.3.1.3 Social impact

People are concerned by the prevalence of storm overflows especially once informed about them. Whilst 41% of the population have an awareness of storm overflows these people are three times more likely than others (35% to 11%) to attribute river quality problems to water company assets and practices. Overall, 36% of people place storm overflow concerns in their top three environmental issues with 8% citing it as their most important issue. (See Appendix C for further details on public attitudes from a survey completed for this research.)

A simple measure for social impact per water body is the VWSF. In water bodies with a high VWSF the public is more likely to notice and be concerned by storm overflow activity, whether this has a significant impact on river and public health or not.

Figure 3-6 illustrates how VWSF varies across England in eight categories. The dark orange and red areas of the map are places most likely to have high social impact from storm overflows. It is where discharges are most frequent.

Figure 3-6 SOEP evaluation of social impact due to storm overflow for 2020 (current day)



3.3.2 Predicting harm in 2050

The evaluations for river health, public health and social impact have also been made for 2050 in the 'do nothing' situation, where no changes are made to infrastructure between now and then. This 2050 prediction then becomes the baseline for evaluation of policies and scenarios.

The method uses water company predictions of storm overflow performance for 2050 (see 3.2.1 on page 3.10) and amends river flow for climate change too. The approach to river flow reduction is simplistic and applies a uniform reduction of 3.5% nationally[30]. In practice, this varies basin by basin but work is ongoing through UKWIR[31] to provide updated flow predictions for each river for water quality uses using outputs from the UKCP18 climate model simulations.

The effect of increased storm overflow spill volume, frequency and reduced river flow increases predicted harm by all three measures, as reported in detail in Section 4.

3.3.3 Uncertainties and limitations

Quantification of harm (river health, public health and social impact) is on a water body basis. This does not capture situations where a local impact of a storm overflow is acute in a water body, which is otherwise acceptable, for example in headwaters where river flows are low.

The maps provided in this section, showing the level of harm caused by storm overflow on each water body, should not be over interpreted locally. They are provided to illustrate how estimates of harm are built-up for England as a whole. While some validation has occurred (for example, for river health) this is not possible for public health and social impact mapping.

The river health evaluation method provides an Equivalent Ecological Status evaluation as if there were no other risks to that water body other than storm overflows. It is an indication of the risk that storm overflows pose to each water body. In practice, the assimilative capacity of rivers to absorb the impact of storm overflow is conditioned by the other sources of pollutant present from upstream water bodies, treated final effluent and urban and rural diffuse pollution. Factors such as stream gradient and water depth are also important. Proper evaluation of harm due to storm overflow should have regard to this context and be done through water quality monitoring and modelling as described

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[30] Kay AL, Watts G, Wells SC, Allen S. The impact of climate change on U. K. river flows: A preliminary comparison of two generations of probabilistic climate projections. *Hydrological Processes*. 2020;34:1081–1088. https://doi.org/10.1002/hyp.13644

[31] Reference to UKWIR SAGIS update (https://ukwir.org/view/$55WR-70!)

in the SOAF[32]. The analysis does not capture where the load from one water body also affects the next downstream.

Discharges from storm overflows carry other pollutants not considered in this research, such as microplastics, metals, hydrocarbons and nutrients. The impact of these pollutants is chronic (builds up over time) whilst this research's assessment of river health is focused on the acute (short-lived) impacts of recurring low oxygen and high ammonia known to be toxic to aquatic life and the basis on which storm overflow have been managed historically. Some of the scenarios using SuDS could contribute to reducing the load from other pollutants, but this has not been accounted for in the benefit calculations.

The public health evaluation method takes no account of whether storm overflows in one water body may also have an impact on downstream water bodies. In practice, the levels of bacteria in rivers will be high where there is treated wastewater final effluent present. This is because treated effluent is not generally disinfected, and environmental permits have not required this because there have been no bathing water designations on inland rivers until the recent designation of the River Wharfe at Ilkley[33].

3.4 Testing policies and scenarios

3.4.1 Approach

This research assessment of costs and benefits considers different storm overflow control policies and how these are delivered using different engineering approaches (scenarios). The approach makes an estimation of the engineering changes necessary to reduce harm from storm overflows.

The policies tested consider the universal implementation of permits to control storm overflow spill frequency to an average of either 40, 20, 10, 5 or 0 (zero) times per year (named F40, F20, F10, F5 and F0, respectively).

A further hybrid policy considers a universal implementation of an F40 limit but with F10 applied in a subset of protected or sensitive water bodies (F40-10):

- Rivers passing nearby to Sites of Special Scientific Interest (SSSI)
- Rivers passing nearby to Special Areas of Conservation (SAC)
- Rivers designated as Sensitive Areas Eutrophic
- Chalk streams

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[32] http://www.water.org.uk/wp-content/uploads/2018/12/SOAF.pdf
[33] https://deframedia.blog.gov.uk/2020/12/22/part-of-river-wharfe-at-ilkley-becomes-first-river-bathing-site-in-england/

Three scenarios are also considered, describing the engineering approach used to deliver policies. The first relies on a conventional approach to capture spills from storm overflows using network storage (W) which is sized sufficiently to capture spills and allow for these to slowly return to the sewer network for treatment.

The other two augment the conventional approach with partly or wholly nature-based technologies (retrofitted SuDS) at two levels: 10 percent of impermeable area controlled (S10) and 50 percent of impermeable area controlled (S50). In this context, controlled means that these flows do not enter the combined sewer system. The SuDS solutions are implemented in addition to sewer network storage; therefore creating mixed grey-green solutions. The S10 level of SuDS is at a modest level across the catchment, whilst the S50 level is at a high level. Controlling runoff from 50% of impermeable area (S50) is broadly equivalent to preventing all highway runoff entering combined sewers in a fully combined catchment. This research's working assumption of a combination of SuDS measures to manage 1ha of impermeable area is described in Section 3.4.1.3

Separately, a cost estimate has been made for the separation of all combined sewers into foul and surface water sewers.

Water companies supplied data on the frequency and volume of storm overflow discharges in 2020 and 2050. Using these data as inputs, a method was developed to estimate the following:

1. Size of network storage to limit spill frequency (40, 20, 10, 5, 0) for scenarios W, S10 and S50
2. The quantity of SuDS needed to manage 10% (S10) and 50% (S50) of impermeable area contributing runoff to each storm overflow
3. Annual spill volume to river when spill frequency limits (40, 20, 10, 5, 0) are met. This is used to model changing river health.

3.4.1.1 Estimating network storage requirements to achieve a spill frequency standard

The project was granted access to comprehensive analysis completed for two water companies developed using detailed hydraulic network models. This archive of analysis had sized the network changes necessary to deliver spill frequency targets, with and without SuDS, for approximately 400 and 900 storm overflows respectively. These data were used to develop generalized formulae which could be applied to any storm overflow with reasonable robustness suitable for investment planning purposes.

To determine the nth spill volume a relationship was developed using the total spill volume and the 1st spill volume and had good to reasonable correlations:

$$n^{th} spill\ volume = \frac{Total\ spill\ volume}{c} \times k_{n^{th}}$$

Where c is the constant that derives a relationship between total spill volume at an overflow and 1st spill volume and k a constant to estimate the nth spill volume.

Storage volumes are estimated based on the spill volume with a factor to allow for the return using the following equation based on good to reasonable correlations:

$$Storage\ volume = nth\ spill\ volume\ \times s_{n^{th}}$$

Where s is a constant for different nth events that align with the policy options

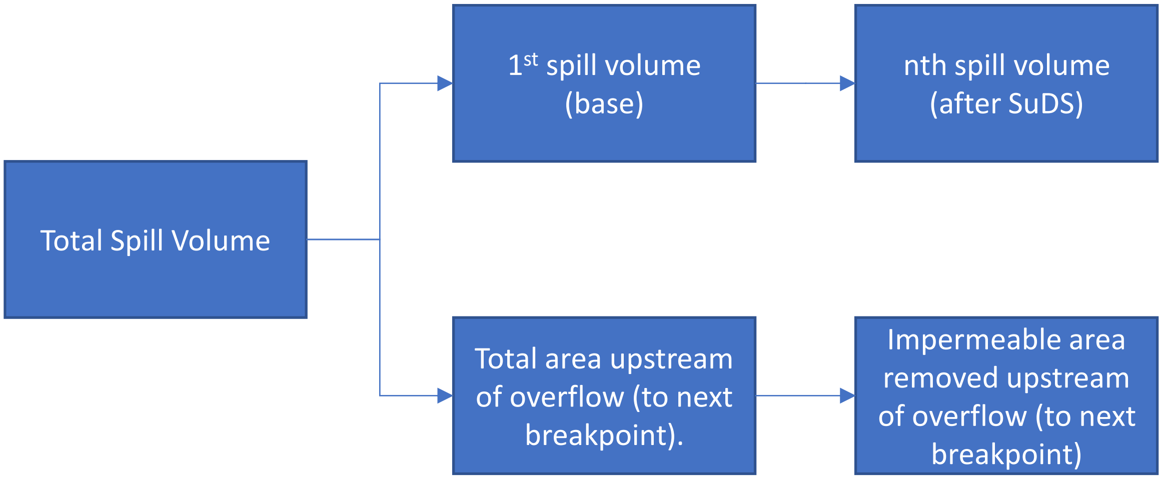
Appendix B includes the constants values for the different scenarios and policies (nth spill volumes)

3.4.1.2 Estimating the size of impermeable area to remove

Analysis of model simulations provided by a water company for over 400 overflows provided the evidence to assess the amount of impermeable area to remove. The analysis examined two scenarios: 10% and 50% impermeable area reduction, and its effect on the reduction in spill volumes and frequency for each storm overflow. The work analysed the removal of impermeable area upstream of an overflow to the next ‘breakpoint’. This was either the head of the catchment or the next overflow or pumping station. It assumed that the overflow offers a level of control downstream, and therefore was used as a break in the catchment. Due to the significant variation in how overflows operate and their historical inclusion in the network, there was significant variation in the results, as would be expected.

The analysis of the 400 overflows was limited to data that were available within the data sets provided by water companies on overflow performance. Total spill volume was a value widely available for the data from all water companies. Therefore, this parameter forms the basis of the analysis of the 400 overflows and the application of the analysis to estimate the size of the impermeable area to remove and the benefit this makes in reducing storm overflows. Figure 3-7 shows the steps undertaken.

Figure 3-7 Steps to estimate the benefit of removing impermeable area and the amount of impermeable area to remove based on a 10% and 50% scenario.



Regression analysis was used to relate the baseline total spill volume and baseline 1st spill volume achieving a good fit. The baseline 1st spill volume was used to derive the baseline and after SuDS for the nth events (i.e., 5th, 10th…) to support the wider analysis. A good to reasonable correlation was achieved, with the correlation reducing as the nth events became bigger. The nth spill volumes after SuDS were then adjusted to determine the storage still required to meet the policy option targets (e.g., 20 spills). The same equation format to determine the nth spill volumes (section 3.4.1.1) but with SuDS was used. The co-efficient values to calculate the volumes are included in Appendix B.

The impermeable area estimates used the baseline total spill volume at each storm overflow. Regression analysis of the total spill volume and total upstream catchment area was used to develop a relationship. A number of bands for the baseline spill volumes were used to account for the variability in the data (0-2000, 2000-10000, 10,000-100,000 and >100,000. The correlation was poor, considered due to the variation in overflow settings and historical implementation of storm overflows. The total area was used to estimate the impermeable area removed where a good correlation existed. The equation below outlines the calculation:

$$Impermeable\ area\ to\ remove\ (ha) = \frac{Total\ Spill}{Volume} \times a_{Vol\ Band} \times b_{\%\ removal}$$

Where a is the constant that represents a relationship between total spill volume and the total area for different bands of spill volume and b is a constant that represents a relationship between the total volume and impermeable area for a 10% or 50% reduction in impermeable area.

3.4.1.3 Estimating the size of SuDS to manage a hectare of impermeable area

Whilst a programmatic approach has been taken to estimating costs for SuDS, indicative types and sizes of measures have been estimated to facilitate benefits, operational and carbon estimates. A typical urban scenario was used to estimate the size and type of the SuDS retrofit, where 50% of the surface water from an impermeable area was managed through SuDS. This built on work previously undertaken with a water company in preparation for 2019 price review. The aim of the SuDS was to disconnect the surface water from the combined sewer system, and hence the measures need to be joined together. Removing surface water (impermeable area) from the combined sewer system was considered important for two primary reasons:

1. As the need to remove more volume increases (e.g., when spill frequency scenarios become smaller) then a source control approach alone will not tend to provide the required capacity.
2. To enable other benefits to be considered, with some being valued (e.g., flood risk) and others not (e.g., management of urban diffuse pollution)

There are numerous alternatives to full disconnection that can be considered on a scheme-by-scheme basis but they were not considered appropriate to apply on a national scale.

The scenario developed to estimate the size and type of measures in a typical urban scenario consisted of the following characteristics:

- Catchment area = 4ha
- Road and roof area = 1 ha respectively
- Population = 500 with an average of 1.8 adults per property
- Number of properties = 200 (assuming 50 properties per ha)
- Length of road = 800m

A range of SuDS interventions were chosen to represent the management of surface water from the impermeable area. The surface water assessment presumes that the surface water entering the SuDS is no longer discharged to the combined sewer. These had previously been assessed as part of other water company work to manage circa 1 ha of impermeable area. These SuDS included:

- Street and public space interventions including:
    - 24 trees in pits to manage water locally

  - 480m swales / street side rain gardens with additional connecting pipework to intercept and convey flows between measures
  - 480m^3 of storage basins to attenuate flows before they are released downstream (e.g., into water bodies). Note this is the excavated size of the basin and not the storage required.
- Property level interventions that intercept and disconnect flows from the system and manage locally:
  - 100 water butts for properties
  - 100 property rain gardens
  - 100 property level planters.

The cumulative costing for these measures for the urban scenario was circa £1m per ha of impermeable area removed without allowances for utilities and other risks. This estimate is comparable to the limited number of UK programmes and major schemes involving a catchment approach to manage surface water. For example, Thames Water's programme in AMP6 was £20m for 20ha of impermeable area removed. A recent Welsh Water[34] scheme indicated a similar unit rate of £1m/ha removed. SuDS delivery costing does not assume aligned programmes across different stakeholders in the built environment – e.g., SuDS implementation and highway improvements – which would share the cost burden and potentially reduce the overall cost (e.g., shared overheads).

The costs for SuDS also compare well with high-level sewer cost estimates summarised in the next section. If an equivalent length of works in the highway with pipework was required, even considering 50% of the low unit cost would create a value of over £0.5m for the circa 480m of swales / rain gardens with interconnected pipework to enable disconnection.

3.4.1.4 Estimating a stand-alone full separation scenario

A stand-alone scenario has been considered for CAPEX estimation only. The scenario considers the theoretical replacement of all combined sewers with a new sewer (of same size and depth) leaving the original combined sewer for rainwater and the new sewer for wastewater.

This approach is heavily simplified due to the available data (sewer lengths) only being available but could be supplemented further by knowing the size and depth of the pipes and an estimation of foul flow.

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[34] Rainscape Llanelli | Dwr Cymru Welsh Water

The standalone separation would also require a new connection from the property to take the foul flow and connect to the new system.

Table 3-3 contains the main assumptions in the calculation, the results of which are included in Section 4.

Table 3-3 Assumption for stand-alone separation scenario

Classification	Low estimate	High estimate
Sewer replacement cost (£/m)	2000	3000
Total length of sewer separated (km)	138,000	
Cost per property of lateral connections	3800	7700
Sewer replacement costs are derived from water company data collated from completed projects and estimating tools. They include manhole construction and assume open cut replacement. The total length of sewer is all designation combined sewers and 50% of all foul sewers on the assumption that these are *de facto* operating as combined sewers with some surface water within the pipe (e.g., misconnection, partially separated, historical connection of surface water sewers, infiltration). The connections and laterals calculation assumes that sewers are shallow and that all properties currently served by combined sewer require one lateral sewer.		

3.4.1.5 Estimating residual storm overflow spill volumes to river with frequency control policy in place

The project was granted access to a comprehensive analysis completed for one water company where the reduction in annual spill volume was calculated, using hydraulic models, for strategies which progressively decreased spill frequency. This comprehensive analysis of over 400 storm overflows represented sewer networks of different sizes and complexity.

To determine the post improvement or revised annual average spill volume, after an intervention to limit the frequency of spills, a relationship was developed using the original average spill volume and had good correlations:

$$Revised\ annual\ average\ spill\ volume = \frac{annual\ spill\ volume}{annual\ spill\ frequency} \times r_{n^{th}}$$

Where r is the constant for the achieved n^{th} spill.

The revised annual average spill volume was used to determine the changing impact on river water quality as spill frequency is reduced. Appendix B includes the constant values for the different scenarios and policies (n^{th} spill volumes).

3.4.1.6 Worked example to illustrate approach

The application of these formulae is illustrated through a simple worked example from a notional storm overflow with an annual average spill volume of 60,000m^3 and an annual average spill frequency of 50. Table 3-4 shows how the formulae can be applied in this instance to calculate nine values (each row in the table) subsequently used to evaluate water quality impact and the costs of providing network storage and/or SuDS. Note how the requirement for network storage reduces with increasing ambition in SuDs.

Table 3-4 Worked example

	Average annual spill frequency				
	40	**20**	**10**	**5**	**0**
Annual spill volume (m3)	54,034	30,000	15,187	8,400	-
W network storage needed (m3)	703	1,994	3,863	7,559	24,315
W additional treatment required (m3/year)	5,966	30,000	44,813	51,600	60,000
S10 network storage needed (m3)	549	1,494	3,019	5,045	22,608
S10 impermeable area controlled through SuDS (Ha)	3.2				
S10 additional treatment required (m3/year)	5,370	27,000	40,332	46,440	54,000
S50 network storage needed (m3)	241	869	1,788	3,691	14,351
S50 impermeable area controlled through SuDS (Ha)	16.2				
S50 additional treatment required (m3/year)	2,983	15,000	22,406	25,800	30,000

3.4.2 Uncertainties and limitations

The methodology described here makes estimates for the quantity of network storage and/or SuDS to achieve different policy options controlling the frequency of overflow. It also makes estimates for the residual spill volume to rivers once frequency is controlled.

Though based on relationships observed from design activities in over 900 overflows to review spills and 400 overflows to estimate the impermeable area to remove, the approach cannot accurately propose solutions for individual storm overflows in all circumstances and in all company operating regions.

A significant variation in overflow performance means the prediction of the impermeable area to manage has low confidence. The data available to assess all the overflows was limited to spill flow volume and frequency. This, in turn, limits the type of analysis possible and its subsequent application to the whole overflow data set.

A typical area was used to enable a unit sizing and costing approach. The types and size of SuDs will vary in reality within areas, and variations of the measures and sizes could be considered. However, for the purposes of this research, the approach enables the potential cost (compared to a programmatic approach), carbon and benefits to be evaluated.

There are numerous factors that will also affect the type and size of measures. These include:

- the local area and its current infrastructure
- the opportunity (spatially and temporarily with other stakeholders)
- whether real time control is used in the drainage system to maximise benefit
- the amount of impermeable area to manage which in turn may require larger infrastructure to manage the flows

There is work being completed as part of the DWMP, along with a number of ‘catchment’ wide schemes in design or to be designed but not ready for inclusion in this work. This evidence will help validate these approaches, including cost and carbon in the near future.

Overall, whilst a number of assumptions have been made for the sizing, we consider it is suitable for a national scale assessment, planning and costing purposes.

3.5 Costs and benefits

This section explains how this research has estimated the costs and benefits of applying different storm overflow policies and scenarios.

3.5.1 Costs

3.5.1.1 Capital cost (CAPEX)

The capital cost of applying policies for different scenarios is applied through using low and high unit cost estimates for network storage (m^3) and SuDS (Ha of impermeable area managed) as described in Table 3-5. The range represents unknowable but location specific factors which affect costs such as land use, land availability (although not land purchase), traffic management costs, SuDS opportunities and capacity at treatment facilities. The wider costs and benefits associated with construction on the local economy are excluded.

Methodologies used for estimating storage and SuDS requirements are described in Section 3.4.

Table 3-5 CAPEX unit costs

Unit	Low	High	Notes & assumptions
Network storage construction (£/m^3)	1,300	2,000	From water company programmes of constructing storage tanks on combined sewer networks and also estimating tools based on same data
Upgrading existing WwTW (£/m^3) for additional treatment capacity	12	25	Allowance for cost of upgrading treatment facility to accept more rainwater which is no longer discharged to river but treated instead
SuDS control runoff from urban surface (£/Ha of impermeable area) with surface water disconnected from the sewer system and not infiltrated to ground.	1,000,000	1,500,000	From water company programmes of surface water removal (Thames Water and Welsh Water[35]) furthered through unit rate analysis. Does not assume aligned programmes across different stakeholders in the built environment – e.g., SuDS implementation and highway improvements – which would share the cost burden and potentially reduce it.

3.5.1.2 Operating cost (OPEX)

Sewer flows no longer spilled to rivers require additional operational costs (e.g., power, chemicals, labour), and SuDS require regular ongoing maintenance. High and low estimates of operating cost of applying policies for different scenarios are provided in

Table 3-6. The operating costs of sewerage infrastructure is excluded because this is an existing not new burden.

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[35] Rainscape Llanelli | Dwr Cymru Welsh Water

Table 3-6 OPEX unit costs

Operating expenditure	Cost	**Notes & assumptions**
SuDS maintenance (£/ha/year)	6,214	Considered the maintenance requirements to manage a range of SuDS considering the different frequencies required ranging from litter pick and sediment removal through to capital maintenance repairs anticipated. An average cost has been adopted smoothing the different operational frequencies.
Additional treatment (£/m3)	0.02	
Maintenance of storage tanks (£/tank)	2150	43 hrs per tank per year
Pumping (£/m3)	0.0096	
Labour (£/hr)	50	

3.5.1.3 Embedded carbon

Carbon associated with the construction of sewer network storage and SuDS is reported as a comparative measure between policies and scenarios. Only embedded carbon has been included. A summary of the values used is presented in Table 3-7. All embedded carbon calculations were carried out in line with the UKWIR CL01B207 embodied carbon guidelines report (2012).

Separately, the valuation of greenhouse gas emissions has been included in benefit cost appraisal calculations applying the latest guidance values[36] from the Department for Business, Energy, and Industrial Strategy (BEIS). These values (Figure 3-8) are monetary, increase into the future and reflect the value that society places on one tonne of carbon dioxide equivalent.

Table 3-7 Summary of embedded carbon values

Unit	**Value**
Kg/CO2e per unit (m3) of network storage	Range: 212-286
Kg/CO2e per unit (Ha) of area managed by SuDS	98,300

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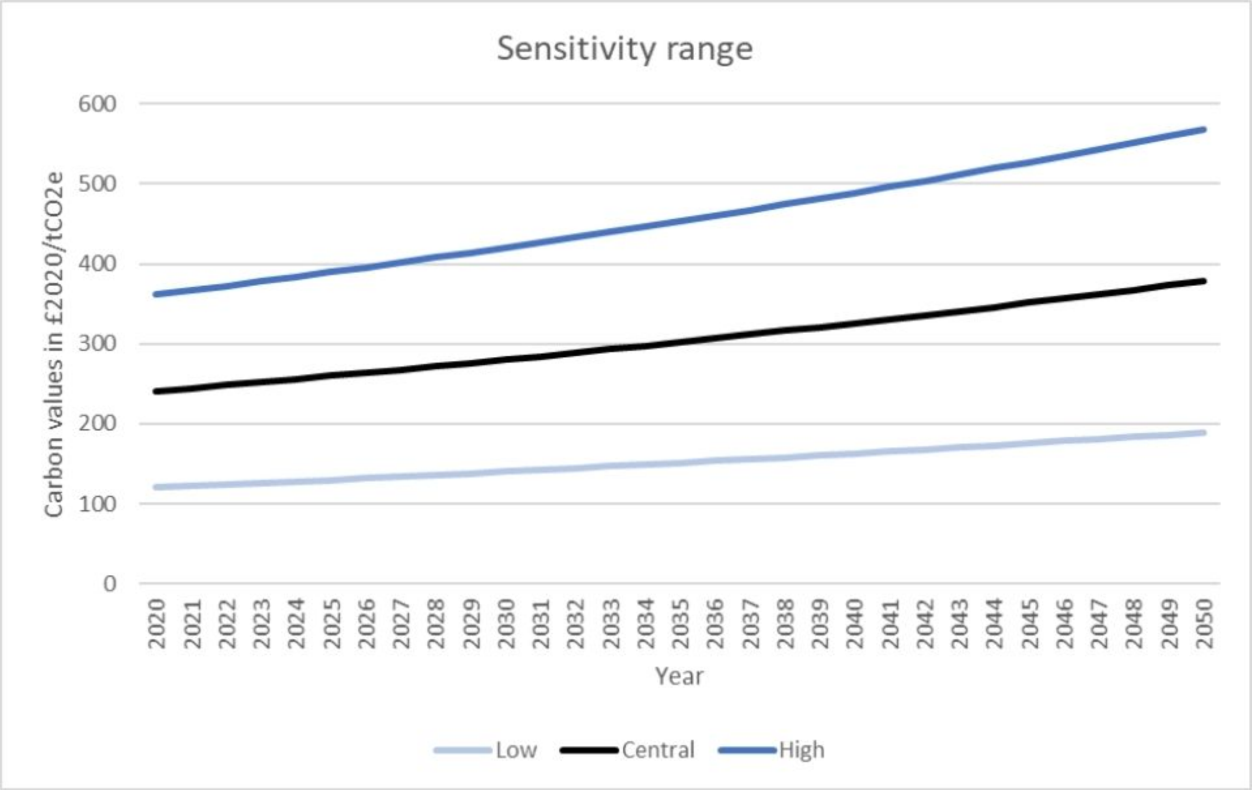
[36] Valuation of greenhouse gas emissions: for policy appraisal and evaluation

Figure 3-8 Carbon values for use in policy appraisal (source: BEIS Sept 2021)



The general approach taken for the carbon assessment is outlined below.

Network Storage

The embedded carbon per m^3 of network storage capacity provided was calculated based on a ‘typical’ storage tank arrangement, which was used as a reference case. This approach includes the following assumptions:

- The reference storage tank has a storage volume of 900m^3
- The reference storage tank is located within 100m of the combined sewer and returns spill flows to the sewer at approximately the same location.
- All M&E items (pumps, kiosk etc.) are renewed on a 20-year lifecycle.
- The embedded carbon associated with additional treatment capacity provided at sewage treatment works is not estimated directly but is assumed to be proportionate to the estimated capital cost of the treatment capacity required. This proportion varies depending on the policy option.

SuDS

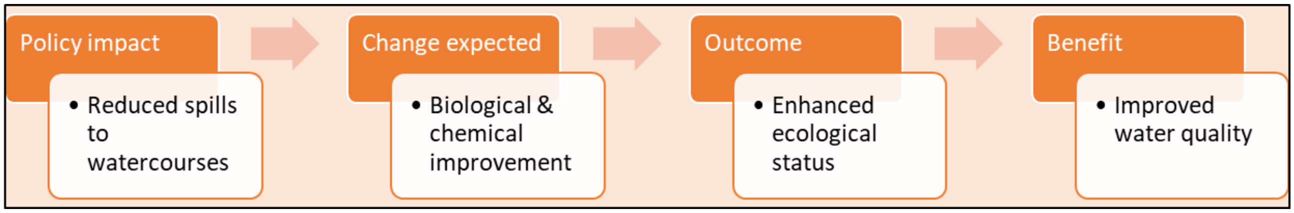
The embedded carbon per hectare of impermeable area managed was calculated directly from the reference range of SuDS interventions listed in Section 3.4.1.3. The calculation accounts for the key constraints and assumptions stated here.

3.5.2 Benefits

3.5.2.1 Improving river health

This research predicts the effect that current day, future and different storm overflow control policies have on river health (see section 3.3.1.1). It calculates an Equivalent Ecological Status for each water body as a consequence of storm overflow discharges and simulates how it changes as spill volumes and frequencies change in response to different policies. The 'pathway' linking policy options to river health benefits that can be valued is shown in Figure 3-9.

Figure 3-9: Impact pathway for river health



The benefits assessment counts the length of the water body which changes between classifications bad-poor-moderate-good and applies a unit length benefit for England and Wales from the National Water Environmental Benefit Survey[37] (NWEBS) methodology. This was a primary valuation survey, updated in 2013, to develop average values across river basins and catchments for the benefits of investing in measures to improve water bodies (rivers, lakes, canals and coastal waters) as part of the EU Water Framework Directive. The updated NWEBS values are acknowledged by Defra and the Environment Agency as providing the most appropriate and most practical way to use the currently available evidence on monetary values for non-market benefits for implementation of the Directive.[38] Values per km are provided for all catchments of changes in quality, from bad to poor, poor to moderate, and moderate to good. Low, central and high estimates are provided. The values used are described in Table 3-8.

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[37] NWEBS values are based on Metcalfe, P.J., Baker,W., Andrews, K., Atkinson, G., Bateman, I.J., Butler, S., Carson, R.T., East, J., Gueron, Y., Sheldon, R. & K. Train (2012) An assessment of the nonmarket benefits of the Water Framework Directive for households in England and Wales, Water Resources Research, Vol. 48, W03526, doi:10.1029/2010WR009592, 2012 . The survey and values are subsequently discussed and applied in Environment Agency (2016) Water Appraisal Guidance; Assessing Costs and Benefits for River Basin Management Planning. Version 2 – November 2016. The values have been updated (a) to take account of population growth, and (b) to 2021 prices using information provided by Defra (pers. Comm.).

[38] Defra (2021) ENCA: Enabling a Natural Capital Approach.

The original NWEBS values from which the estimates shown are derived are (£/km/year, 2021 prices):

- ‘Bad’ to ‘poor’: £19,090 (low) - £26,012 (high)
- ‘Poor’ to ‘moderate’: £20,815 (low) - £29,931(high)
- ‘Moderate’ to ‘good’: £24,171 (low) - £34,758 (high)

One-half of the total NWEBS value above is applied to river health improvements. This is in line with previous work in this area[39] which assumes that three of the six components considered in NWEBS (fish, invertebrates, plants) are potentially improved.

The length of water body improved is 50% of the actual water body length, allowing for a distribution of storm overflows throughout the water body.

Table 3-8 Benefits of improving river health

Change in classification	Low estimate of benefit (£/km/year)	High estimate of benefit (£/km/year)
‘bad’ to ‘poor’	9,045	13,006
‘poor’ to ‘moderate’	10,408	14,966
‘moderate’ to ‘good’	12,086	17,379

The values above are multiplied by the estimated length of water body improved to provide a total annual benefit. When water bodies move more than one category, the benefits of intermediate improvements are added together.

3.5.2.2 Improving public health

This research predicts the effect that current day, future and different storm overflow control policies have on public health (see section 3.3.1.2) by considering the VWSF in each water body receiving storm overflows. Where VWSF is less than or equal to 5, the water body is considered safe for swimming, assuming that other sources of pollution are managed. The ‘pathway’ linking policy options to public health benefits that can be valued is shown in Figure 3-10.

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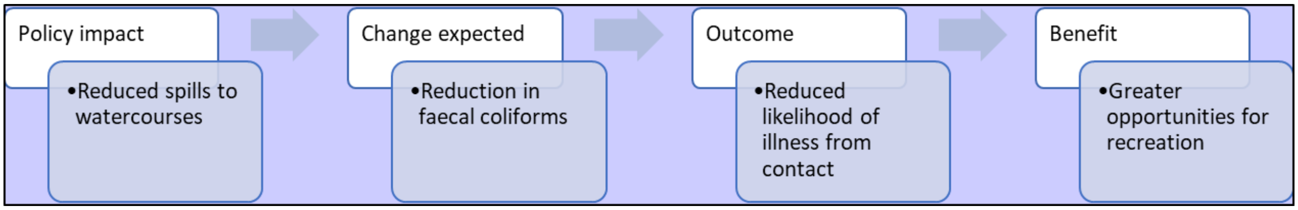
[39] For example, Water UK/Environment Agency (2017) Valuing the Benefits of Storm Discharge Improvements for Use in Cost-Benefit Analysis.

Figure 3-10: Impact pathway for public health



The benefits assessment counts the length of water body, which changes between ‘swimmable’ and ‘non-swimmable’ and applies a unit length benefit taken from NWEBS as described in Table 3-9. The same source and approach to valuation, based on NWEBS, was applied as that described in Section 3.5.2.1. However, on this occasion, one-sixth of the total NWEBS value is applied to public health improvements. This assumes that one of the six components considered in NWEBS (safety of the water for recreational contact) is potentially improved. This means that the unit value for the public health benefit will be one-third that of the unit value for the river health benefit. This reflects the approach adopted by the Environment Agency in applying NWEBS and perhaps also the fact that, whilst swimming in inland water bodies is increasingly popular, it is not the main activity and source of value for most people.

The length of water body improved is 50% of the actual water body length, allowing for a distribution of storm overflows throughout the water body.

Table 3-9 Benefits of improving public health

Change in classification	Low estimate of benefit (£/km/year)	High estimate of benefit (£/km/year)
‘Non-swimmable’ to ‘swimmable’	4,029	5,793

Other valuation sources were considered, specifically those relating to bathing water improvements, including PR19 water company willingness to pay (WTP) information[40] and an Environment Agency study into bathing waters[41]. However, it is currently not possible to reliably or robustly apply the quantitative parameter (km water body becoming swimmable) to the ‘per bathing water’ values derived from these studies.

The values above are multiplied by the estimated length of water body improved to provide a total annual benefit.

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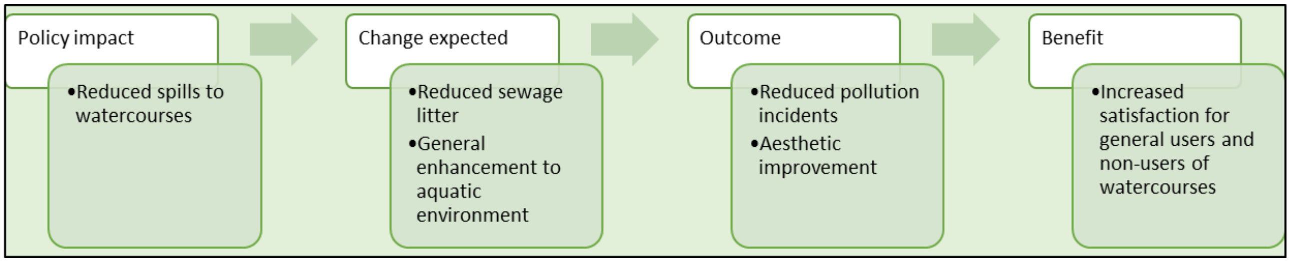
[40] Accent/PJM Economics (2018) Comparative Review of PR19 WTP Results.

[41] eftec (2014) Bathing Water Valuation Study: National Survey Summary Report. For the Environment Agency

3.5.2.3 Reducing social impact

Social impact is calculated by considering how the VWSF in each water body is improved and equating this reduction to a proportionate reduction in all types of pollution incident (from a base of 1,750 incidents in 2020[42] inflated for 2050 using the percentage increase in VWSF of 10.1%). The 'pathway' linking policy options to public health benefits that can be valued is shown in Figure 3-11. This was considered most appropriate approach, as most spills do not result in pollution incidents.

Figure 3-11: Impact pathway for social impact



The improvement is valued using average water company willingness to pay values for reductions in minor pollution incidents as described in Table 3-10[43]. So, a 10% reduction in VWSF is equivalent to a 10% reduction in pollution incidents. It is currently not possible to value the social impact of spills from overflows directly, so linking spills to all pollution incidents and applying values for pollution incidents in this way appears to be an appropriate approach available. Applying willingness to pay values for pollution incidents (1,750 occurrences in 2020) to all spills (250,000 occurrences per year on average) would not be theoretically correct and would likely result in a significant overestimate of benefits. One key recommendation is therefore to undertake an economic valuation study that specifically encompasses spills from storm overflows.

Table 3-10 Benefits of reducing social impact

Reduction spill	Low estimate of benefit (£/incident/year)	High estimate of benefit (£/incident/year)
Reduction of one pollution incident	79,085	86,456
Reduction of one VWSF count	1,503	1,643

The values above are multiplied by the estimated reduction in pollution incidents to provide a total annual benefit.

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[42] https://www.gov.uk/government/publications/water-and-sewerage-companies-in-england-environmental-performance-report-2020

[43] The values are based on Accent/PJM Economics (2018) Comparative Review of PR19 WTP Results. Outlier values are excluded, resulting in a median value (used for low estimate) and mean value (used for high estimate).

3.5.2.4 Benefits associated with SuDS

The S10 and S50 scenarios tested in this research include SuDS and these provide a range of benefits to communities which add to benefits from improved river health, public health and reduced social impact.

The benefits are applied per hectare of impermeable area managed using SuDS. We have assumed a 'typical' mix of SuDS measures outlined in section 3.4.1.3. These include a range of green infrastructure (trees, swales, basins and rain gardens) along with some grey infrastructure to connect measures together.

We applied the principles of B£ST[44] with the 'typical' population numbers outlined in section 3.4.1.3 to compute benefits per hectare in the categories described in Table 3-11. The monetised values are multiplied by the amount of impermeable removed to provide a total annual benefit (high).

Table 3-11 Benefits of SuDS, confidence values and annual values

Benefit category	Estimate of annual benefit (£/ha)		Notes
	Low	High	
Air Quality	115	230	Reducing air pollution
Amenity	1,502	4,005	Improving quality of place (does not include property price increases)
Biodiversity	11	29	Green infrastructure provides habitats
Carbon sequestration	37	66	Trees and plants absorb carbon from atmosphere[45]
Education	114	228	Learning about the water cycle in cities
Health	2355	6280	Improved health outcomes for those with a view over green space and number of visits to green space.
Groundwater	50	202	Increased infiltration to groundwater, helping to maintain natural hydrology, increase availability of water for abstraction or reduce treatment costs.
Flood risk	5,465	14,572	Reduced risk of surface water and sewer flooding (also includes mental health impact of flooding[46])
TOTAL	**9,649**	**25,612**	

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[44] CIRIA (2019) B£ST (Benefits Estimation Tool – valuing the benefits of blue-green infrastructure)

[45] Sequestration through trees are not linear over time, therefore a 40-year accumulation for 'medium' size trees was calculated and averaged per year to support the yearly analysis.

[46] Based on Defra (2020) Mental health costs of flooding and erosion https://www.gov.uk/government/publications/partnership-funding-supporting-documents/mental-health-costs-of-flooding-and-erosion

We included assumptions on the quantities before applying the confidence percentages related to the quantity and monetised values, following the guidance within B£ST. For example, estimating the health benefits, especially the quantities, are particularly difficult and open to interpretation. The high (pre-confidence) annual values are multiplied by the confidence percentages to determine the low (post-confidence values). The confidence percentage values, along with an overview of the benefit assumptions, are in Table 3-12.

Table 3-12 Overview of confidence percentages and assumptions to determine the benefits

Benefit category	Confidence Quantity (%)	Confidence Monetary (%)
Air Quality	50	100
Assumes existing air quality is poor. Pollutant uptake estimated based on types of interventions with uncertainty on quantity and uses high confidence HM Government benefit values.		
Amenity	50	75
Assumes 2/3 of adults gain a benefit (240). Low monetary value used for street greening. Reduced confidence percentages applied to account for significant variability in the locations and transfer of values. Values do not include property price increase.		
Biodiversity	50	75
A land use change to improved grasslands used. Reduced confidence percentages applied to account for significant variability in the locations and transfer of values.		
Carbon sequestration	75	75
Estimation of benefit based on 24 medium-sized trees. Assumes difficulty to retrofit in some areas and potential for trees loss.		
Education	50	100
Assumes 10% of students (non-adults) visit the SuDS and learn (14). Monetary value transferrable, with 50% confidence to account for visits may not happen.		
Health	50	75
View over green space; assumes only 16 adults have this view based on limited space and change to the urban area to create the significant green space. This effects the confidence in the quantity, considering this may not be possible (50%) and that the transfer of the monetary value is not precise to the context. For potential to visit new green space created, assumes of all adults (360), only ¼ are close enough to visit, ½ of adults won't visit and those who do visit four times per year. Uncertainty as to the number of visits (50% selected for confidence) and the transfer of the monetary value is not precise to the context.		

Benefit category	Confidence Quantity (%)	Confidence Monetary (%)
Ground-water	25	100
Assumes that 25% of SuDS contribute to the benefit with 25% in water stressed areas. Average rainfall of 870mm/yr for England (over last 20 years)[47]. Low confidence in quantity as various factors may prevent infiltration. Monetary values 100% from HM Government.		
Flood risk	50	75
Estimates are based on the estimated number of properties at reduced risk of flooding (change in return period) as a result of the impermeable area intercepted. This includes the impact on the mental health on two adults per property only assuming a depth of up to 0.3m of water. Quantity of 50% applied to account for variability in the risk being where the SUDS are retrofitted. Monetary value of £19k[48] considered robust but recognise damage could be lower (depth) for surface water events, therefore 75% applied.		

3.5.3 Comparing costs and benefits

Costs and benefits are assessed over a 50-year period (2025-2075) with future costs and benefits discounted at the appropriate rate (initially 3.5%, declining to 3% after 30 years) in line with HM Treasury Green Book guidance. Two decision support criteria are calculated: Net Present Value (NPV, benefits minus costs) and Benefit Cost Ratio (BCR, benefits divided by costs), providing an indication of both the absolute and the relative value of policy options.

To provide a ‘worst case’ NPV/BCR scenario, high estimates of costs are compared with low estimates of benefits. To provide a ‘best case’ NPV/BCR scenario, low estimates of costs are compared with high estimates of benefits.

It is assumed that construction (capital expenditure) occurs over a 25-year period from 2025 and that benefits do not occur in full until construction is complete but are applied *pro rata* before then (e.g., when half the construction is complete, half the benefits apply). Benefits begin to accrue in 2026, i.e., the year after construction starts.

Operational costs increase in line with CAPEX, i.e., increasing linearly until 2050. After this time, OPEX is assumed to remain constant.

Benefits are calculated by comparing the ‘do nothing’ baseline in 2050 with the situation resulting from the application of different polices and scenarios.

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[47] From MET office: https://www.metoffice.gov.uk/pub/data/weather/uk/climate/datasets/Rainfall/date/England.txt

[48] £19K is based on economic cost per property (damage from 2007 summer floods) (see Environment Agency 2018, Estimating the economic costs of the 2015-2016 winter floods)

3.5.4 Calculating impact on bills

A simple approach has been applied to calculate the impact of storm overflow improvement CAPEX and OPEX on water bills using the formula:

$$\frac{Bill\ impact}{(\pounds\ per\ year\ per\ household)} = \frac{OPEX}{(\pounds\ per\ year)} + \frac{CAPEX}{Life\ of\ the\ asset} + X\%\ of\ CAPEX$$

Where, X is weighted average cost of capital (WACC) = 2.96%, the number of households is 25 million and asset life is 80 years.

The approach[49] assumes that the burden is shared equally across all households in England. Investment needs do vary considerably region by region, and household bill increases for different companies would reflect this. In addition, the burden would be spread between households and non-households, so the impact on household bills would be lower than that shown (approximately 77% of these values). Other factors not accounted for here are retail margin and corporation tax due on revenue. More sophisticated bill modelling would be required to be more accurate in the customer burden of a storm overflow improvement programme.

3.5.5 Uncertainties and limitations

The unit cost approach to valuing national network storage and SuDS requirements is simple and takes no account of local factors affecting costs. Key limitations of this approach are the differences in costs of working in dense urban areas (with many services and heavily trafficked streets) and more suburban space with plentiful green space. The cost of land acquisition has not been included and water companies can do this to secure spaces under private ownership for the construction of storage shafts. The circumstances of each project differ, and it is challenging to generalise without using site specific information at this stage.

The unit costs of retrofitted SuDS are difficult to estimate because there is no established UK practice of implementation at scale and the engineering supply chain is inexperienced. The unit costs could fall should retrofit SuDS become business as usual and technologies and the supply chain adjust to the substantial business opportunities that would be presented. A key assumption of this work is that infiltration to the ground is not possible, and surface water flows are disconnected from the combined system. Where infiltration is possible, and there is confidence that the flows will not infiltrate into the sewer, the costs to achieve overflow spill reduction will be lower.

The capital cost of SuDS can be reduced through co-delivery and programming in public and private sectors, or at least the portion of costs payable by water companies.

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[49] As applied in UKWIR report Water Framework Directive; Disproportionate Costs 15/RG/08/10 2015.

For example, different socio-political futures may include incentives to ‘green’ urban areas, making them more climate resilient and suitable for new transportation modes (e.g., autonomous vehicles). Drainage improvements made at the same time may be deliverable at reduced marginal cost. Similarly, local authority programmes to cyclically re-build pavements and highways could be done with different drainage practices in mind rather than a simple reinstatement of the historical drainage pattern. This approach could achieve considerable drainage and storm overflow benefits for marginal additional costs on top of typically highways asset maintenance. Adjacent new or brown-field redevelopment can also be a catalyst for neighbourhood drainage improvements.

Partnership delivery of SuDS is essential for their uptake over large urban areas (as envisaged in this research) and would require a degree of programmatic coordination between local authorities and water companies that is unprecedented. Furthermore, this will require flexibility in implementation, with some works temporarily paused and others sped up to maximise on the opportunity.

In some locations, it may not be physically possible to build solutions at all (for all scenarios), therefore, costs could vary significantly.

The benefits within the water body applies a 50% reduction to the length improved to account for the spatial variability of the overflows within the water body. This could be a conservative estimate. If improvements are made to a water body upstream, they will benefit the water body downstream. Accordingly, this approach could help reduce the concern that many water bodies fail due to other reasons, therefore this approach removes the assumption that all the benefit is attributed to storm overflows improvement.

Benefits from SuDS will be spatially variable dependent on context. This research takes no account of these opportunities. Furthermore, care has been taken to avoid double counting, which may result in lower benefit values nationally and can be explored on a local basis. Some benefits from SuDS have been omitted but may become more important in the future or included in more detailed analysis, for example:

- Greater climate resilience such as enhanced shade and cooling from introducing more green space, which could reduce heat stress mortality, improve comfort, and reduce energy bills
- Increase in local property prices as a result of improved urban vista with green infrastructure
- Recreational benefits
- Reduced water demand if more surface water is re-used
- Reducing the discharge of urban diffuse pollution from highway runoff
- Creation of green maintenance jobs that support the economy

Operational costs may vary significantly. SuDS operational costs, in particular, may reduce if communities maintain the assets. In England, this type of community management of SuDS is in its infancy, with examples starting to be seen.[50], [51]

Retrofitting SuDS and creating new rainwater collection systems removes pressure on combined sewers but introduces a new risk of pollution via contaminated stormwater which may also need to be mitigated. Highway runoff can be heavily contaminated with hydrocarbons, microplastics and heavy metals.

The bill impact calculation is simplified and is only indicative of possible household bill increases associated with additional CAPEX and OPEX. Ofwat and water companies have more sophisticated methods which account for the influence of non-household customers, retail margin and corporation tax.

Cities across the world are adopting blue-green infrastructure as part of their adaptation to climate change and endeavours to reduce river pollution. These measures are often in combination with conventional upgrades to buried network systems. Approaches to measuring benefits from this type of SuDS solution are in their infancy and often insufficiently trusted or agreed upon to prevent conventional approaches being the norm. In a post-COVID-19 world, it is widely agreed that outdoors and green space is evermore appreciated by the public as are clean rivers. It is hence likely that further improvements to natural capital accounting systems will continue to attract utilities and planners towards blue-green solutions.

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[50] Lea Brook Valley, Dronfield (arocha.org.uk)
[51] https://www.linkedin.com/feed/update/urn:li:activity:6844609842368282624

4.0 Results

This research's results are structured as follows:

1. Changes to river health risks, comparing 2020 and 2050 (do nothing) and the outcome from policies F40, F40-10, F20, F10, F5 and F0
2. Changes to public health risks, comparing 2020 and 2050 (do nothing) and the outcome from policies F40, F40-10, F20, F10, F5 and F0
3. Changes to social impact risks, comparing 2020 and 2050 (do nothing) and the outcome from policies F40, F40-10, F20, F10, F5 and F0
4. CAPEX and OPEX estimates to achieve each policy under three delivery scenarios (W, S10 and S50) and also embedded carbon comparisons
5. Impact on bills for policies and scenarios
6. Benefit cost appraisal for policies and scenarios

Each section contains a short commentary to aid results interpretation.

Methodology and assumptions are outlined in Section 3.

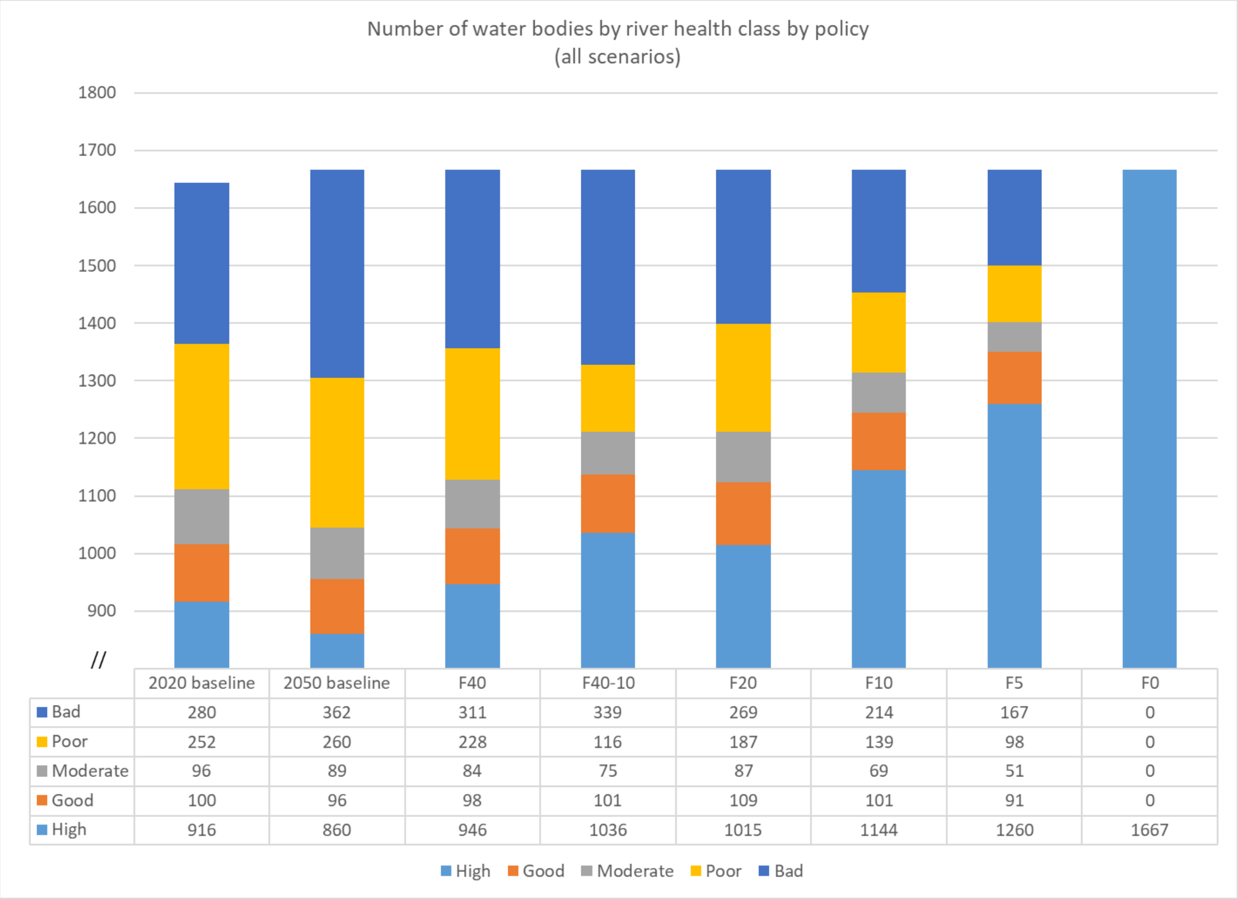
To account for incomplete performance information on storm overflows it is recommended that costs and benefits could be inflated by 30% (± 10 percentage points). Inflated capital cost estimates for different polices and scenarios are included in Appendix F.

A series of additional policies (requested by Defra) focused on improving only certain water bodies are also explored. These are presented in Appendix D and explore:

- Applying an average 10 spills per year to only sensitive water bodies and/or those with RNAG linked to storm overflows
- Applying an average five spills per year to only water bodies used recreationally

4.1 Changes to river health risks, comparing 2020 and 2050 (do nothing) and the outcome from policies F40, F40-10, F20, F10, F5 and F0

Figure 4-1 Number of water bodies in storm overflow equivalent ecological class by policy



	2020 baseline	2050 baseline	F40	F40-10	F20	F10	F5	F0
■ Bad	280	362	311	339	269	214	167	0
■ Poor	252	260	228	116	187	139	98	0
■ Moderate	96	89	84	75	87	69	51	0
■ Good	100	96	98	101	109	101	91	0
■ High	916	860	946	1036	1015	1144	1260	1667

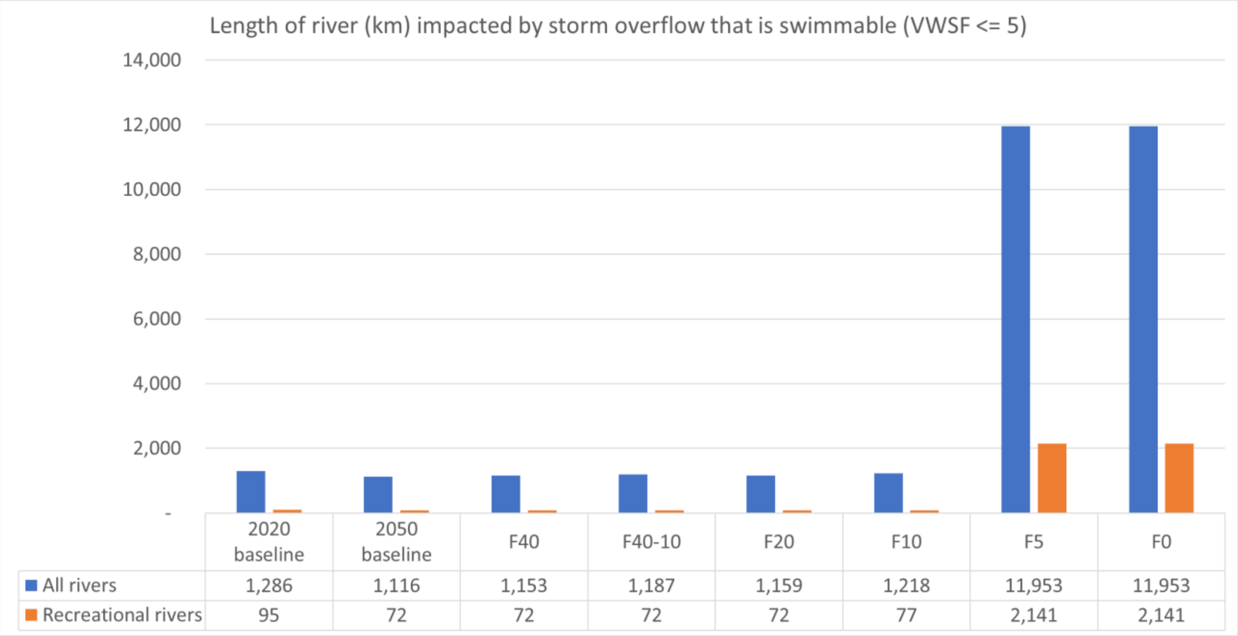
1. There is a deterioration in water quality between 2020 and 2050 because of reduced river flows and increased discharges through storm overflows. The number of water bodies not achieving good increases by 83, a 13% increase.
2. Reducing spill frequency (and hence volumes) through different policies progressively improves water quality until when there are zero spills (F0) there are no risks to water quality from storm overflows.
3. The F40-10 policy is broadly equivalent to the F20 policy in terms of outcome.

4. A step change in water quality occurs with the F10 policy when the percentage of water bodies achieving moderate or better reaches 75%, a measure which improves to 81% for F5.

5. Note that there are many other sources of harm to river health; this analysis only considers storm overflows.

4.2 Changes to public health risks, comparing 2020 and 2050 (do nothing) and the outcome from policies F40, F40-10, F20, F10, F5 and F0

Figure 4-2 Length of river impacted by storm overflow where public health risks are acceptable



	2020 baseline	2050 baseline	F40	F40-10	F20	F10	F5	F0
■ All rivers	1,286	1,116	1,153	1,187	1,159	1,218	11,953	11,953
■ Recreational rivers	95	72	72	72	72	77	2,141	2,141

1. There is a deterioration in this risk between 2020 and 2050 because of increases in the frequency of discharges through storm overflows. The length of river considered suitable for swimming good decreases by 170km (13%). Of rivers where there is existing recreational use, the decrease is 23km (24%).

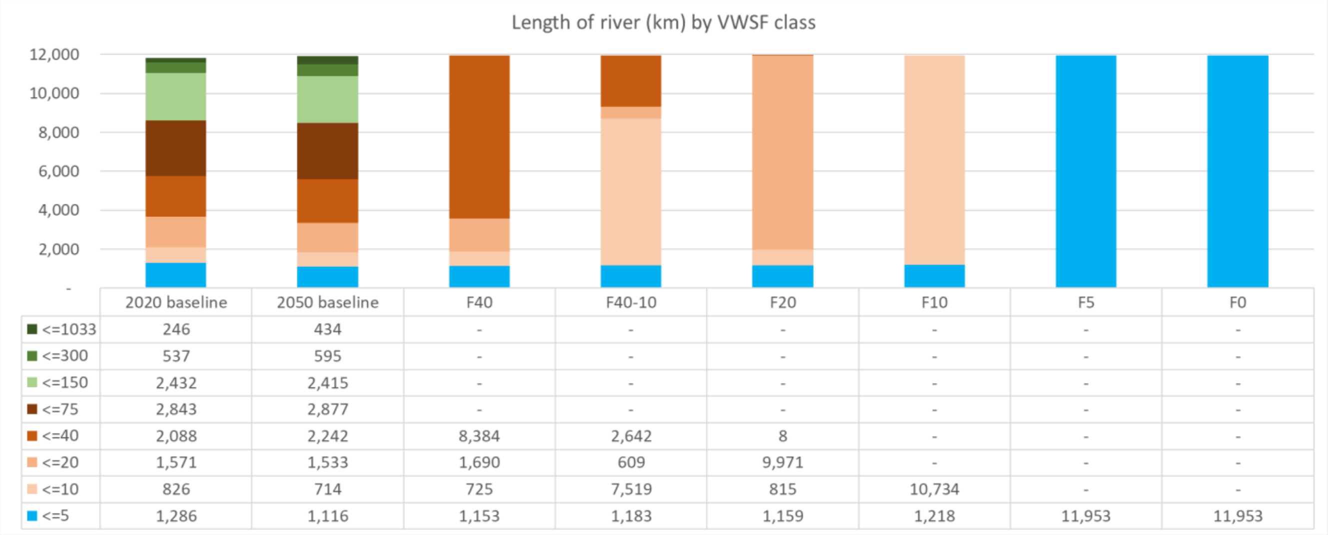
2. In 2050 only 9% of water bodies (by length) receiving storm overflows will be swimmable by this measure. Of rivers where there is existing recreational use, the equivalent value is 3%.

3. The F5 policy immediately brings all storm overflow water bodies to a swimmable standard (by this measure) due to the assumption that F5 this limits the likelihood of harm.

4. Note that there are many other sources of harm to public health in rivers; this analysis only considers storm overflows. It may be safe to swim in rivers with high storm overflow spill frequencies or higher spill policy options if warnings (during and after wet weather) are provided and adhered to.

4.3 Changes to social impact risks, comparing 2020 and 2050 (do nothing) and the outcome of each policy

Figure 4-3 Length of river by VWSF class equating to risk of social impact



	2020 baseline	2050 baseline	F40	F40-10	F20	F10	F5	F0
■ <=1033	246	434	-	-	-	-	-	-
■ <=300	537	595	-	-	-	-	-	-
■ <=150	2,432	2,415	-	-	-	-	-	-
■ <=75	2,843	2,877	-	-	-	-	-	-
■ <=40	2,088	2,242	8,384	2,642	8	-	-	-
■ <=20	1,571	1,533	1,690	609	9,971	-	-	-
■ <=10	826	714	725	7,519	815	10,734	-	-
■ <=5	1,286	1,116	1,153	1,183	1,159	1,218	11,953	11,953

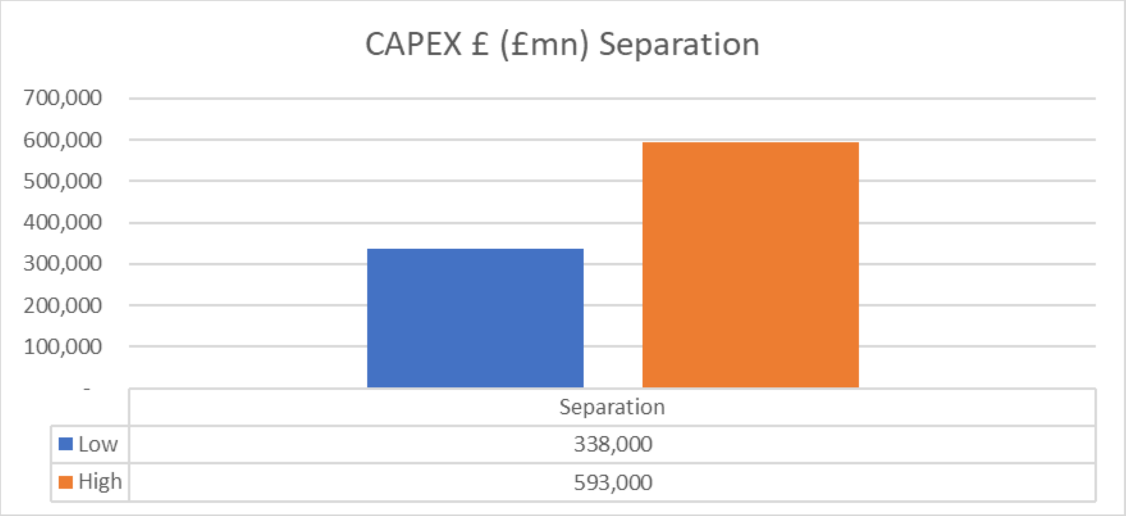
1. There is a deterioration in this risk between 2020 and 2050 because of increases in the frequency of discharges through storm overflows. The length of river where VWSF is greater than 40 increases by 262km (4%).

2. The most significant step change in social impact occurs between baseline 2050 and F40 when very high frequency overflows are addressed. There will still be significant social impacts at F40 with many rivers receiving frequent discharges from multiple overflows.

4.4 CAPEX and OPEX estimates to achieve each policy under three delivery scenarios (W, S10 and S50)

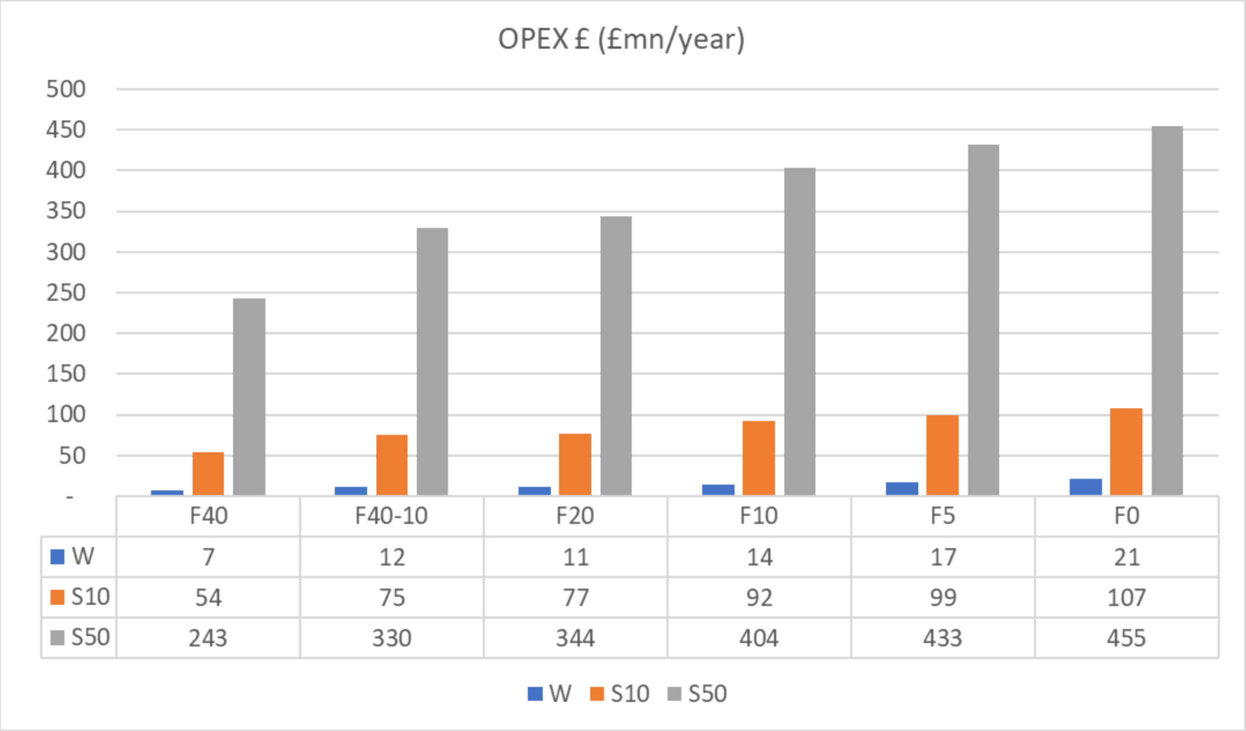
Figure 4-4 CAPEX estimates for policies and scenarios

Figure 4-5 CAPEX estimate for stand-alone separation scenario



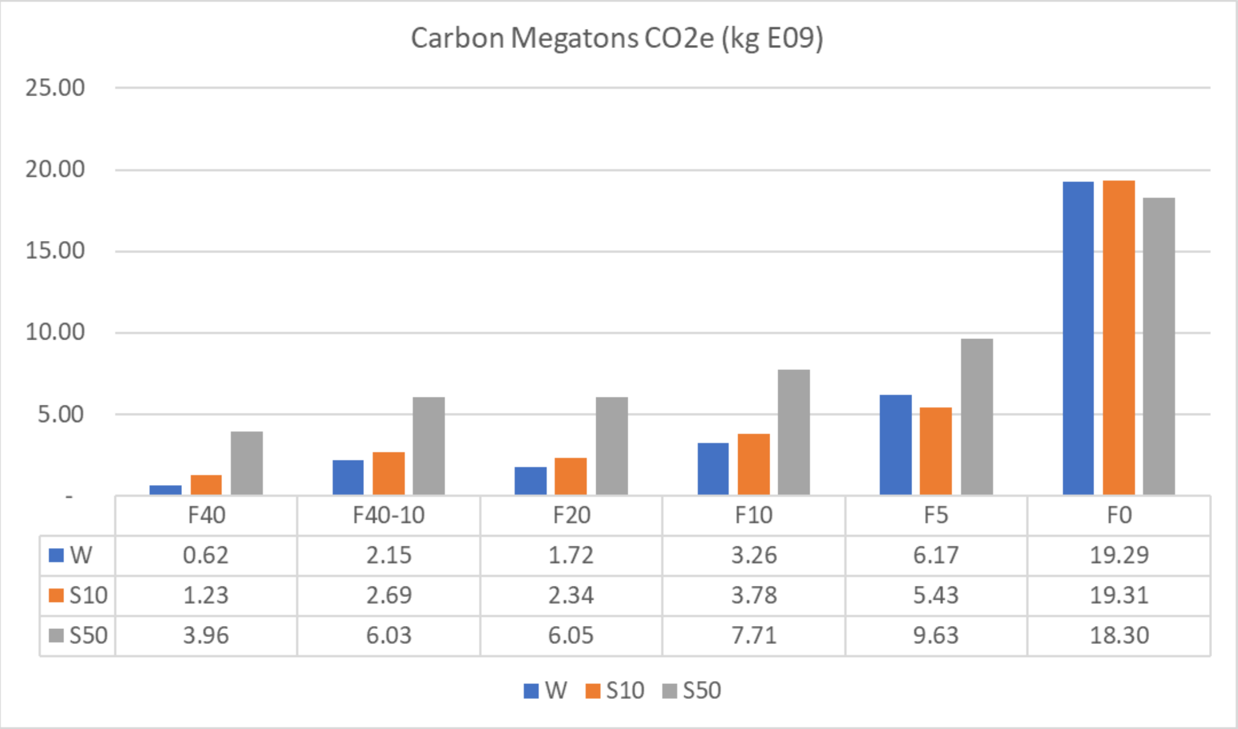
	Separation
Low	338,000
High	593,000

Figure 4-6 OPEX estimates for policies and scenarios



	F40	F40-10	F20	F10	F5	F0
W	7	12	11	14	17	21
S10	54	75	77	92	99	107
S50	243	330	344	404	433	455

Figure 4-7 Embedded carbon estimates for policies and scenarios



	F40	F40-10	F20	F10	F5	F0
■ W	0.62	2.15	1.72	3.26	6.17	19.29
■ S10	1.23	2.69	2.34	3.78	5.43	19.31
■ S50	3.96	6.03	6.05	7.71	9.63	18.30

1. To account for storm overflows not included in this research’s analysis costs could be increased by 30% (± 10 percentage points). Inflated capital cost estimates for different polices and scenarios are included in Appendix F.

2. Carbon for the network storage scenario is relatively low F40 through to F10 as the solutions build upon an existing network and use discrete tank structures to retain flows. Beyond F10 and the size of the storage starts to become considerable and therefore the carbon impact also increases.

3. The distributed nature of SuDS requires them to be connected and joined up to effectively create an additional drainage network. The SuDS approach considers source control, conveyance, and storage. This explains the relatively large carbon estimation for scenarios including SuDS, which is broadly equivalent to the network storage solution for the lower level of SuDS (S10) but higher for higher level of SuDS scenarios (S50). The differences in carbon between scenarios reduces as the reduction in spill frequency increases.

4. The generalised assumptions made here do not preclude the specific circumstances where local opportunities will present low carbon and low-cost solutions with a SuDS or blue-green infrastructure component. The cost and carbon consequences of adopting different solution types locally should always be tested. For example,

   a. It may be possible to infiltrate from the SuDS direct to the ground

   b. There are opportunities for disconnecting surface water network systems from combined sewers and diverting discharges direct to rivers or via other blue-green infrastructure will often provide lower cost and lower carbon options.

5. The generalised assumptions made here about carbon associated with different materials do not allow for innovation and the development of low carbon products in the future.

6. SuDS provide a more adaptable approach. If SuDS were implemented in a programmatic way with other delivery bodies, for example, displacing the carbon associated with highways maintenance and replacement, the net increase in carbon and costs would reduce.

7. For context, the embedded carbon for materials and construction activities for the £5bn Thames Tideway storm overflow tunnel in London has been estimated[52] as tCO2e 790,064 which is 4% of this research's F0-W estimate (tCO2e 19,290,000) for England.

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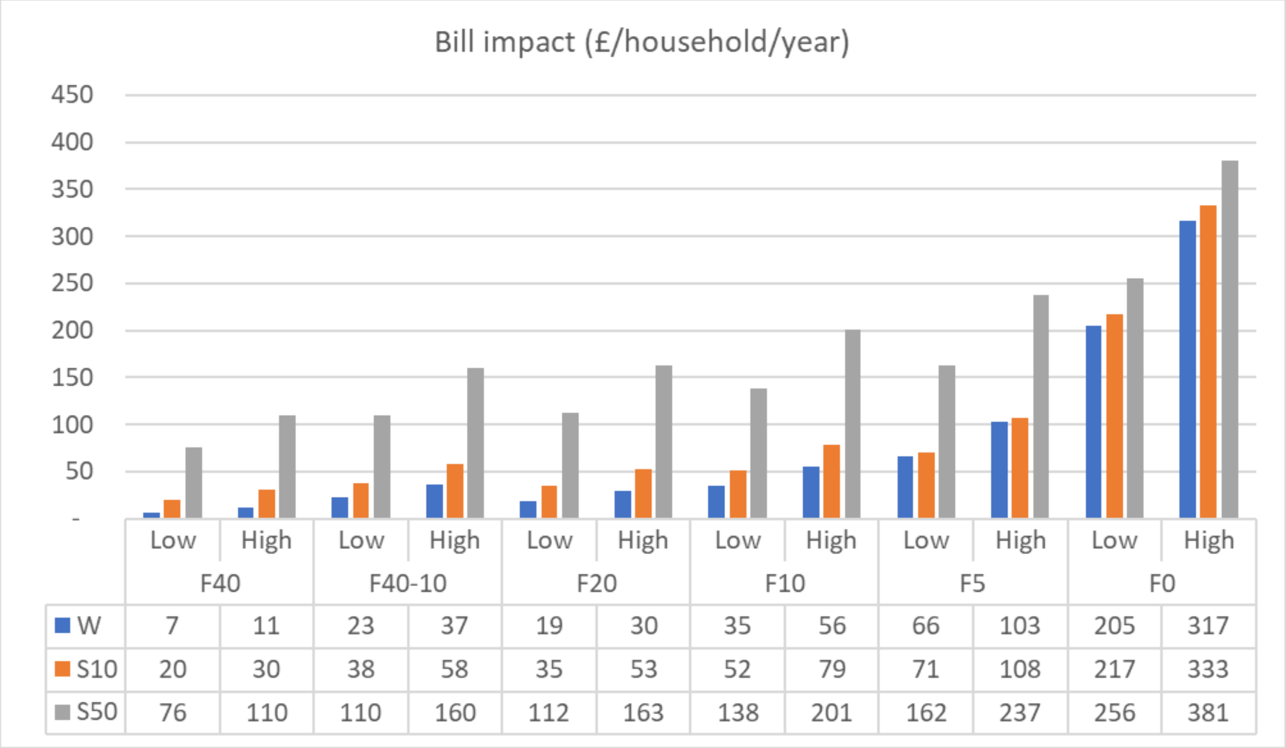
[52] http://www.energyforlondon.org/wp-content/uploads/2013/05/Thames-Tideway-7.08_Energy_and_Carbon_Footprint_Report.pdf

4.5 Impact on bills for policies and scenarios

Figure 4-8 Bill impact estimates for policies & scenarios



	F40		F40-10		F20		F10		F5		F0	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
■ W	7	11	23	37	19	30	35	56	66	103	205	317
■ S10	20	30	38	58	35	53	52	79	71	108	217	333
■ S50	76	110	110	160	112	163	138	201	162	237	256	381

1. The potential bill impact ranges from £7 to £381, depending on the scenario considered and the estimate taken. For context, the expected bill impact of the Thames Tideway tunnel for Thames Water customers is £20 to £25 by the mid-2020s.[53]

2. The bill impact estimate for the stand-alone separation scenario (not illustrated but provided here for comparison) is between £569 and £999 per annum assuming OPEX is unchanged from today.

3. Bill impact forecasts assume that all households in England equally share the burden of storm overflow improvements. In addition, it does not take into account that the burden would be spread between households and non-households, so the impact on household bills would be lower than that shown.

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[53] PN 02/15 Ofwat awards license for Thames Tideway Tunnel - Ofwat

4. Bill impact calculations assume that all investment is made by water companies and hence financed through bill payments from water company customers. Whilst this is reasonable for wastewater network and treatment scenarios (W) it is less so for the S10 and S50 scenarios which include retrofitted SuDS. In these cases, there are opportunities for partnership delivery and sharing of costs. While estimates for total investment needs are robust, the proportion of this financed through water bills is questionable depending on the nature of future partnership arrangements.
5. To account for storm overflows not included in this research's analysis, bill impact could be increased by 30% (±10 percentage points). Adjusted bill impact values are included in Appendix F.

4.6 Benefit cost appraisal for policies and scenarios

Figure 4-9 Benefit cost appraisal for policies and scenarios

Net present value (Scenario W)

	F40	F40-10	F20	F10	F5	F0
■ NPV (£mn) Low (low ben/high cost)	(3,507)	(14,221)	(11,095)	(21,892)	(41,767)	(134,539)
■ NPV (£mn) High (high ben/low cost)	(1,328)	(7,789)	(5,788)	(12,347)	(24,324)	(83,027)

Benefit cost ratio (Scenario W)

	F40	F40-10	F20	F10	F5	F0
■ Low (low ben/high cost)	0.28	0.11	0.14	0.09	0.07	0.02
■ High (high ben/low cost)	0.54	0.21	0.27	0.17	0.13	0.05

Net present value (Scenario S10)

	F40	F40-10	F20	F10	F5	F0
■ NPV (£mn) Low (low ben/high cost)	(10,506)	(22,613)	(19,271)	(29,909)	(41,473)	(139,042)
■ NPV (£mn) High (high ben/low cost)	(4,121)	(12,801)	(8,604)	(14,656)	(21,162)	(82,764)

Benefit cost ratio (Scenario S10)

	F40	F40-10	F20	F10	F5	F0
■ Low (low ben/high cost)	0.19	0.09	0.15	0.12	0.11	0.04
■ High (high ben/low cost)	0.51	0.21	0.41	0.33	0.29	0.10

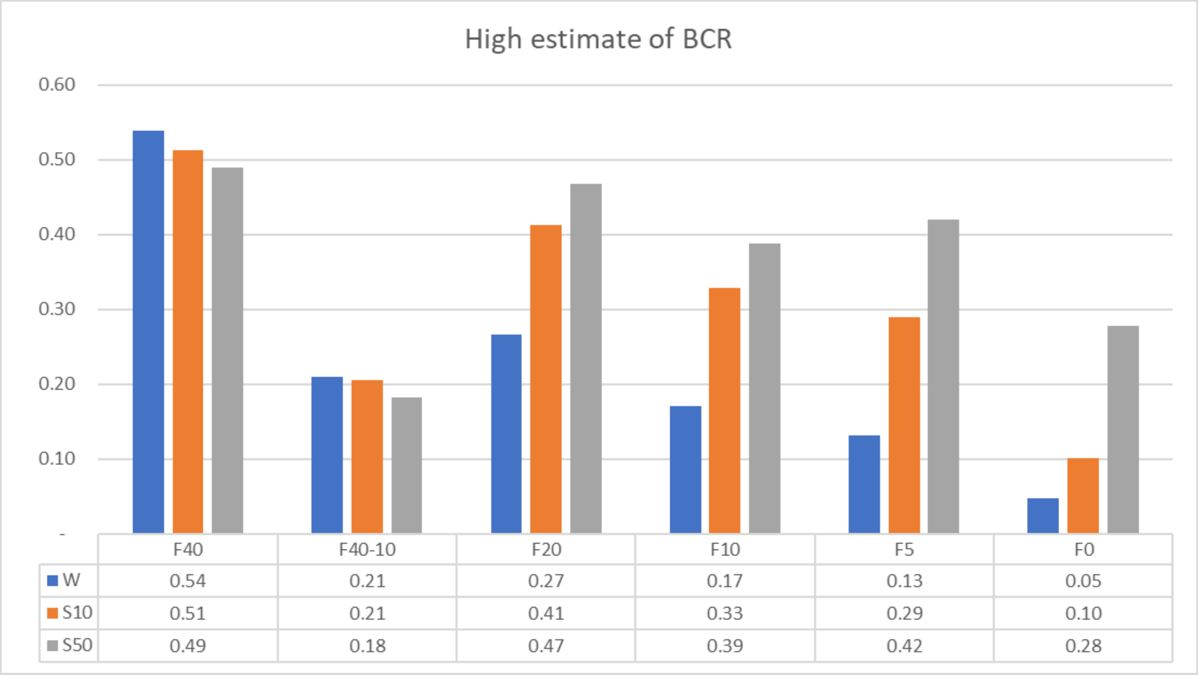
Net present value (Scenario S50)

	F40	F40-10	F20	F10	F5	F0
■ NPV (£mn) Low (low ben/high cost)	(40,110)	(63,798)	(59,862)	(75,709)	(88,685)	(150,471)
■ NPV (£mn) High (high ben/low cost)	(16,261)	(37,666)	(24,958)	(35,294)	(39,395)	(77,771)

Benefit cost ratio (Scenario S50)

	F40	F40-10	F20	F10	F5	F0
■ Low (low ben/high cost)	0.14	0.06	0.13	0.11	0.12	0.08
■ High (high ben/low cost)	0.49	0.18	0.47	0.39	0.42	0.28

Figure 4-10 High estimate of BCR for each policy and scenario



	F40	F40-10	F20	F10	F5	F0
🟦 W	0.54	0.21	0.27	0.17	0.13	0.05
🟧 S10	0.51	0.21	0.41	0.33	0.29	0.10
⬜ S50	0.49	0.18	0.47	0.39	0.42	0.28

1. The overall benefits of the proposals presented in this research range from (present value over 50-year assessment period) £1.4bn (F40 scenario W, low estimate) to £29.9bn (F0 scenario S50, high estimate). For context, the range of estimated benefits of Thames Tideway Tunnel were (present value over 120-year assessment period) £2.7bn (scenario A, Thames Water customers only) to £12.7bn (scenario D, national population).[54] This suggests that the assessment of benefits made in this research broadly aligns with expectations established for Thames Tideway Tunnel.
2. Figure 4-9 shows the NPV and BCR for each policy and scenario with low and high estimates. Figure 4-10 presents a subset of these data focussed on the high estimate of BCR only, allowing for a more direct comparison to be made between different policies and scenarios.
3. The most economically advantageous policy (highest BCR and NPV) is the least ambitious in terms of spill frequency reduction: F40. There are small differences between scenarios for policy F40, but overall, the BCR is always less than one as costs outweigh benefits.

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[54] eftec (2015) Update of the Economic Valuation of the Thames Tideway Tunnel Environmental Benefits. Final Report for Defra

4. Other policies are less economically advantageous by comparison, with declining BCRs as the control of spill frequency increases. However, at these levels of control, the quantity of SuDS necessary to control spills in the S10 and S50 scenarios introduce additional benefits and, in every case, the SuDS based policies are more economically advantageous than the conventional network storage alternative. Scenario S50 is superior to scenario S10 in all policies F20, F10, F5 and F0. However, it should be noted that the benefits associated with S50 come with significant additional cost and potential water-bill burden on customers or other funders (see Figure 4-8).
5. The most uncertain and unvalidated of the benefits included in this appraisal is that due to reduced social impact. In this research, social impact benefits are currently linked to a fraction of the willingness to pay for reduction in pollution incidents and range between £1,503 and 1,643 per avoided volume weighted spill frequency count. This research estimates that if grounds for increasing this benefit to at least £10,000 could be evidenced, then BCR would approach or exceed a value of one across a number of polices and scenarios.

5.0 Recommendations for reducing uncertainties and improving evidence

This strategic national assessment indicates substantial investment is required to reduce harm from storm overflows. This research has used data from water companies and made a number of assumptions to estimate harm caused by storm overflows and potential policy options and scenarios, along with their costs and benefits.

To improve the confidence in the assessment and remove some uncertainty, the following is recommended:

- Undertake customer engagement using the findings from this strategic assessment to understand the general public's desire for improvements and the willingness to pay for alternative policy options and scenarios. Such engagement should explore the potential to treat spill flows rather than only reduce storm overflows. It should seek to encompass (but value separately where possible) the range of river health, public health, social and other benefits of reducing spills.
- Undertake benefit evaluation studies to gain a greater and focused understanding of the wider benefits related to SuDS. In particular, there should be a focus on the health and wellbeing benefits to enable greater confidence in the transfer of benefit values and estimating the quantities.
- Undertake studies to gain a better understanding of the whole life carbon and whole life costs of implementing SuDS over large urban areas, including how costs can be shared though co-creation opportunities. A first step to strengthen the costs should be to review current large scale retrofit programmes being designed and the work of the DWMPs in the Option Development and Appraisal stage.
- Undertake a national level assessment on the synergies between urban drainage improvements to manage storm overflows (this research) and closely related interventions to reduce the risk of flooding, including from extreme events as a result of climate change. It is important not to consider storm overflows in isolation from other urban drainage adaptations that will be necessary over the next 30 years. There are opportunities to engineer solutions with multiple benefits, calling on a variety of funding routes. These are being explored through some DWMP, but a national assessment (building on SOEP) would be beneficial.
- Request and utilise more granular data from the water companies (e.g., pipe and catchment data) that would enable more accurate development of storage, in particular impermeable area reductions estimates, the ease of retrofitting SuDS and whether infiltration was possible.

- Evaluate the limitations of constructing some solutions. In particular, focus on constraints around building large network storage solutions within urban areas. This should include GIS analysis to indicate space and land availability requirements. As part of this assessment, the viability of increasing the treatment capacity at works should be evaluated further.

- Explore the potential cost and water quality effect of treating storm overflows nationally using hard engineered and nature-based solutions.

- In-depth analysis of sewer network hydraulic model predictions vs EDM data to consider further the effect differences may have on predictions of harm and solution costs and benefits. For example, by better understanding the percentage of spills which could be eliminated through better sewer asset management and operations and through education programmes to change the public’s behaviour over what to flush.

- Examine quantitative information on the causes of storm overflow to determine the balance of hydraulic capacity drivers (the focus of this research) and issues related to asset health and customer behaviour.

- Improve understanding of the role storm overflows play in overall water body status, and the likely effect of storm overflow improvements in water bodies where they are/are not the main reason for failure.

- Undertake an assessment of other (not storm overflow) pollution issues that may remain if storm overflows are improved and also make some water bodies sensitive to harm from storm overflows. For example, this assessment should examine the pollution from surface water sewers, often due to mis-connections at a property level.

APPENDICES

Appendix A Engineering Approaches

Underground Storage Tanks

Underground storage tanks have typically been one of the 'go-to' solutions for reducing storm overflows in the industry. The solution creates volume within the network that can be mobilised in a storm event. The volume created flattens the peak (flow and level) within the network, reducing the frequency of spills to river. Once the storm event is over, the stored volume is returned to the network.

While the total volume and number of overflows is reduced, this solution does not generally improve the quality of any flows that still spill to river.

Storage tanks can be located in the public realm but optimal locations are heavily dependent on the sewer network hydraulics. Once constructed, the level of disruption to the community is small (usually just a kiosk and vent column above ground). However, there are typically no wider socio-environmental benefits as a result of this solution.

In some networks, the overall impact of a storage tank strategy could be significantly improved by connecting them with tunnels. However, while this approach may enhance the long term adaptability of the solution, the associated cost and disruption would be substantial.

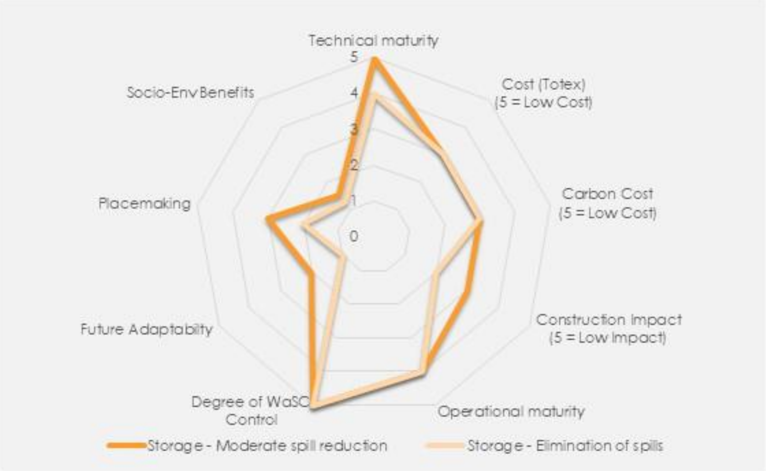
Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
STW

Solution Type
Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
Concentrated
Distributed

Effective vs Groundwater
Yes
No

An underground storm storage tank in construction



Pros

- Well established across the industry and the impact of implementation on the sewer network can be predicted with a high degree of confidence.
- Although the construction phase is disruptive, the land-take, once operational, is relatively small.
- Overall effectiveness and adaptability can be enhanced, in certain networks, by linking storage tanks with tunnels.

Cons

- May require increased hydraulic and treatment capacity to be added as a result of more volume being retained within the system. This factor becomes more challenging and complex as more storage tanks are added to the system.
- Does not reduce spills that are driven by groundwater (as opposed to stormwater).
- This solution typically requires pumps to empty the tank after a storm. Increases operational cost and carbon. Depending on the size of the tank it may also require a large kiosk for operational purposes.
- Deep shafts may introduce other technical complexities (e.g. energy dissipation) that increase cost.

SuDS

SuDS (sustainable drainage systems) is a collective term for surface water management practices that aim to replicate the natural environment by storing and conveying water on (or close to) the surface. Where ground conditions permit, SuDS allow surface water to infiltrate into the ground. SuDS also provide the net effect of slowing down surface water runoff before it enters the sewer network, reducing the number and volume of combined sewer overflows.

SuDS can have a significant impact on network capacity (and consequently storm overflows) when applied in a targeted manner. They also provide a wide range of wider benefits and improve the aesthetic qualities of the built environment.

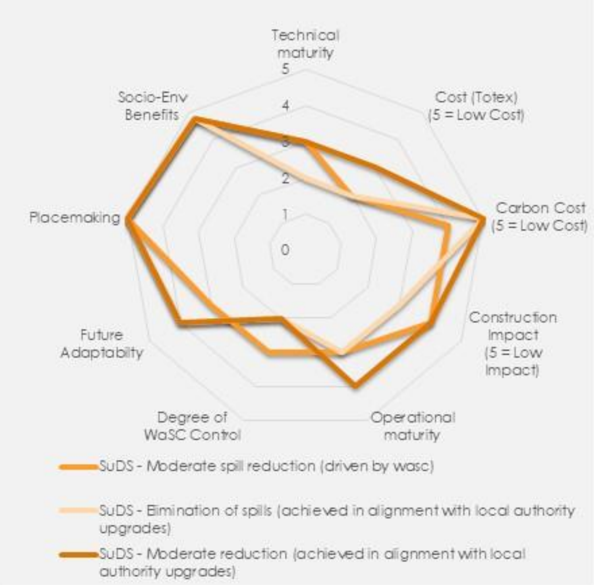
Courtesy of susdrain

Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
STW

Solution Type
Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
Concentrated
Distributed

Effective vs Groundwater
Yes
No

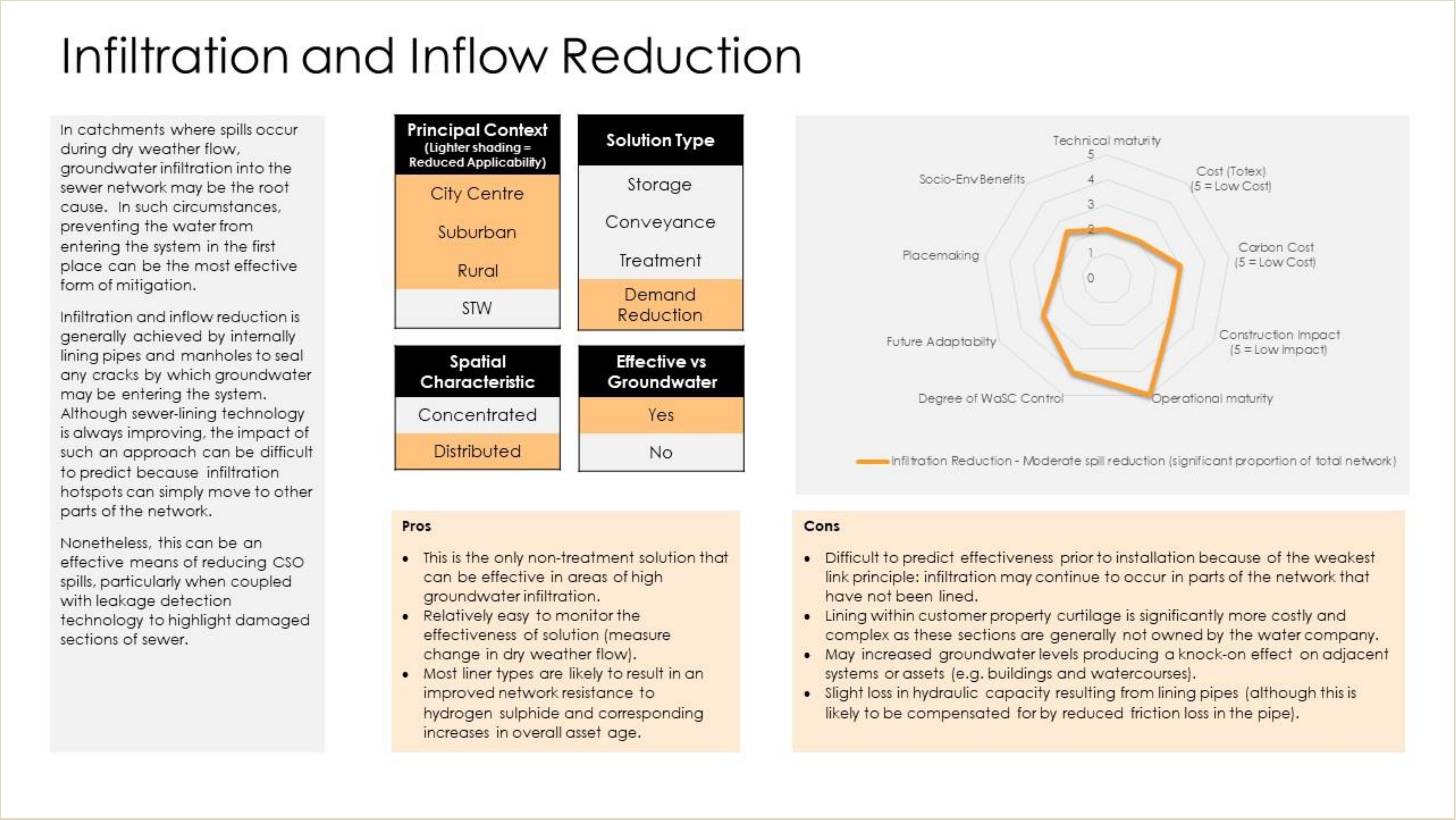


Pros

- SuDS deliver a wide range of long term socio-environmental benefits and a make significant placemaking contribution.
- Number and type of SuDS measures across an entire catchment can be gradually increased to respond to changing requirements.
- Can be delivered as a long term programme, potentially also in alignment with local authority improvements.
- Can also be designed for exceedance to improve performance under extreme weather conditions.

Cons

- Hydraulic modelling tools are relatively slow and complex, resulting in increased uncertainty when scaled-up to catchment level.
- Certain SuDS types are less well-understood by stakeholders than others. May have implications for adoption of these measures.
- Speed of delivery (on a catchment-wide scale) is limited due to requirement for multi-stakeholder acceptance.
- Inconsistent approach to adoption of SuDS by WaSCs. Long term statutory status is currently unclear.
- Optimal hydraulic performance usually requires additional controls to prevent backflow from the sewer network, increasing design and installation costs.



Infiltration and Inflow Reduction

In catchments where spills occur during dry weather flow, groundwater infiltration into the sewer network may be the root cause. In such circumstances, preventing the water from entering the system in the first place can be the most effective form of mitigation.

Infiltration and inflow reduction is generally achieved by internally lining pipes and manholes to seal any cracks by which groundwater may be entering the system. Although sewer-lining technology is always improving, the impact of such an approach can be difficult to predict because infiltration hotspots can simply move to other parts of the network.

Nonetheless, this can be an effective means of reducing CSO spills, particularly when coupled with leakage detection technology to highlight damaged sections of sewer.

Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
STW

Solution Type
Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
Concentrated
Distributed

Effective vs Groundwater
Yes
No

Pros

- This is the only non-treatment solution that can be effective in areas of high groundwater infiltration.
- Relatively easy to monitor the effectiveness of solution (measure change in dry weather flow).
- Most liner types are likely to result in an improved network resistance to hydrogen sulphide and corresponding increases in overall asset age.

Cons

- Difficult to predict effectiveness prior to installation because of the weakest link principle: infiltration may continue to occur in parts of the network that have not been lined.
- Lining within customer property curtilage is significantly more costly and complex as these sections are generally not owned by the water company.
- May increased groundwater levels producing a knock-on effect on adjacent systems or assets (e.g. buildings and watercourses).
- Slight loss in hydraulic capacity resulting from lining pipes (although this is likely to be compensated for by reduced friction loss in the pipe).

Active System Management

Active system management (ASM) covers a wide range of measures, all aimed at proactively monitoring the combined sewer system in order to predict an outcome (e.g. spill to river) and then take action to prevent it happening.

Although ASM can take multiple forms in the context of reducing CSO spills, this solution will focus on the use of discrete control points in the network to mobilise available network storage during storm events. The control points in question could be pumping stations or penstocks and they would operate (or not) in response to predicted weather and sewer flow conditions.

Where there is no available storage in the network, this approach is likely to have minimal impact unless such storage is created as part of the solution (e.g. buried storage tank). In many cases, ASM is best used as an enabling technology to optimise the performance of another solution. ASM may also be used to facilitate a dynamic consenting strategy, whereby CSO spills are permitted only during certain periods depending on fluctuations in receiving water quality.

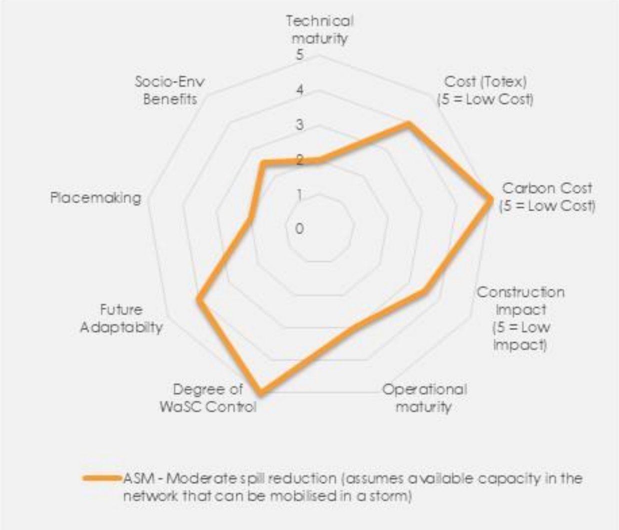
Active monitoring of network health, flows and levels can detect the occurrence of anomalies providing early warning of operational issues (e.g. blockages) which if acted on may avoid overflows caused in this this way. Such 'smart sewer' solutions are now becoming more commonplace.

Principal Context (Lighter shading = Reduced Applicability)
🟧 City Centre
🟧 Suburban
🟧 Rural
🟧 STW

Solution Type
🟧 Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
🟧 Concentrated
Distributed

Effective vs Groundwater
Yes
🟧 No



Pros

- Optimises the existing system. Unlocks potential within the existing network by maximising the use of existing available storage.
- Highly flexible. The flexibility of the system is theoretically increased with every monitor and/or control point that is added to the system.
- Can compliment other network solutions by maximising the use of any additional capacity created.

Cons

- Likely to bring limited benefit to systems that do not have unused storage potential (e.g. low-gradient catchments that surcharge significantly prior to spills occurring).
- All but the simplest systems require an effective analytics capability. Although the technology in this area is improving rapidly, such capability can be challenging to embed into an operating organisation.
- System failure can have potentially serious consequences (i.e. flooding, pollution).

Combined Sewer Separation

A combined sewer network may be converted into a separate system by installing a new network of pipes to carry surface (or foul) water only. In principle, this would theoretically eliminate CSO spills. Such a conversion would require extensive construction activity and would be highly disruptive, as existing sewer connections would need to be modified as well as new sewers installed. For this reason, it is unlikely that combined sewer separation could be achieved using trenchless excavation techniques. It also complicates the potential of installing a new system of smaller foul water pipes within the existing sewers (although this is theoretically possible).

In most cases, the entire sewer catchment would need to be fully separated before any significant benefit would be realised. The solution would also be vulnerable to misconnections, particularly if the existing combined sewer was converted into a surface water sewer.

This approach is not suitable for catchments where groundwater infiltration is the main spill driver, as the resulting foul water-only network would be at risk of filling with groundwater.

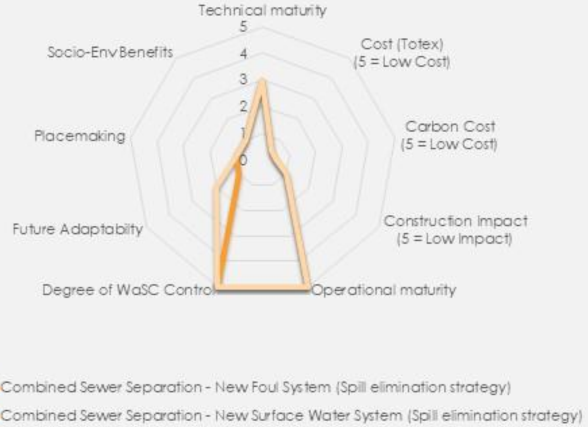
Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
STW

Solution Type
Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
Concentrated
Distributed

Effective vs Groundwater
Yes
No

New sewer construction in London



Pros

- In theory, this approach can eliminate CSO spills across a catchment.
- Although costly, this can be an opportunity for a water company to re-calibrate a sewer network that is hydraulically overloaded (e.g. due to extensive property development)
- Where a new surface water system is installed, the overall capacity (and resilience) of the network can be increased to account for future storm flow increases.

Cons

- Highly disruptive – street closures required in most cases to install new pipes and re-configure surface and foul connections.
- Vulnerable to misconnections (and river pollution), particularly if the existing combined sewer is converted to a surface water sewer.
- No socio-environmental benefits as all construction work is underground.
- Significant construction safety risk compared to other solutions due to the need for extensive excavation work on roads and potential for utility service strikes.

Treatment in the network: Integrated Constructed Wetlands

In principle, it is possible to use treatment techniques to eliminate the effect of a CSO spill without eliminating the spill itself. However, in most cases, this would require the CSO in question to be replaced with a full treatment works. One alternative to this is to treat the spill flow using a wetland.

Constructed wetlands can be used to treat wastewater to remove the polluting effect of CSO spills. Where these wetlands are integrated with wider objectives (e.g. placemaking, biodiversity), significant additional benefits can result.

There are two main types of constructed wetlands: surface flow and subsurface flow wetlands. For treatment of spill flows, land requirements are typically 3-10 m²/PE, depending on wetland type and configuration.

Prior to entry into the wetland, spill flows need to be effectively screened at the CSO and, in most cases, primary treatment is also needed (for removal of solids). The wetland acts as a form of secondary treatment for the wastewater. If tertiary treatment is required to satisfy the requirements of the watercourse, this would have to be provided separately.

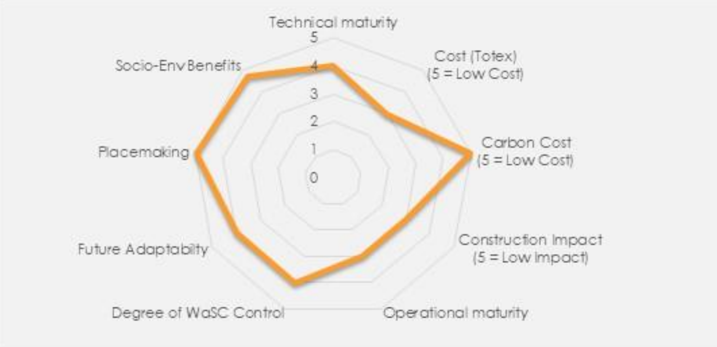
Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
STW

Solution Type
Storage
Conveyance
Treatment
Demand Reduction

Spatial Characteristic
Concentrated
Distributed

Effective vs Groundwater
Yes
No


Integrated Constructed Wetlands

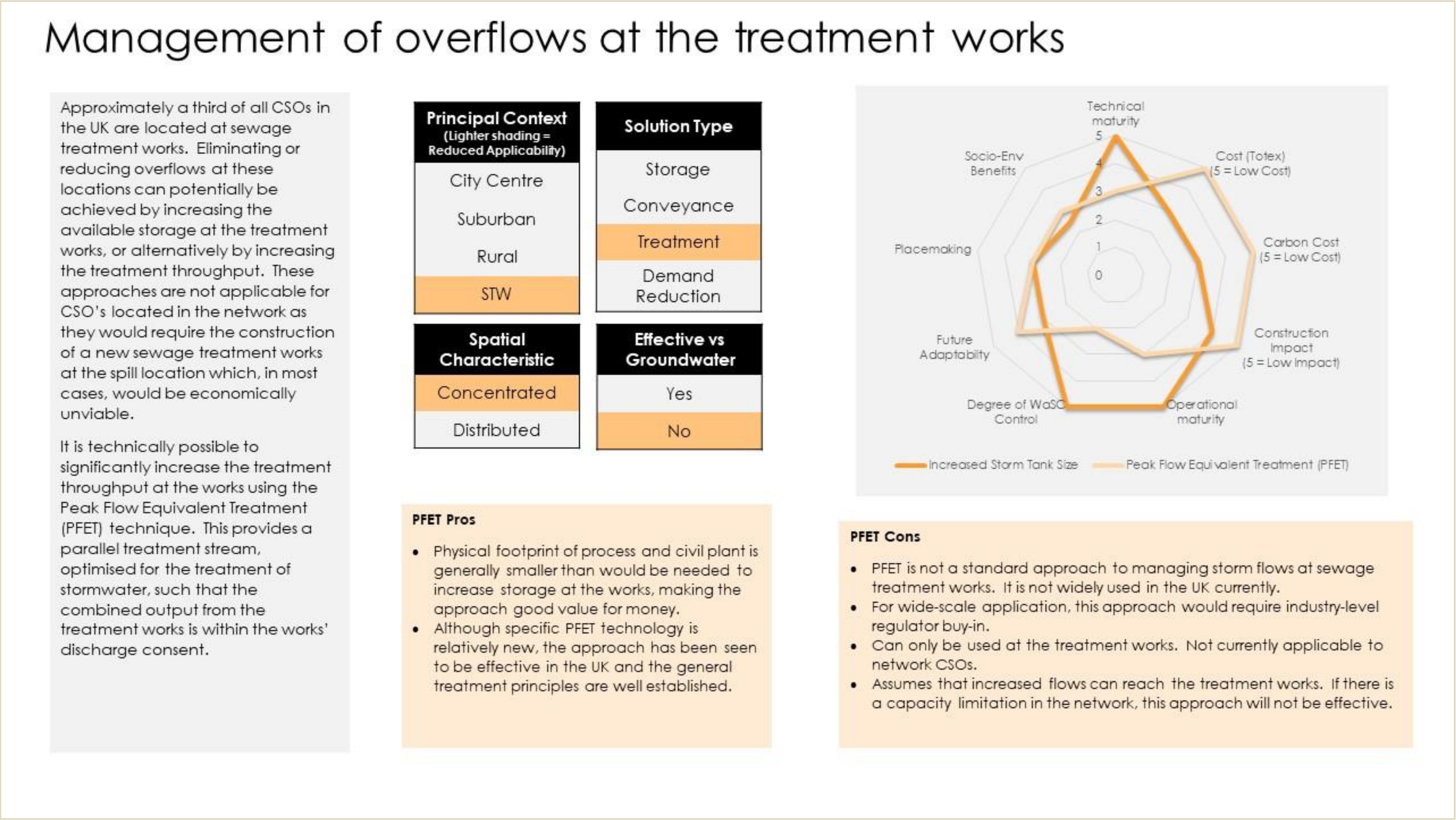


Pros

- A well-designed wetland can provide a wide range of socio-environmental and placemaking benefits. This solution is generally well-perceived by society.
- The solution technology is well-understood and generally resilient to temporary peaks in flow and load.

Cons

- The land requirements are significant and this is probably the limiting factor for applicability of wetlands in most areas. Subsurface wetlands (particularly vertical flow) have a better footprint efficiency but in general integrated constructed wetlands are unlikely to be a viable solution for large sewer networks.
- In some cases, surface flow wetlands can introduce odour and/or mosquito issues if not maintained properly.
- There is not currently believed to be a standardised approach for adoption of constructed wetlands.
- Wetland performance is higher in the summer than winter, especially with respect to nutrients and phosphorus.



Management of overflows at the treatment works

Approximately a third of all CSOs in the UK are located at sewage treatment works. Eliminating or reducing overflows at these locations can potentially be achieved by increasing the available storage at the treatment works, or alternatively by increasing the treatment throughput. These approaches are not applicable for CSO's located in the network as they would require the construction of a new sewage treatment works at the spill location which, in most cases, would be economically unviable.

It is technically possible to significantly increase the treatment throughput at the works using the Peak Flow Equivalent Treatment (PFET) technique. This provides a parallel treatment stream, optimised for the treatment of stormwater, such that the combined output from the treatment works is within the works' discharge consent.

Principal Context (Lighter shading = Reduced Applicability)
City Centre
Suburban
Rural
[✓ STW]

Solution Type
Storage
Conveyance
[✓ Treatment]
Demand Reduction

Spatial Characteristic
[✓ Concentrated]
Distributed

Effective vs Groundwater
Yes
[✓ No]

PFET Pros

- Physical footprint of process and civil plant is generally smaller than would be needed to increase storage at the works, making the approach good value for money.
- Although specific PFET technology is relatively new, the approach has been seen to be effective in the UK and the general treatment principles are well established.

PFET Cons

- PFET is not a standard approach to managing storm flows at sewage treatment works. It is not widely used in the UK currently.
- For wide-scale application, this approach would require industry-level regulator buy-in.
- Can only be used at the treatment works. Not currently applicable to network CSOs.
- Assumes that increased flows can reach the treatment works. If there is a capacity limitation in the network, this approach will not be effective.

Appendix B Storage and impermeable area constants

Linking to work in 3.4.1.1:

$$n^{th} spill\ volume = \frac{Total\ spill\ volume}{c} \times k_{n^{th}}$$

Where c is the constant that derives a relationship between total spill volume at an overflow and 1st spill volume and k a constant to estimate the nth spill volume.

$$Storage\ volume = nth\ spill\ volume\ \times s_{n^{th}}$$

Where s is a constant for different nth events that align with the policy options

nth spill	**Baseline**		**S10 – manage 10% impermeable area**		**S50 – manage 50% impermeable area**		**Spill to storage**
	c	$k_{n^{th}}$	c	$k_{n^{th}}$	c	$k_{n^{th}}$	$s_{n^{th}}$
1st (F0)	5.4054	1.0000	5.4054	0.9298	5.9512	0.6499	2.1902
5th (F5)		0.5061		0.3378		0.2721	1.3453
10th (F10)		0.2646		0.2068		0.1349	1.315
20th (F20)		0.1456		0.1091		0.0699	1.2336
40th (F40)		0.0621		0.0485		0.0234	1.0203

Linking to work in 3.4.1.2:

$$Impermeabe\ area\ to\ remove\ (ha) = \begin{matrix} Total\ Spill \\ Volume \end{matrix} \times a_{Vol\ Band} \times b_{\%\ removal}$$

Where a is the constant that represents a relationship between total spill volume and the total area for different bands of spill volume and b is a constant that represents a relationship between the total volume and impermeable area for a 10% or 50% reduction in impermeable area.

Total spill volume band (m^3)	$a_{Vol\ Band}$
0 to < 2,000	0.0569 * Volume
2,000 to <10,000	0.0074 * Volume + 68.687
10,000 to <100,000	0.0007 * Volume + 97.792
>100,000	0.0003 * Volume + 213.15

Impermeable area removal scenario	$b_{\%\ removal}$
S10	0.0231
S50	0.1161

Linking to work in 3.4.1.5

$$Revised\ annual\ average\ spill\ volume = \frac{annual\ spill\ volume}{annual\ spill\ frequncy} \times r_{n^{th}}$$

Where r is the constant for the achieved n^{th} spill.

n^{th} spill	$r_{n^{th}}$
1st (F0)	0
5th (F5)	7.000
10th (F10)	12.656
20th (F20)	25.000
40th (F40)	45.028

Appendix C Public Attitudes Survey

Appendix C Public Attitudes Survey

November 1, 2021

Stantec

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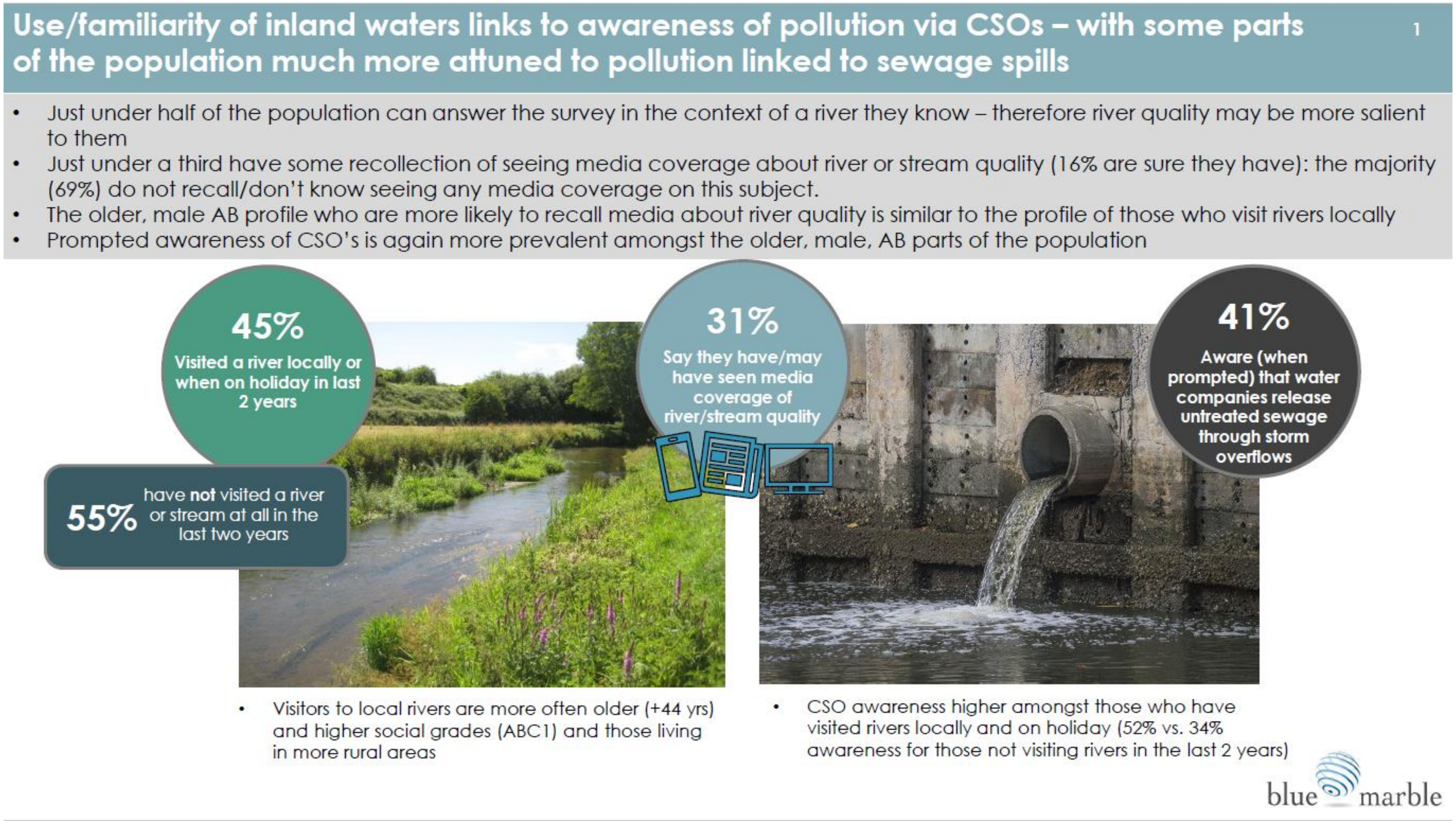
Inland Water Quality Research

Executive summary

June 2021



Use/familiarity of inland waters links to awareness of pollution via CSOs – with some parts of the population much more attuned to pollution linked to sewage spills

1

- Just under half of the population can answer the survey in the context of a river they know – therefore river quality may be more salient to them
- Just under a third have some recollection of seeing media coverage about river or stream quality (16% are sure they have): the majority (69%) do not recall/don't know seeing any media coverage on this subject.
- The older, male AB profile who are more likely to recall media about river quality is similar to the profile of those who visit rivers locally
- Prompted awareness of CSO's is again more prevalent amongst the older, male, AB parts of the population

45% Visited a river locally or when on holiday in last 2 years

55% have **not** visited a river or stream at all in the last two years

31% Say they have/may have seen media coverage of river/stream quality

41% Aware (when prompted) that water companies release untreated sewage through storm overflows

- Visitors to local rivers are more often older (+44 yrs) and higher social grades (ABC1) and those living in more rural areas

- CSO awareness higher amongst those who have visited rivers locally and on holiday (52% vs. 34% awareness for those not visiting rivers in the last 2 years)

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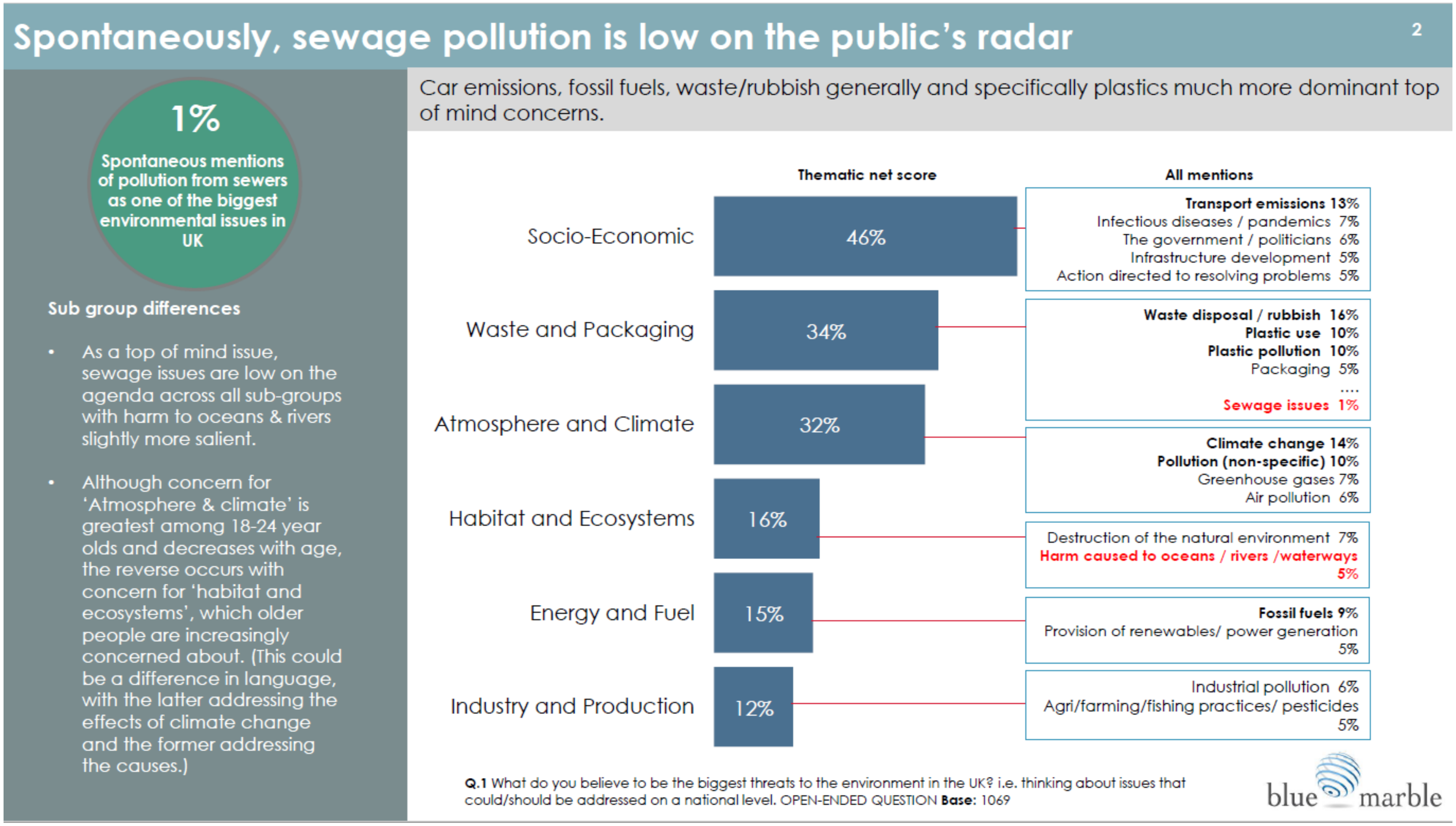

Spontaneously, sewage pollution is low on the public's radar

1%

Spontaneous mentions of pollution from sewers as one of the biggest environmental issues in UK

Sub group differences

- As a top of mind issue, sewage issues are low on the agenda across all sub-groups with harm to oceans & rivers slightly more salient.
- Although concern for 'Atmosphere & climate' is greatest among 18-24 year olds and decreases with age, the reverse occurs with concern for 'habitat and ecosystems', which older people are increasingly concerned about. (This could be a difference in language, with the latter addressing the effects of climate change and the former addressing the causes.)

Car emissions, fossil fuels, waste/rubbish generally and specifically plastics much more dominant top of mind concerns.

	Thematic net score	**All mentions**
Socio-Economic	46%	**Transport emissions 13%** Infectious diseases / pandemics 7% The government / politicians 6% Infrastructure development 5% Action directed to resolving problems 5%
Waste and Packaging	34%	**Waste disposal / rubbish 16%** **Plastic use 10%** **Plastic pollution 10%** Packaging 5% .... **Sewage issues 1%**
Atmosphere and Climate	32%	**Climate change 14%** **Pollution (non-specific) 10%** Greenhouse gases 7% Air pollution 6%
Habitat and Ecosystems	16%	Destruction of the natural environment 7% **Harm caused to oceans / rivers /waterways 5%**
Energy and Fuel	15%	**Fossil fuels 9%** Provision of renewables/ power generation 5%
Industry and Production	12%	Industrial pollution 6% Agri/farming/fishing practices/ pesticides 5%

Q.1 What do you believe to be the biggest threats to the environment in the UK? i.e. thinking about issues that could/should be addressed on a national level. OPEN-ENDED QUESTION **Base:** 1069

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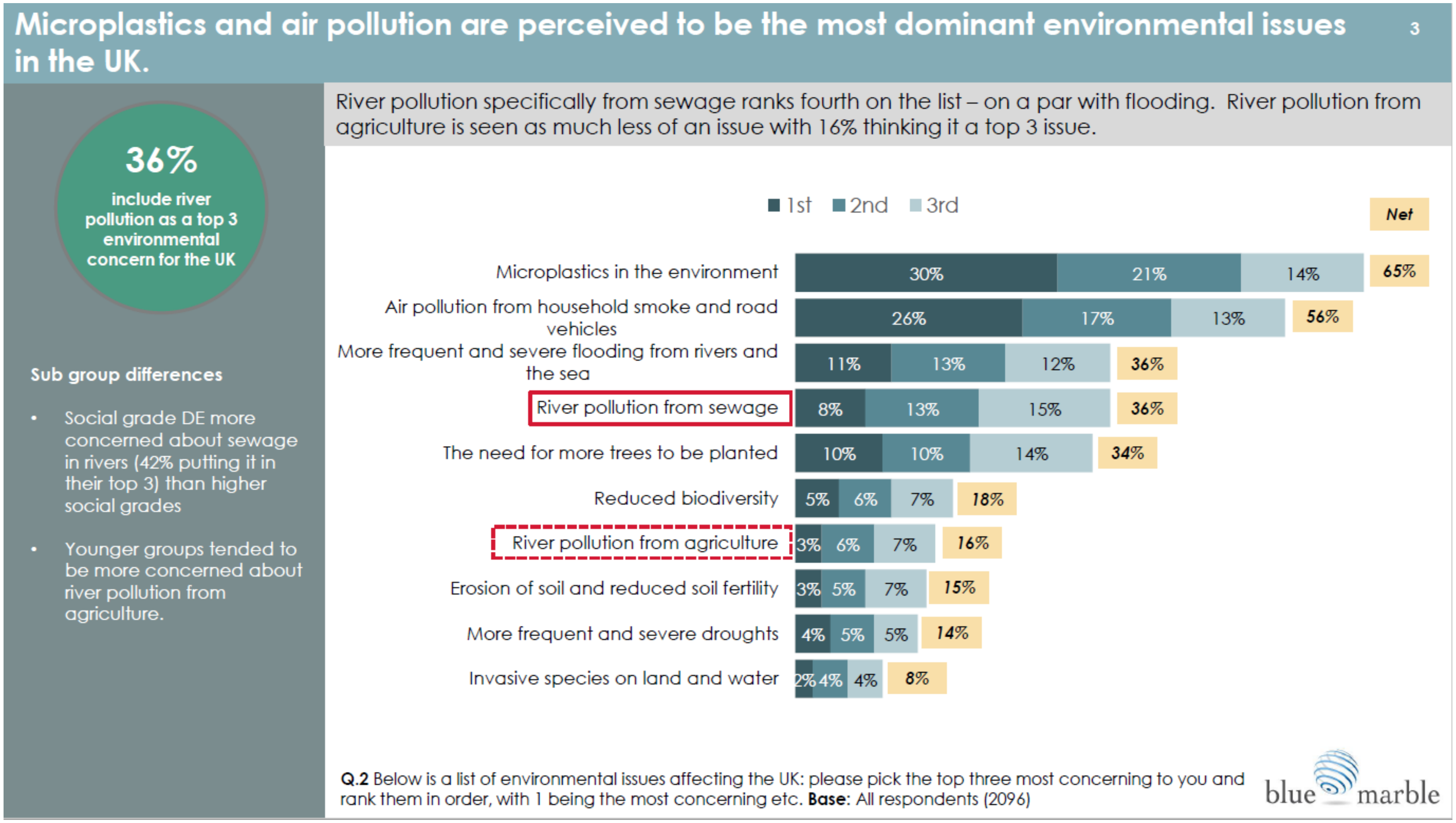

Microplastics and air pollution are perceived to be the most dominant environmental issues in the UK.

3

36%

include river pollution as a top 3 environmental concern for the UK

Sub group differences

- Social grade DE more concerned about sewage in rivers (42% putting it in their top 3) than higher social grades
- Younger groups tended to be more concerned about river pollution from agriculture.

River pollution specifically from sewage ranks fourth on the list – on a par with flooding. River pollution from agriculture is seen as much less of an issue with 16% thinking it a top 3 issue.

	1st	2nd	3rd	Net
Microplastics in the environment	30%	21%	14%	65%
Air pollution from household smoke and road vehicles	26%	17%	13%	56%
More frequent and severe flooding from rivers and the sea	11%	13%	12%	36%
River pollution from sewage	8%	13%	15%	36%
The need for more trees to be planted	10%	10%	14%	34%
Reduced biodiversity	5%	6%	7%	18%
River pollution from agriculture	3%	6%	7%	16%
Erosion of soil and reduced soil fertility	3%	5%	7%	15%
More frequent and severe droughts	4%	5%	5%	14%
Invasive species on land and water	2%	4%	4%	8%

Q.2 Below is a list of environmental issues affecting the UK: please pick the top three most concerning to you and rank them in order, with 1 being the most concerning etc. **Base:** All respondents (2096)

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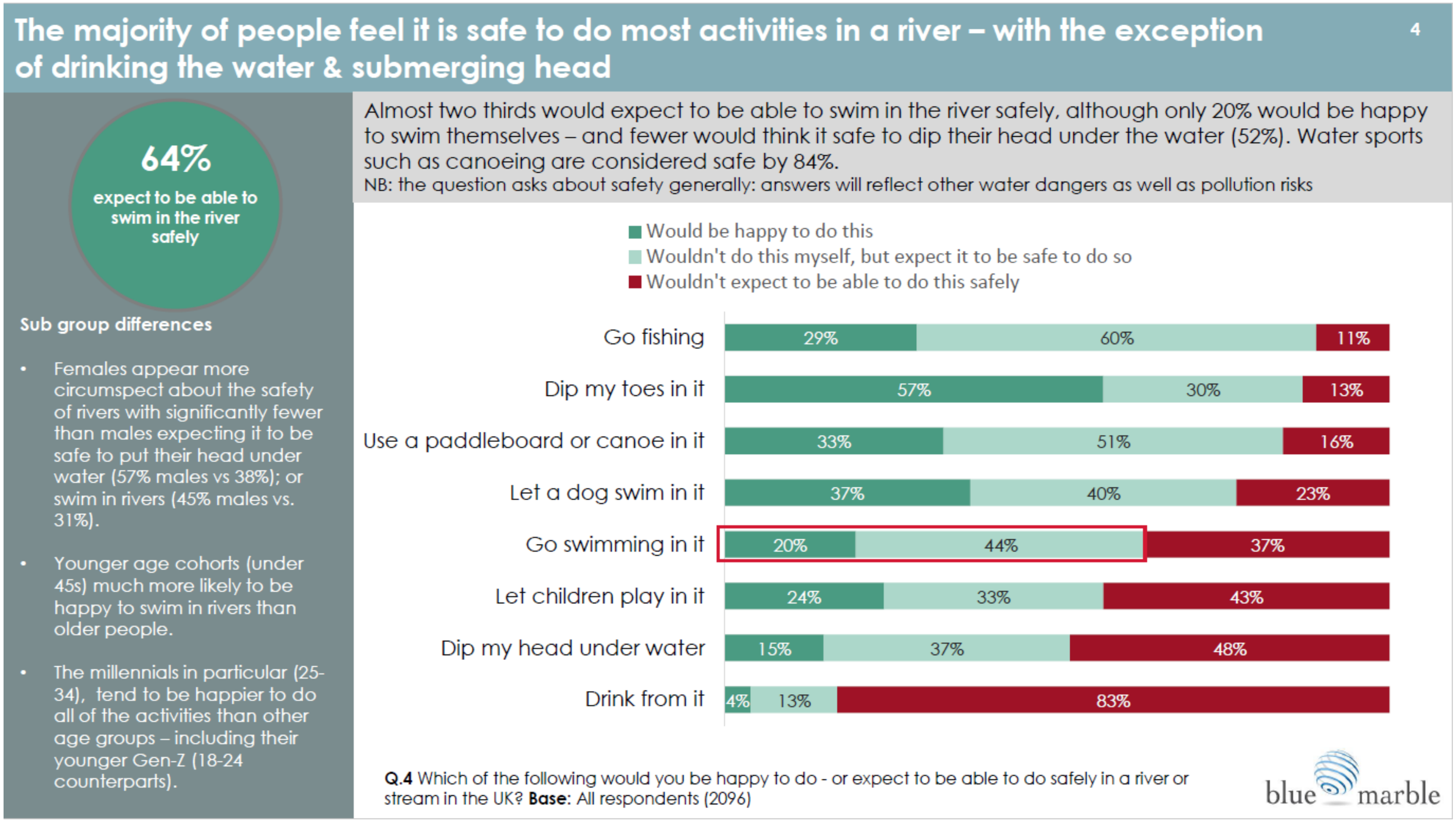

The majority of people feel it is safe to do most activities in a river – with the exception of drinking the water & submerging head

64%

expect to be able to swim in the river safely

Sub group differences

- Females appear more circumspect about the safety of rivers with significantly fewer than males expecting it to be safe to put their head under water (57% males vs 38%); or swim in rivers (45% males vs. 31%).
- Younger age cohorts (under 45s) much more likely to be happy to swim in rivers than older people.
- The millennials in particular (25-34), tend to be happier to do all of the activities than other age groups – including their younger Gen-Z (18-24 counterparts).

Almost two thirds would expect to be able to swim in the river safely, although only 20% would be happy to swim themselves – and fewer would think it safe to dip their head under the water (52%). Water sports such as canoeing are considered safe by 84%.
NB: the question asks about safety generally: answers will reflect other water dangers as well as pollution risks

Q.4 Which of the following would you be happy to do - or expect to be able to do safely in a river or stream in the UK? **Base:** All respondents (2096)

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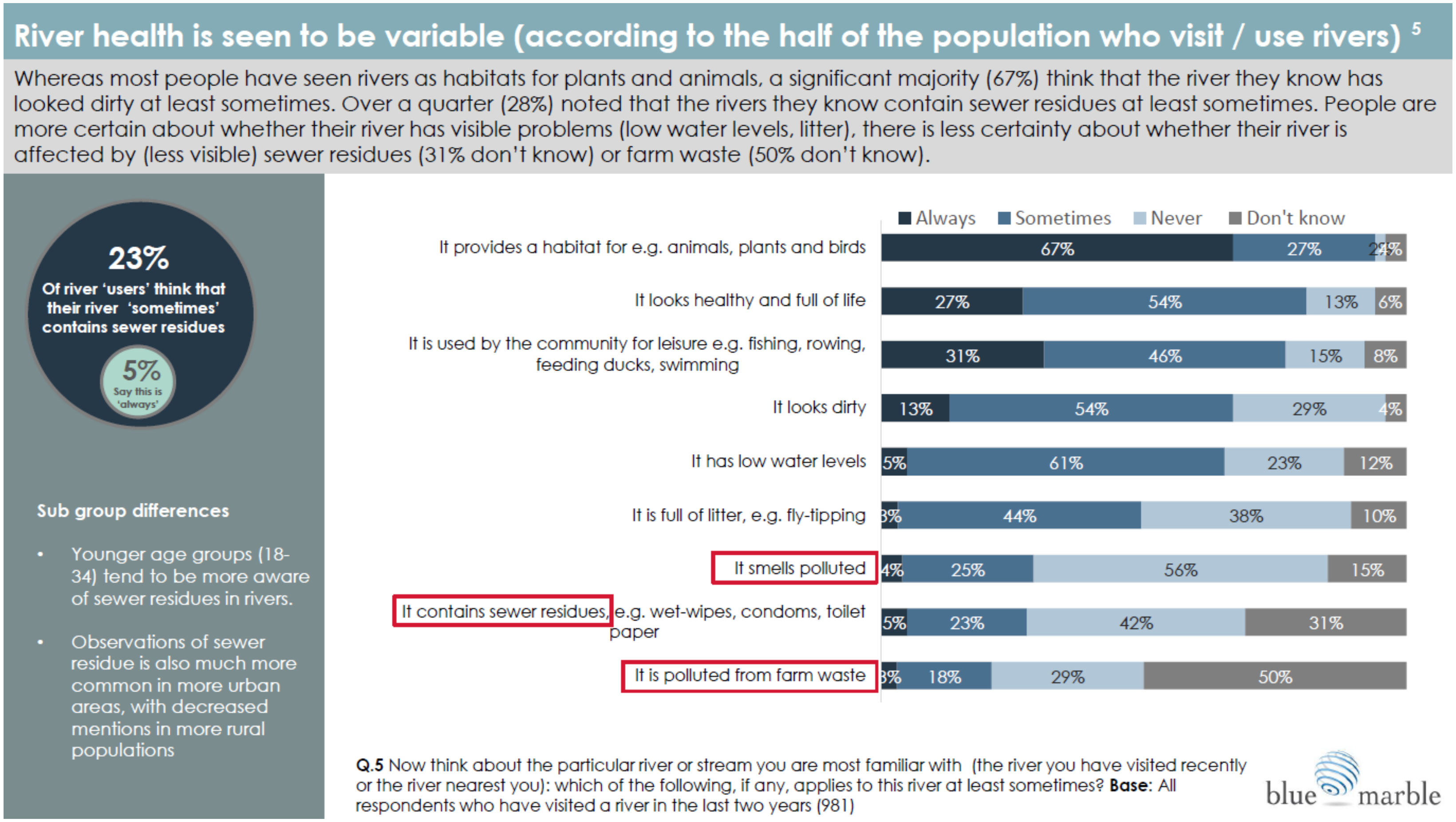

River health is seen to be variable (according to the half of the population who visit / use rivers) [5]

Whereas most people have seen rivers as habitats for plants and animals, a significant majority (67%) think that the river they know has looked dirty at least sometimes. Over a quarter (28%) noted that the rivers they know contain sewer residues at least sometimes. People are more certain about whether their river has visible problems (low water levels, litter), there is less certainty about whether their river is affected by (less visible) sewer residues (31% don't know) or farm waste (50% don't know).

23%
Of river 'users' think that their river 'sometimes' contains sewer residues

5%
Say this is 'always'

Sub group differences

- Younger age groups (18-34) tend to be more aware of sewer residues in rivers.
- Observations of sewer residue is also much more common in more urban areas, with decreased mentions in more rural populations

Q.5 Now think about the particular river or stream you are most familiar with (the river you have visited recently or the river nearest you): which of the following, if any, applies to this river at least sometimes? **Base:** All respondents who have visited a river in the last two years (981)

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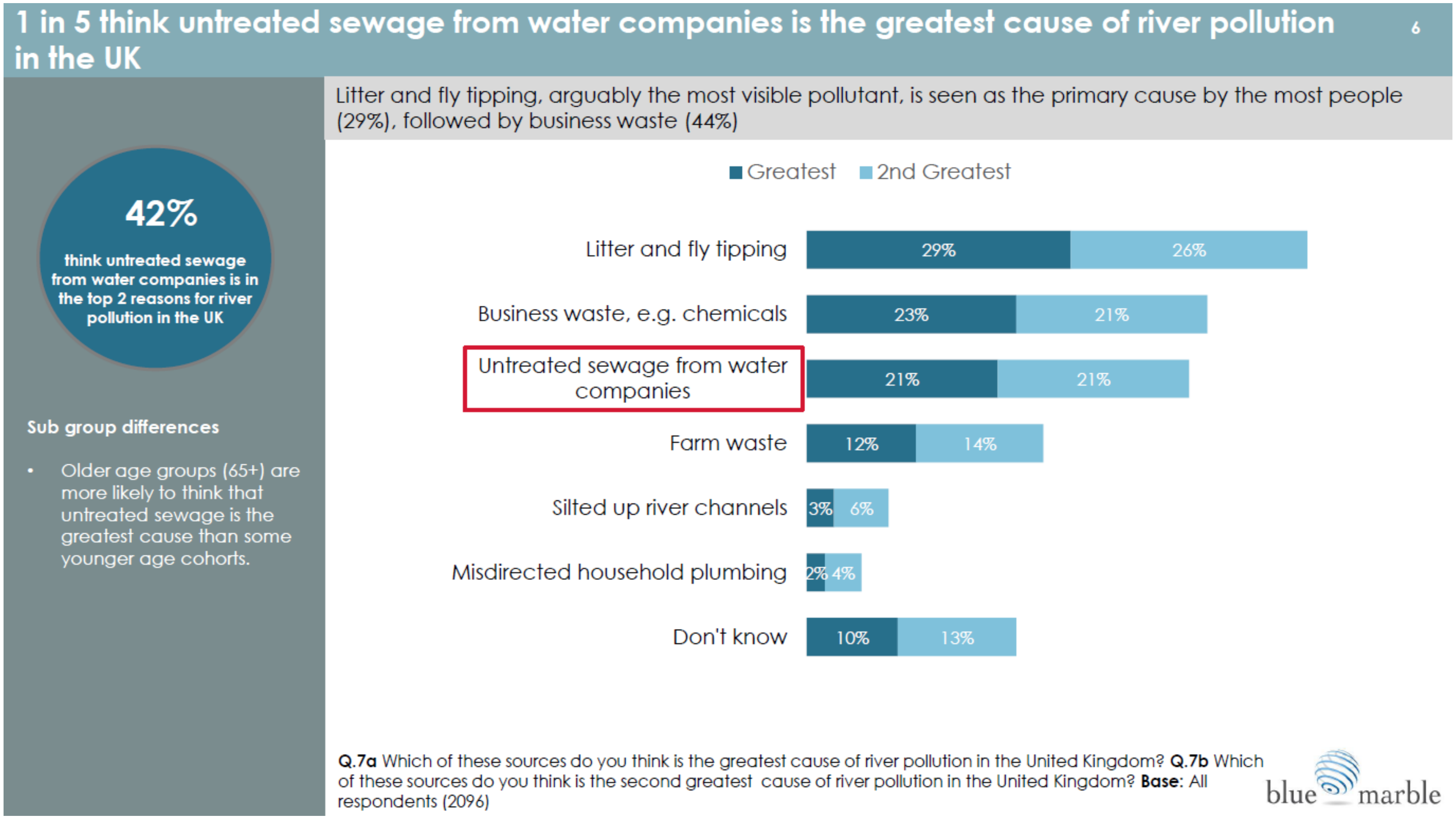


1 in 5 think untreated sewage from water companies is the greatest cause of river pollution in the UK

6

Litter and fly tipping, arguably the most visible pollutant, is seen as the primary cause by the most people (29%), followed by business waste (44%)

42%

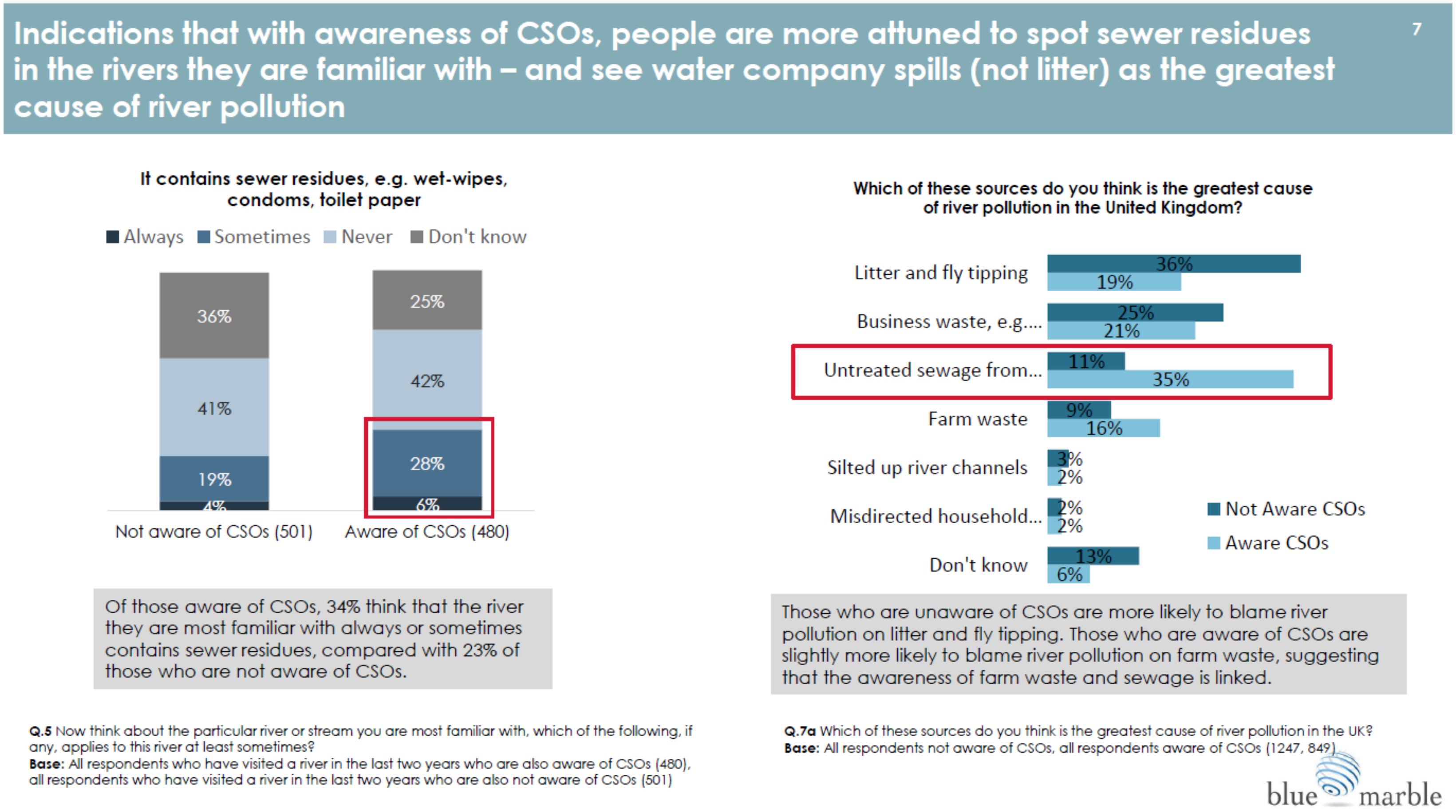
think untreated sewage from water companies is in the top 2 reasons for river pollution in the UK

Sub group differences

- Older age groups (65+) are more likely to think that untreated sewage is the greatest cause than some younger age cohorts.

Q.7a Which of these sources do you think is the greatest cause of river pollution in the United Kingdom? **Q.7b** Which of these sources do you think is the second greatest cause of river pollution in the United Kingdom? **Base**: All respondents (2096)

blue marble



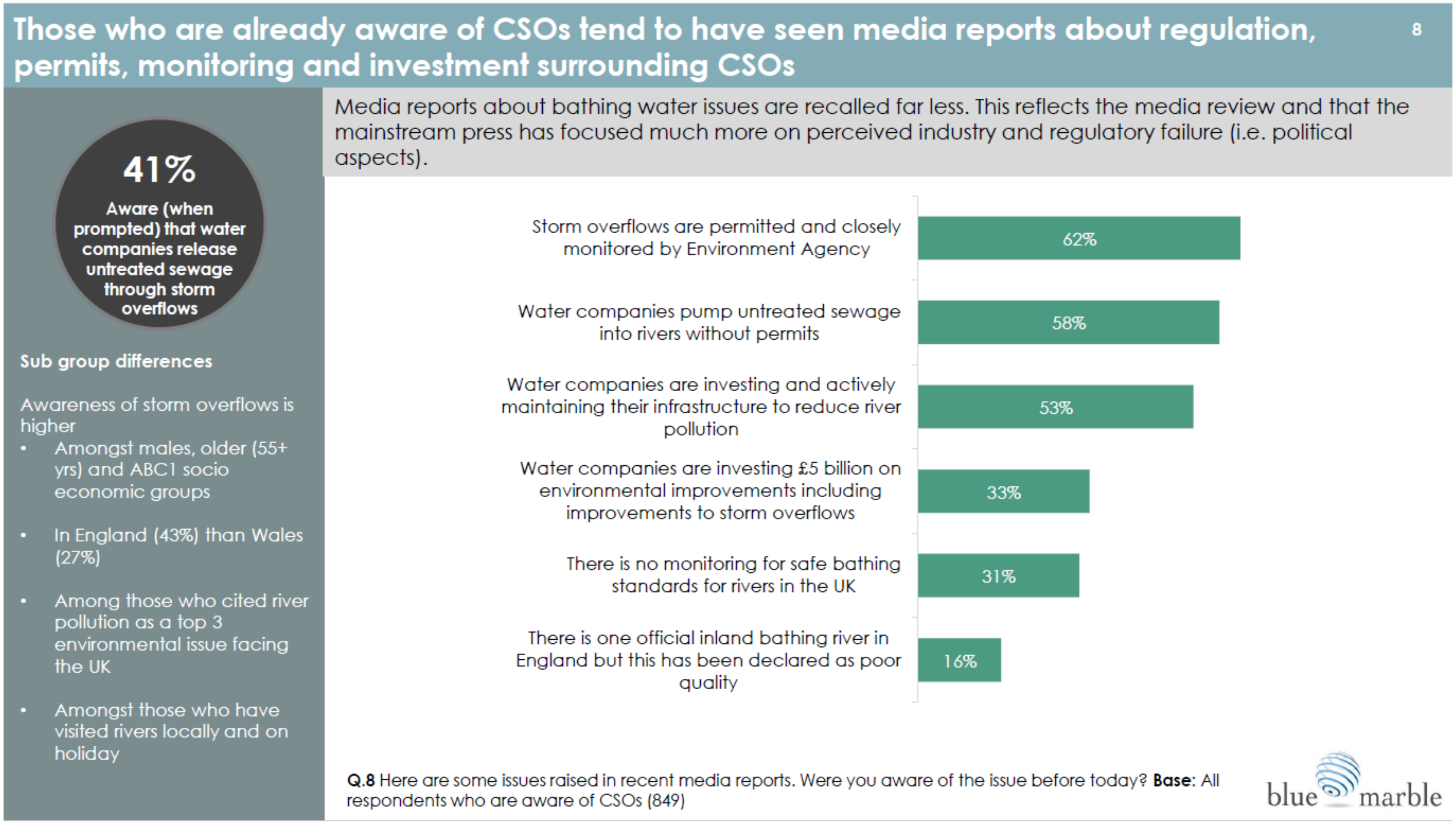
Indications that with awareness of CSOs, people are more attuned to spot sewer residues in the rivers they are familiar with – and see water company spills (not litter) as the greatest cause of river pollution

Of those aware of CSOs, 34% think that the river they are most familiar with always or sometimes contains sewer residues, compared with 23% of those who are not aware of CSOs.

Those who are unaware of CSOs are more likely to blame river pollution on litter and fly tipping. Those who are aware of CSOs are slightly more likely to blame river pollution on farm waste, suggesting that the awareness of farm waste and sewage is linked.

Q.5 Now think about the particular river or stream you are most familiar with, which of the following, if any, applies to this river at least sometimes?
Base: All respondents who have visited a river in the last two years who are also aware of CSOs (480), all respondents who have visited a river in the last two years who are also not aware of CSOs (501)

Q.7a Which of these sources do you think is the greatest cause of river pollution in the UK?
Base: All respondents not aware of CSOs, all respondents aware of CSOs (1247, 849)



Those who are already aware of CSOs tend to have seen media reports about regulation, permits, monitoring and investment surrounding CSOs

41%

Aware (when prompted) that water companies release untreated sewage through storm overflows

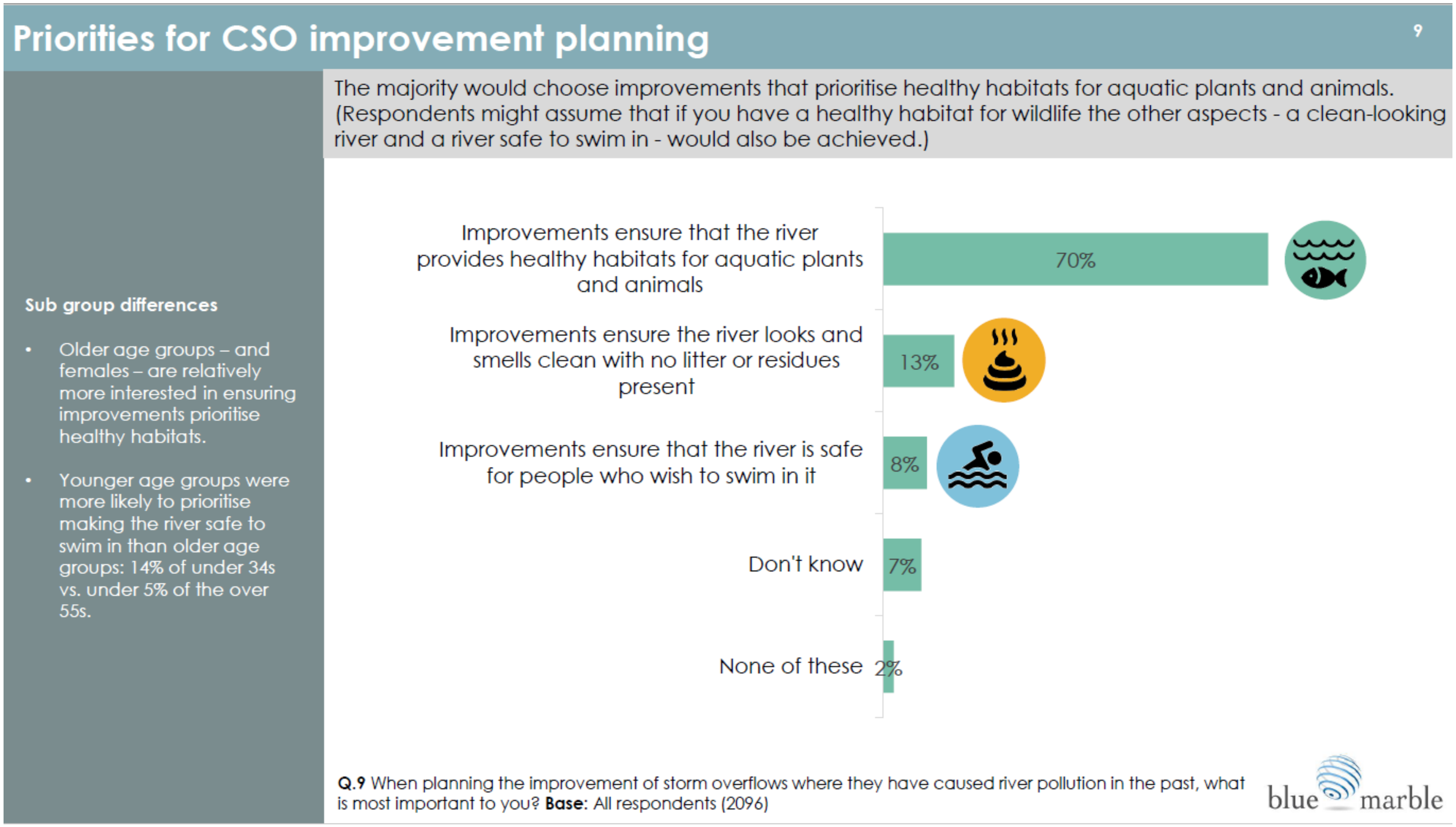
Sub group differences

Awareness of storm overflows is higher

- Amongst males, older (55+ yrs) and ABC1 socio economic groups
- In England (43%) than Wales (27%)
- Among those who cited river pollution as a top 3 environmental issue facing the UK
- Amongst those who have visited rivers locally and on holiday

Media reports about bathing water issues are recalled far less. This reflects the media review and that the mainstream press has focused much more on perceived industry and regulatory failure (i.e. political aspects).

Q.8 Here are some issues raised in recent media reports. Were you aware of the issue before today? **Base**: All respondents who are aware of CSOs (849)



Priorities for CSO improvement planning

The majority would choose improvements that prioritise healthy habitats for aquatic plants and animals. (Respondents might assume that if you have a healthy habitat for wildlife the other aspects - a clean-looking river and a river safe to swim in - would also be achieved.)

Sub group differences

- Older age groups – and females – are relatively more interested in ensuring improvements prioritise healthy habitats.
- Younger age groups were more likely to prioritise making the river safe to swim in than older age groups: 14% of under 34s vs. under 5% of the over 55s.

Improvements ensure that the river provides healthy habitats for aquatic plants and animals	70%
Improvements ensure the river looks and smells clean with no litter or residues present	13%
Improvements ensure that the river is safe for people who wish to swim in it	8%
Don't know	7%
None of these	2%

Q.9 When planning the improvement of storm overflows where they have caused river pollution in the past, what is most important to you? **Base:** All respondents (2096)

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Appendix D Supplementary Results

Subsequent to the analysis reported in Section 4, some refinements were made to examine stand-alone policies focussed on specific types of water body only.

The policies are as follows:

A. Average 10 spills per year to sensitive[55] waters only (improving 2,642 overflows)
B. Average 10 spills per year where RNAG is related to storm overflows (improving 1,727 overflows)
C. Average 10 spills per year to A or B (improving 3,543 overflows)
D. Average 10 spills per year to A[56] or B (improving 3,234 overflows)
E. Average 5 spills per year to waters used recreationally only (improving 859 overflows)

Table D1 presents CAPEX and bill impact[57] values (low and high estimates) for these policies applied with scenarios W, S10 and S50. BCR values for policies C and D were not calculable with the data structure used.

Table D 1 CAPEX, bill impact and BCR for select policies

		A	B	C	D	E
CAPEX (W) £mn	Low	11,960	9,866	16,317	15,335	5,990
	High	19,072	15,712	26,004	24,440	9,415
CAPEX (S10) £mn	Low	16,630	12,837	22,520	21,013	6,164
	High	25,915	20,036	35,090	32,751	9,584
CAPEX (S50) £mn	Low	41,453	29,785	55,724	51,608	13,387
	High	62,730	45,121	84,330	78,111	20,293
Bill impact (W) £/household/yr	Low	20	17	28	26	10
	High	32	27	44	41	16
Bill impact (S10) £/household/yr	Low	30	23	41	38	11
	High	46	35	62	58	17
Bill impact (S50) £/household/yr	Low	79	57	106	98	25
	High	115	83	154	143	37
BCR (W)	Low	0.10	0.04	N/A	N/A	0.04

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[55] Where sensitive waters are defined as in F40-10: SSSI, SAC, chalk streams, sensitive areas eutrophic
[56] Where sensitive waters are defined as above but excluding sensitive areas eutrophic.
[57] Bill impact calculation includes OPEX

		A	B	C	D	E
	High	0.18	0.08	N/A	N/A	0.07
BCR (S10)	Low	0.12	0.08	N/A	N/A	0.08
	High	0.33	0.24	N/A	N/A	0.24
BCR (S50)	Low	0.13	0.11	N/A	N/A	0.02
	High	0.45	0.42	N/A	N/A	0.07

Appendix E Case studies

Four case studies provide examples of storm overflow management practices.

Case Study 1 – River Croal (United Utilities)

Case Study 2 – River Medlock (United Utilities)

Case Study 3 – Piddle Valley Sewers (Wessex Water)

Case Study 4 – Hanging Langford Reedbed (Wessex Water)

E.1 Case Study 1 River Croal catchment

E.1.1 Introduction

This case study covers the improvement of storm overflows in the River Croal catchment (a tributary of the River Irwell), located in Greater Manchester. The improvements are currently being delivered by United Utilities as part of its AMP7 £20m+ investment in Croal catchment river water quality. Material for this case study was derived with permission from a United Utilities publication.

E.1.2 Background

The catchment contains 72 storm overflows which are mapped in Figure E 1. The improvements were designed to ensure that the river achieves Good Ecological Status as assessed through comparing modelled water quality with percentile standards. There are 90 (or 10) percentile standards for ammonia, dissolved oxygen, and biological oxygen demand (BOD). There are 99 percentile standards for ammonia, unionised ammonia, and BOD.

The approach uses a planning and design water quality modelling methodology called Urban Pollution Management (UPM)[58]. This approach is commonly used by UK water companies when determining the reductions in storm overflow spills necessary to support river health. It is designed to achieve the desired water quality outcome without being prescriptive over the volume and frequency of storm overflow spills. The approach takes account of some other discharges into the river, such as treated final effluent. It does not necessarily take account of all influences on water quality and river health not related to storm overflows.

Its purpose is to determine investment requirements at storm overflows throughout the catchment that will result in river reaches achieving Good Ecological Status provided that other inputs are appropriately managed. The investments at storm overflows are often to provide storage, but can also include improving flow to treatment, reducing flows entering combined sewers or treating storm overflow discharges.

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[58] Urban Pollution Management manual

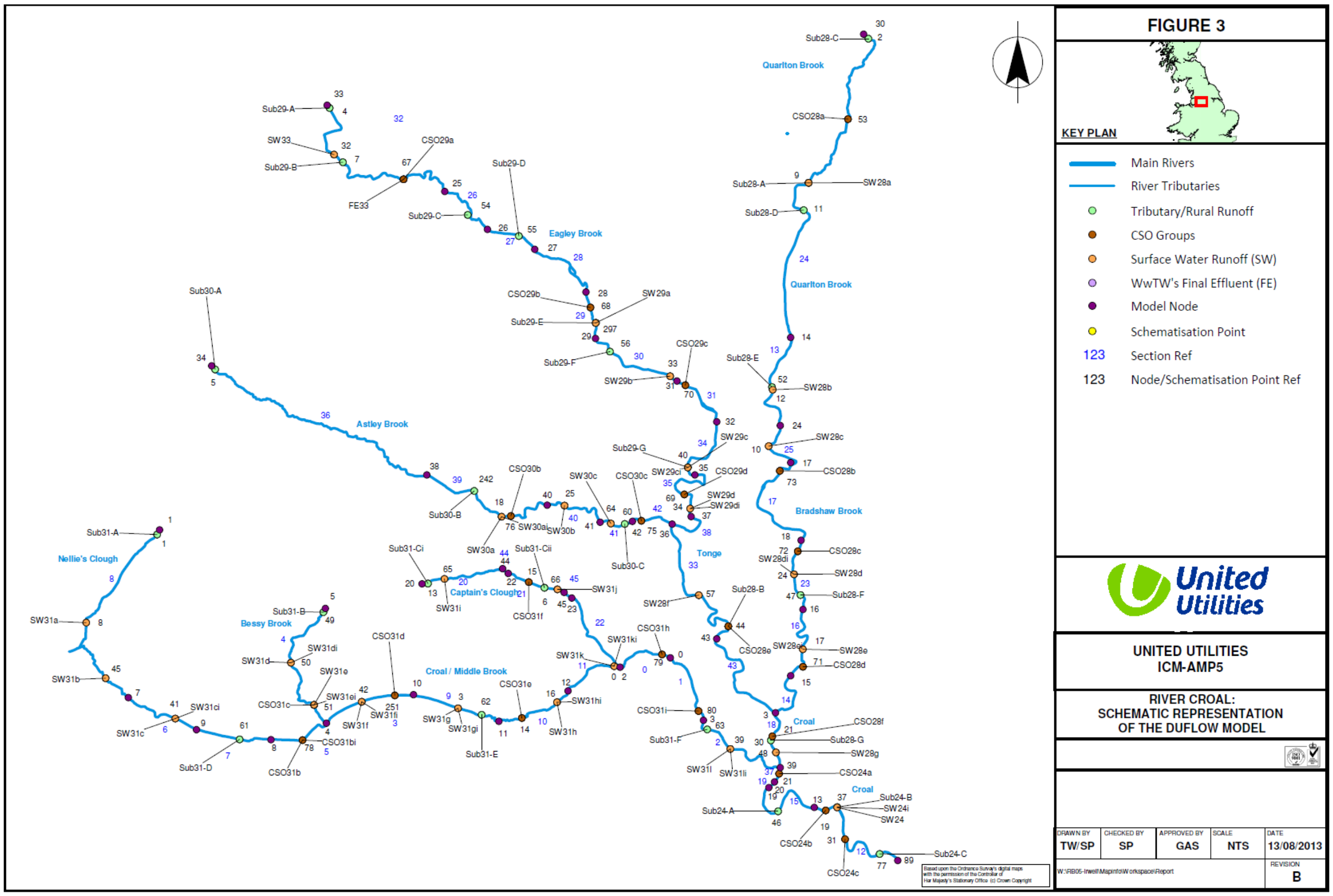

Figure E 1 River Croal catchment showing

E.1.3 Details

Whilst the whole catchment contains 72 overflows, water quality modelling showed that only eight required improvements to achieve target water quality throughout the catchment.

CROAL	Baseline			Solution				
Overflow reference	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)	Additonal storage (m3)	Increase to passforward flow (l/s)	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)
Storm overflow 1	130	1,397,122	861					
Storm overflow 2	135	890,631	545					
Storm overflow 3	90	394,167	526					
Storm overflow 4	108	256,882	243					
Storm overflow 5	98	255,864	257	150		79	238,033	221
Storm overflow 6	117	242,923	1,809	2,600		35	134,362	849
Storm overflow 7	102	234,608	352	570		68	195,059	260
Storm overflow 8	50	206,397	222					
Storm overflow 9	104	175,020	380	750		52	130,553	235
Storm overflow 10	184	172,498	1,257					
Storm overflow 11	89	137,935	629	400		56	114,212	455
Storm overflow 12	195	121,188	1,980		10	155	72,431	897
Storm overflow 13	100	97,934	140					
Storm overflow 14	15	75,179	35					
Storm overflow 15	93	70,333	545	400		43	48,436	333
Storm overflow 16	173	66,630	865					
Storm overflow 17	174	65,243	640					
Storm overflow 18	134	61,300	276					
Storm overflow 19	82	56,935	165					
Storm overflow 20	73	41,156	332					
Storm overflow 21	73	36,341	212					
Storm overflow 22	56	32,209	83					
Storm overflow 23	74	28,331	120					
Storm overflow 24	26	27,416	32					
Storm overflow 25	66	26,472	205	240		29	17,095	114
Storm overflow 26	30	23,917	29					
Storm overflow 27	36	22,813	61					
Storm overflow 28	49	21,919	70					
Storm overflow 29	24	20,268	56					
Storm overflow 30	82	19,862	114					
Storm overflow 31	104	17,788	185					
Storm overflow 32	81	11,566	233					
Storm overflow 33	75	10,725	121					
Storm overflow 34	32	7,517	44					
Storm overflow 35	59	6,816	60					
Storm overflow 36	47	4,564	30					
Storm overflow 37	10	4,348	4					
Storm overflow 38	62	3,986	39					
Storm overflow 39	21	3,483	40					
Storm overflow 40	22	2,611	20					
Storm overflow 41	32	1,972	12					
Storm overflow 42	31	1,658	28					
Storm overflow 43	6	1,646	6					
Storm overflow 44	42	1,524	17					
Storm overflow 45	188	1,197	179					
Storm overflow 46	8	869	4					
Storm overflow 47	8	862	13					
Storm overflow 48	7	782	4					
Storm overflow 49	17	766	5					
Storm overflow 50	1	497	0					
Storm overflow 51	1	347	0					
Storm overflow 52	1	300	1					
Storm overflow 53	8	224	2					
Storm overflow 54	3	179	1					
Storm overflow 55	3	82	1					
Storm overflow 56	1	81	0					
Storm overflow 57	1	79	1					
Storm overflow 58	0	57	0					
Storm overflow 59	1	37	0					
Storm overflow 60	1	30	0					
Storm overflow 61	1	16	0					
Storm overflow 62	1	11	0					
Storm overflow 63	14	10	2					
Storm overflow 64	1	1	0					
Storm overflow 65	0	0	0					
Storm overflow 66	0	0	0					
Storm overflow 67	0	0	0					
Storm overflow 68	0	0	0					
Storm overflow 69	0	0	0					
Storm overflow 70	0	0	0					
Storm overflow 71	0	0	0					
Storm overflow 72	0	0	0					

Table E 1 shows the baseline modelled annual spill volume, frequency and duration of each overflow (renamed for this case study and ranked by baseline spill volume), highlighting the eight requiring improvements, the network storage (or improved pass forward rate) necessary to make the improvements and the predicted future pattern of spills. As assessed through a modelling investigation, these improvements are all that is necessary to support river health. The improvements are usually described in the environmental permit issued for each overflow to the water company. The success of the approach can be assessed through EDM to check that future spills are (on average) as planned and ecological surveys or water quality monitoring in the river to check on outcomes.

CROAL	Baseline			Solution				
Overflow reference	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)	Additonal storage (m3)	Increase to passforward flow (l/s)	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)
Storm overflow 1	130	1,397,122	861					
Storm overflow 2	135	890,631	545					
Storm overflow 3	90	394,167	526					
Storm overflow 4	108	256,882	243					
Storm overflow 5	98	255,864	257	150		79	238,033	221
Storm overflow 6	117	242,923	1,809	2,600		35	134,362	849
Storm overflow 7	102	234,608	352	570		68	195,059	260
Storm overflow 8	50	206,397	222					
Storm overflow 9	104	175,020	380	750		52	130,553	235
Storm overflow 10	184	172,498	1,257					
Storm overflow 11	89	137,935	629	400		56	114,212	455
Storm overflow 12	195	121,188	1,980		10	155	72,431	897
Storm overflow 13	100	97,934	140					
Storm overflow 14	15	75,179	35					
Storm overflow 15	93	70,333	545	400		43	48,436	333
Storm overflow 16	173	66,630	865					
Storm overflow 17	174	65,243	640					
Storm overflow 18	134	61,300	276					
Storm overflow 19	82	56,935	165					
Storm overflow 20	73	41,156	332					
Storm overflow 21	73	36,341	212					
Storm overflow 22	56	32,209	83					
Storm overflow 23	74	28,331	120					
Storm overflow 24	26	27,416	32					
Storm overflow 25	66	26,472	205	240		29	17,095	114
Storm overflow 26	30	23,917	29					
Storm overflow 27	36	22,813	61					
Storm overflow 28	49	21,919	70					
Storm overflow 29	24	20,268	56					
Storm overflow 30	82	19,862	114					
Storm overflow 31	104	17,788	185					
Storm overflow 32	81	11,566	233					
Storm overflow 33	75	10,725	121					
Storm overflow 34	32	7,517	44					
Storm overflow 35	59	6,816	60					
Storm overflow 36	47	4,564	30					
Storm overflow 37	10	4,348	4					
Storm overflow 38	62	3,986	39					
Storm overflow 39	21	3,483	40					
Storm overflow 40	22	2,611	20					
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Storm overflow 43	6	1,646	6					
Storm overflow 44	42	1,524	17					
Storm overflow 45	188	1,197	179					
Storm overflow 46	8	869	4					
Storm overflow 47	8	862	13					
Storm overflow 48	7	782	4					
Storm overflow 49	17	766	5					
Storm overflow 50	1	497	0					
Storm overflow 51	1	347	0					
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Storm overflow 55	3	82	1					
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Storm overflow 57	1	79	1					
Storm overflow 58	0	57	0					
Storm overflow 59	1	37	0					
Storm overflow 60	1	30	0					
Storm overflow 61	1	16	0					
Storm overflow 62	1	11	0					
Storm overflow 63	14	10	2					
Storm overflow 64	1	1	0					
Storm overflow 65	0	0	0					
Storm overflow 66	0	0	0					
Storm overflow 67	0	0	0					
Storm overflow 68	0	0	0					
Storm overflow 69	0	0	0					
Storm overflow 70	0	0	0					
Storm overflow 71	0	0	0					
Storm overflow 72	0	0	0					

Table E 1 Baseline and solution Croal overflows

E.1.4 Conclusions

This example is notable because only eight of 72 overflows required an improvement and of the eight, only two required a reduction of spill frequency to below 40. The approach efficiently rations investment to the overflows where improvement is necessary to protect river health across the catchment. Note that year-on-year measurements of spill frequency (via EDM) may differ from that calculated as long-term averages in hydraulic models.

Under current guidelines (SOAF) improving all overflows so that they operate less frequently than 40 times per year (as measured by EDM) is not cost beneficial because further reduction in spills does not improve compliance with water quality objectives.

Whilst meeting the needs of river health, these improvements do not address issues of social impact and public health, as described in this research. The approach requires an acceptance that storm overflow spill frequency can remain high provided that river health is not damaged.

Applying this research's unit cost assumptions[59] for network storage improvements makes an interesting comparison. The storage solutions being delivered currently at seven overflows (total 5,110m^3) would cost an indicative £10.2m (assuming £2,000/m^3). Solutions to deliver 40, 20 and 10 spills as an average at every overflow in the catchment would cost an indicative £121m, £351m, £690m respectively.

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[59] This simplification is necessary to make a comparison in costs between a river-needs approach and a comprehensive strategy covering all overflows.

E.2 Case Study 2 – River Medlock catchment

E.2.1 Introduction

This case study covers the improvement of storm overflows in the River Medlock catchment (a tributary of the River Irwell), located in Greater Manchester. The improvements indicated here have already been completed. Material for this case study was derived with permission from a United Utilities publication.

E.2.2 Background

Figure E 2 shows the extent of the river catchment and the four sewered catchments that flow into it and the location of 59 storm overflows. The purpose of the improvement programme was to achieve Good Ecological Status as assessed by compliance with UPM 99 percentile standards (as in case study 1) and fundamental intermittent standards[60]. The upper reaches of the Medlock (to the confluence with Lumb Clough Brook) were designated as Salmonid Spawning Grounds, requiring compliance with a tighter water quality standard to qualify as achieving Good Ecological Status.

The solution, developed through modelling investigations, involved the improvement of six overflows and one wastewater treatment works (WwTW). It was an integrated solution combining new network storage, better use of existing assets and the full treatment of more flows to a higher quality.

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[60] Fundamental Intermittent Standards are concentration-duration-frequency standards for dissolved oxygen and unionised ammonia used in planning and designing storm overflow improvements. They were developed for and described in the Urban Pollution Management manual (www.fwr.org/UPM3/) and require the use of sophisticated water quality models which must first be calibrated and verified against observed water quality responses in the catchment.

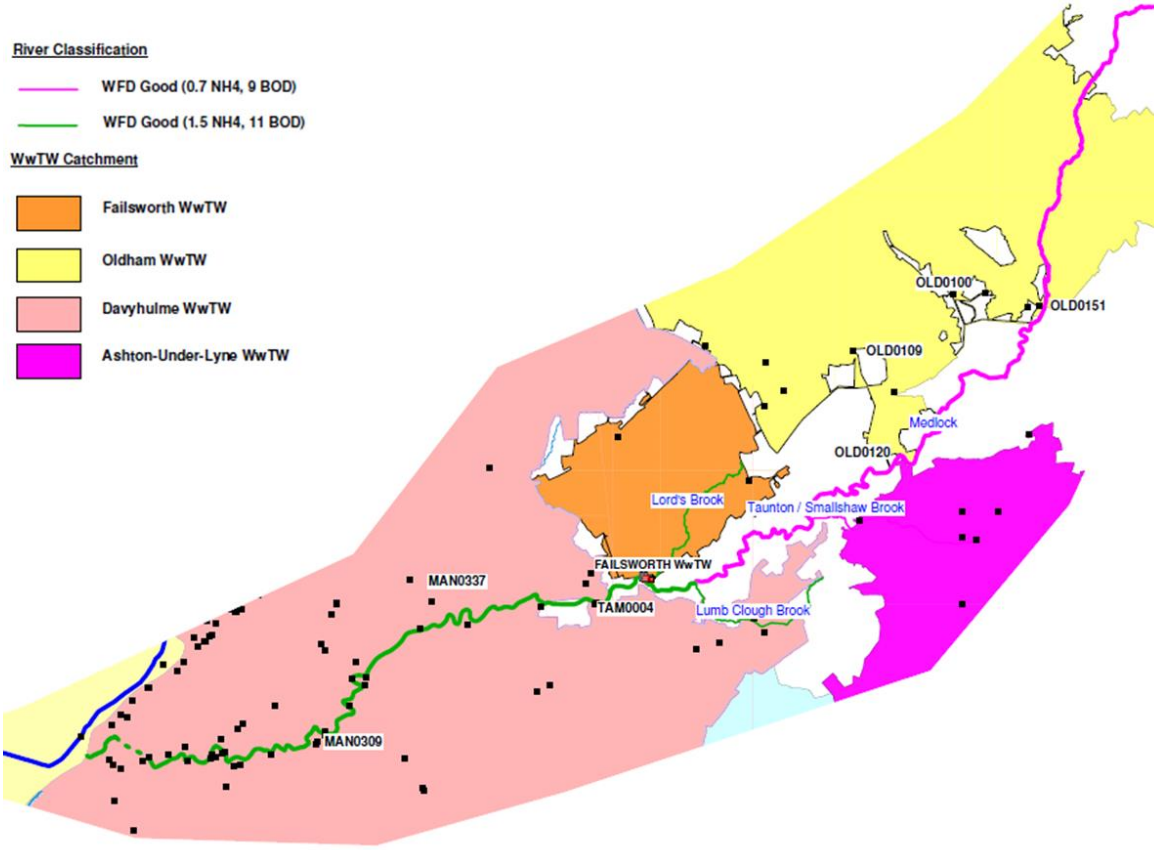

Figure E 2 River Medlock catchment

E.2.3 Details

Table E 2 shows the modelled baseline annual spill volume, frequency, and duration of each overflow (renamed for this case study and ranked by baseline spill volume), highlighting the six requiring improvements, the network storage (or improved pass forward rate) necessary to make the improvements and the predicted future pattern of spills. Note that year-on-year measurements of spill frequency (via EDM) may differ from that calculated as long-term averages in hydraulic models.

At storm overflow one and three penstocks were adjusted or relocated to mobilise existing storage. At the WwTW flow to full treatment was increased, the ammonia permit was tightened, and additional storm storage was provided.

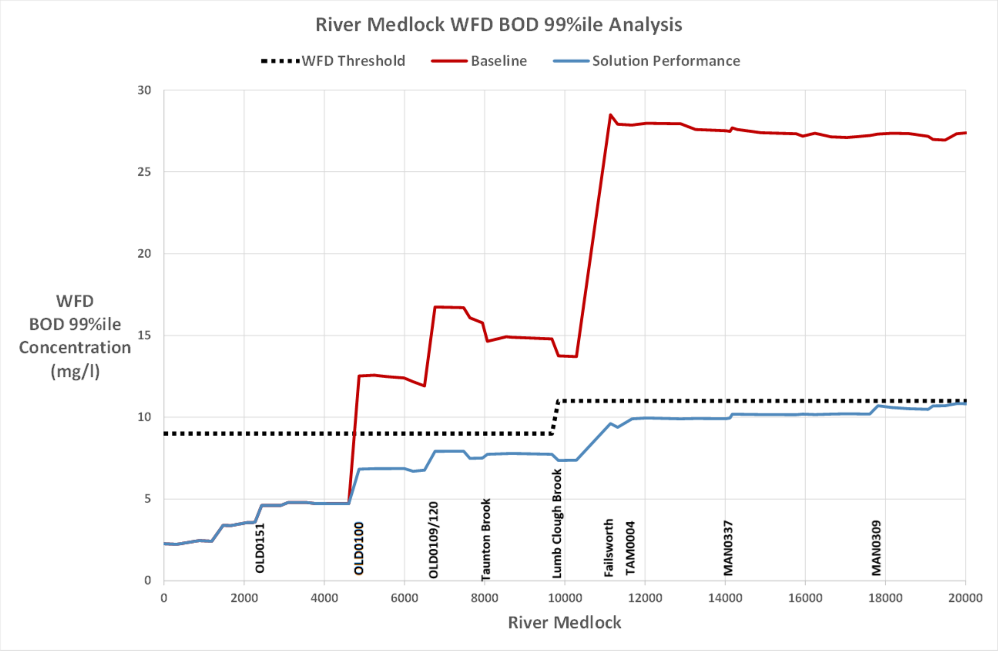

Figure E 3 Long profile of BOD 99 percentile along River Medlock

The total effect on water quality along the Medlock of these improvements can be seen in Figure E3. It compares the baseline modelled river BOD 99 percentile with the WFD Threshold (water quality standard) and the predicted outcome along 20km of river. The solution delivers an outcome water quality that is within the acceptable standard.

MEDLOCK	Baseline			Solution				
Overflow reference	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)	Additonal storage (m3)	Increase to passforward flow (l/s)	Annual Spill Frequency	Annual Spill Volume (m3)	Annual Spill Duration (hrs)
Storm overflow 1	39	711,468	148			29	696,114	119
WwTW Storm Tank overflow 1	79	586,554	704	10,000		13	31,992	94
Storm overflow 2	54	190,170	110	5,400		9	42,494	29
WwTW Inlet overflow 1	42	112,700	92		160	13	98,061	76
Storm overflow 3	24	107,099	55			14	62,440	29
Storm overflow 4	30	104,819	57					
Storm overflow 5	61	72,057	81					
Storm overflow 6	56	29,138	72					
Storm overflow 7	32	25,634	70					
Storm overflow 8	63	24,541	167	820		8	9,750	62
Storm overflow 9	53	20,434	85					
Storm overflow 10	32	18,490	31					
Storm overflow 11	46	15,284	62					
Storm overflow 12	20	10,616	29					
Storm overflow 13	9	5,148	9					
Storm overflow 14	61	4,214	46					
Storm overflow 15	18	3,616	14					
Storm overflow 16	3	3,412	3					
Storm overflow 17	18	2,910	15					
Storm overflow 18	2	2,381	1					
Storm overflow 19	1	1,927	1					
Storm overflow 20	19	1,168	12					
Storm overflow 21	1	729	0					
Storm overflow 22	1	465	0					
Storm overflow 23	1	288	0					
Storm overflow 24	11	244	5					
Storm overflow 25	1	201	0					
Storm overflow 26	1	197	1					
Storm overflow 27	7	185	3					
Storm overflow 28	3	160	3					
Storm overflow 29	1	107	1					
Storm overflow 30	1	106	0					
Storm overflow 31	1	92	0					
Storm overflow 32	0	69	0					
Storm overflow 33	2	61	1					
Storm overflow 34	1	50	0					
Storm overflow 35	1	50	1					
Storm overflow 36	0	47	0					
Storm overflow 37	0	44	0					
Storm overflow 38	1	34	0					
Storm overflow 39	0	21	0					
Storm overflow 40	1	17	0					
Storm overflow 41	1	14	0					
Storm overflow 42	0	8	0					
Storm overflow 43	1	5	0					
Storm overflow 44	0	3	0					
Storm overflow 45	0	1	0					
Storm overflow 46	1	1	0					
Storm overflow 47	0	1	0					
Storm overflow 48	0	0	0					
Storm overflow 49	0	0	0					
Storm overflow 50	0	0	0					
Storm overflow 51	0	0	0					
Storm overflow 52	0	0	0					
Storm overflow 53	0	0	0					
Storm overflow 54	0	0	0					
Storm overflow 55	0	0	0					
Storm overflow 56	0	0	0					
Storm overflow 57	0	0	0					

Table E 2 Baseline and solution Medlock overflows

E.2.4 Conclusions

The integrated solution for the Medlock catchment was developed to protect river health. It did this through a carefully optimised improvement at some storm overflows and by providing greater wastewater treatment capacity. Some high frequency storm overflows were retained (e.g., storm overflow 5, where annual spill frequency is 61 and annual spill volume is greater than 72,000m^3) but their effect is compensated for elsewhere within a ‘catchment approach’. At two overflows, the post solution spill frequency has been reduced to fewer than 10 spill per year on average. This provided better than necessary river water quality locally but avoided the requirement for further investment downstream.

Applying this research’s unit cost assumptions.[61] for network storage improvements makes an interesting comparison. The new storage solutions which have been delivered at two overflows and a WwTW storm tank (total 16,200m^3) would cost £32m (assuming £2,000/m^3). Solutions to deliver 40, 20 and 10 spills as an average at every overflow in the catchment would cost an estimated £25m, £135m, £263m respectively.

The solution meets river health needs but was not designed or funded to address social impact or public health concerns.

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[61] This is a necessary simplification to make a comparison in costs between a river-needs approach and a comprehensive strategy covering all overflows. The estimated cost of the recent solution may not be indicative of actual costs incurred by the water utility.

E.3 Case Study 3 - Piddle Valley sewers

E.3.1 Introduction

This case study is very different to the previous examples. It addresses the important issue of groundwater inundation into sewers and the consequences of 'spills' which occur as a result. The solution negotiated here between Wessex Water and the Environment Agency in consultation with the community has lessons for any catchment where the occurrence of storm overflow is principally caused by groundwater inundation. The case study also explores the balance between limiting storm overflows and managing risk from flooding. Material for this case study was derived with permission from a Wessex Water publication[62].

E.3.2 Background

The Piddle Valley is situated in rural West Dorset, where the sewerage undertaker is Wessex Water. The topography is such that the hills slope down sharply into a flat river valley. Whilst the slopes are mostly comprised of shallow well-drained calcareous silty soil over chalk, the valley bottoms are made up of deep calcareous and non-calcareous fine silty soils. For these reasons, the valley is prone to high water tables during prolonged wet periods, causing the village of Piddletrenthide to experience river flooding and inundation of the foul sewer. The latter has resulted in surcharging and 'overflowing' sewers and restricted toilet use problems in homes. Wessex Water had published an explainer video[63] on this type of problem common across large areas of rural southern England.

Wessex Water has undertaken extensive surface water removal, land drainage removal and public sewer cleaning and sealing to ensure the sewer is as watertight as possible, but has also installed two new permanent overflows to the river. Whilst not strictly storm overflows (this is not a combined sewer) a permit has been agreed which allows them to operate during times of groundwater inundation providing certain conditions are met. They might be characterised as 'groundwater sewer overflows'.

E.3.1 Details

Piddlehinton Water recycling centre (WRC) receives foul sewage from the Piddle Valley catchment via a 150mm and 225mm public gravity sewer system that is predominantly situated in the valley, adjacent to the river. Dry weather flow is 150 cubic metres per

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[62] https://www.wessexwater.co.uk/-/media/files/wessexwater/environment/dwmp/piddle-valley-inflow-management-report.pdf

[63] https://www.youtube.com/watch?v=7b4uaY4H1Tk

day. Foul sewage flows from Alton Pancras in the north via Piddletrenthide, White Lackington and Piddlehinton to the WRC in south. In 2011 new overflows (Relief Pumping Stations – RPS) were constructed at Rivendell and Piddle Inn as shown in Figure E 4. Their presence avoids the need for temporary pumping of flows to the river in wet winter periods and allows the sewer to provide wastewater drainage to homes. The overflow permits constrain use until conditions are met on flow in the sewer and groundwater level relative to surrounding foul sewers. They also require river quality sampling (every two weeks) to be undertaken when operating so that any impact from the new ‘overflows’ can be understood.

In 2020, event duration monitors showed that the new overflows operated for 1,249hrs (Rivendell) and 973 hours (Piddle Inn). Although discharges were continuous for periods, an equivalent spill frequency can be calculated using an agreed 12/24-hour method. These were 157 and 101 times, respectively.

Figure E 4 shows the pattern of flows (brown line) in the sewer (at the WRC inlet) over a nine-year period with local groundwater level (green line) also shown. The highly seasonal nature of sewer flow is illustrated with winter peaks in most years. The dashed black line indicates the groundwater trigger level at which the relief pumping stations are operated, resulting in reduced sewer levels and greater sewer capacity. It also shows the completion of three public sewer sealing campaigns. A consequence of this flow management practice is that in the winter of 2020/2021 there were no sewer flooding incidents reported.

Although these overflows can be long lasting, monitoring has shown that the water quality impact is minor, reflecting the relatively dilute nature of the discharges. Table E 3 shows upstream and downstream river water quality data which are collected every two weeks when the overflows (relief pumping stations) are operating. The quality and hence impact of the discharges is equivalent to that of the WRC located 4km downstream.

	Upstream of overflows		Downstream of overflows	
Sampling date	BOD atu (mg/l)	Ammonia as N (mg/l)	BOD atu (mg/l)	Ammonia as N (mg/l)
19/12/19	< 4.0	< 0.02	3.0	0.28
30/12/19	< 2.0	< 0.02	4.0	0.31
20/01/20	< 2.0	< 0.02	< 2.0	0.04
31/01/20	< 2.0	< 0.02	< 2.0	0.03
24/02/20	< 2.0	0.04	2.0	0.09
24/03/20	< 2.0	< 0.02	<2.0	0.02

Table E 3 Water quality impact of relief pumping station overflows

E.3.2 Conclusions

The case study is interesting because it demonstrates that the overflows were necessary to avoid sewer flooding and poor (wastewater) customer service even after extensive relining and sealing had been completed in the sewer.

The impact of the overflows was equivalent to that of the downstream fully treated effluent, which makes a poor case for retaining flows in an enlarged network and conventional treatment even if this were technically feasible.

This is why the regulator (Environment Agency) was able to issue a permit for ‘new’ overflows subject to certain conditions on when they could operate (only during periods of groundwater inundation) and with monitoring to check that impacts were acceptable.

The approach offers a potential way forward for conventional combined sewer catchments with overflows which might operate frequently and/or for prolonged periods during times of high winter groundwater. This allows overflows discharges at a high frequency subject to monitoring-based checks on their impact. The approach would be improved by continuous monitoring and telemetry, keeping all stakeholders informed.

Challenges that remain in extending this principle might be around questions of providing ‘effectual drainage’ for the community and whether the system meets the requirements of the Urban Wastewater Treatment Directive in treating sufficient collected flow. Also, dilute but untreated discharges from what might be termed ‘groundwater sewer overflows’ will still deliver a high bacteriological load to river which might be harmful to public health if recreational uses are desirable.

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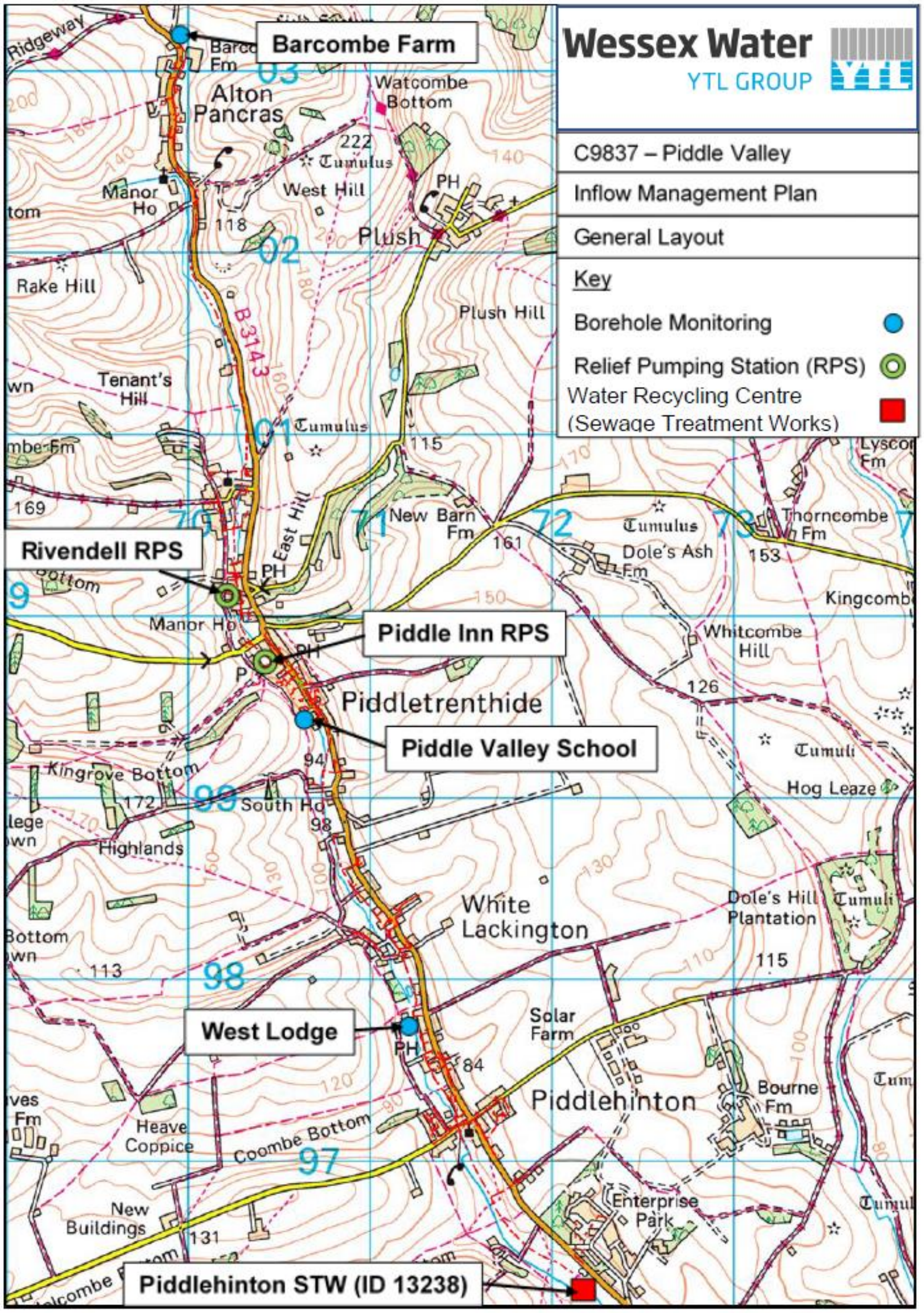

Figure E 4 Piddle Valley sewer

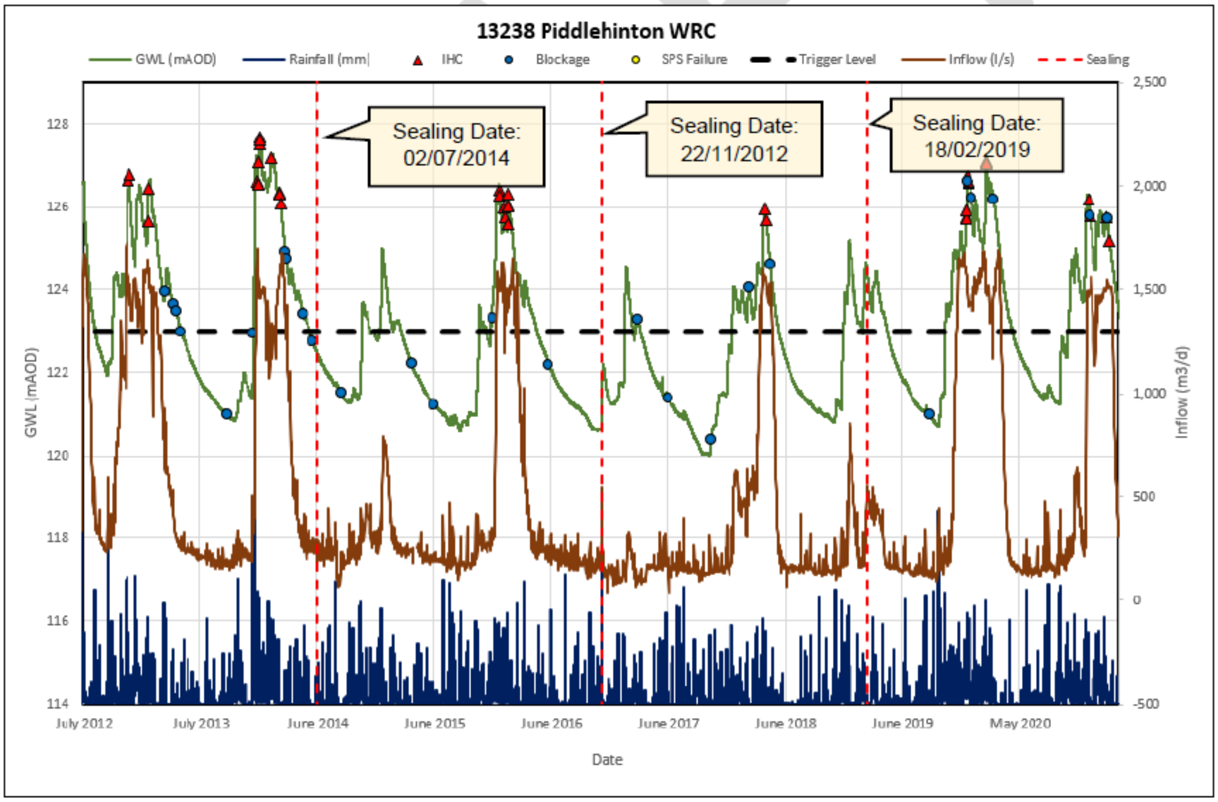

Figure E 5 Piddle Valley response to rainfall and groundwater showing trigger level for pumped overflows

E.4 Case Study 4 – Hanging Langford reedbed

E.4.1 Introduction

This case study develops the concepts of case study three to include a nature-based treatment solution that intercepts groundwater induced storm overflows before discharges are made to a chalk stream (River Wylye). Material for this case study was derived with permission from a Wessex Water publication.

E.4.2 Background

The village of Hanging Langford is in Wiltshire, northwest of Salisbury, and experiences very high groundwater levels most winters, resulting in localised flooding. The sewerage network is effectively used as land drainage and Wessex Water was allowed to pump the sewer network out, directing flows overland to the river to provide a functioning drainage system for residents.

To improve on this arrangement (which was unsightly and impacted on a network of lakes managed by the Wiltshire Wildlife Trust) it was agreed to provide an environmental permit for a pumped and screened groundwater induced storm overflow. This solution was considered more sustainable and affordable than alternatives, such as constructing a new groundwater land drainage system or increasing the capacity of the sewer network and wastewater treatment works.

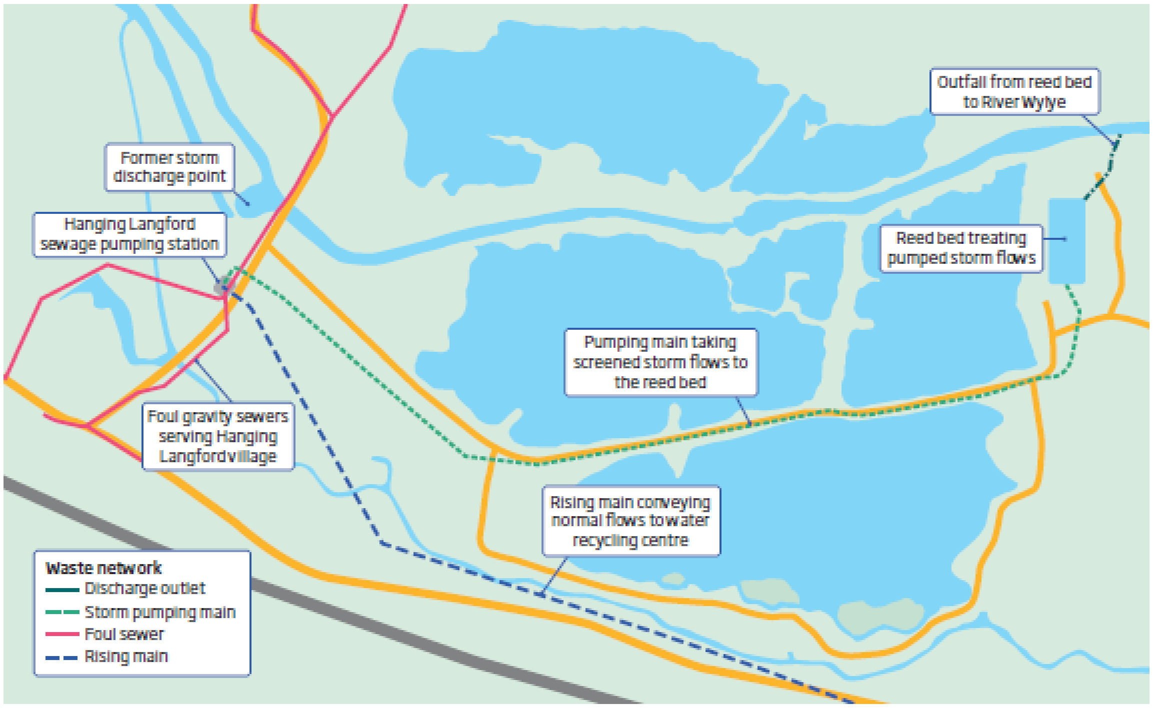

Figure E 6 Hanging Langford storm overflow arrangement

E.4.3 Details

Wessex Water first sealed the sewer network to reduce inflows as far as possible and then discharged the storm overflow to a reed bed next to one of the nature reserve lakes before its discharge to the River Wylye (Figure E 6). The reedbed was constructed in 2010, is 2000m^2 in area and is kept wet using water from the adjacent lake.

River sampling upstream and downstream of the discharge show no detrimental impact on levels of bacteria (Figure E 7) and the reed bed is providing a valuable habitat for species such as dragonflies and warblers.

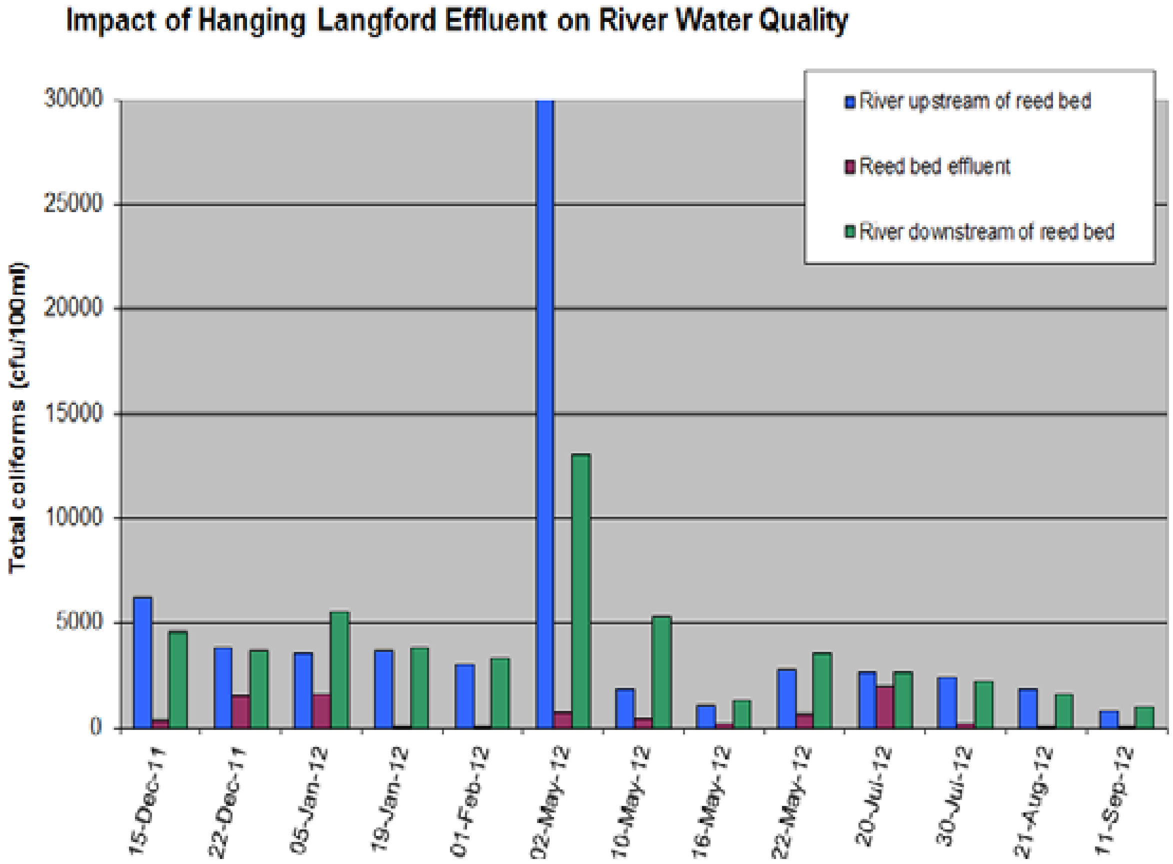

Figure E 7 Impact of Hanging Langford storm overflow

E.4.4 Conclusions

This case study demonstrates how a flexible and collaborative approach, between the water company, the Environment Agency and a local wildlife organisation, has resulted in a solution to a storm overflow problem caused by groundwater ingress to sewers.

It is illustrative of how nature-based solutions (reedbeds or constructed wetlands) may provide sustainable solutions that reduce harm from storm overflows. Such solutions can be lower in capital costs, operating costs, and carbon (than conventional sewerage solutions) but suitability is restricted by the availability of land. Their delivery also requires a collaborative partnership between water company, regulator and land owner.

Appendix F Uplifted values to account for overflows with permits that could not be included in the analysis

Appendix F Uplifted values to account for overflows with permits that could not be included in the analysis

November 1, 2021

Table F1 Uplifted CAPEX values to account for overflows with permits that were not included in the analysis and rounded values for the Executive Summary.

Policy option and delivery scenario		CAPEX Main report value (£mn)	CAPEX 30% increase value (£mn)	Rounded value for use in Executive Summary (£mn)
F40: W	Low	3,867	5,027	5,000
F40: W	High	6,530	8,489	8,500
F40: S10	Low	10,726	13,944	14,000
F40: S10	High	16,734	21,754	22,000
F40: S50	Low	39,585	51,461	51,000
F40: S50	High	59,726	77,644	78,000
F40 - 10: W	Low	13,502	17,553	18,000
F40 - 10: W	High	21,671	28,172	28,000
F40 - 10: S10	Low	20,995	27,294	27,000
F40 - 10: S10	High	32,714	42,528	43,000
F40 - 10: S50	Low	57,683	74,988	75,000
F40 - 10: S50	High	87,211	113,374	110,000
F20: W	Low	10,783	14,018	14,000
F20: W	High	17,473	22,715	23,000
F20: S10	Low	19,058	24,775	25,000
F20: S10	High	29,702	38,613	39,000
F20: S50	Low	58,753	76,379	76,000
F20: S50	High	88,756	115,383	120,000
F10: W	Low	20,489	26,636	27,000
F10: W	High	32,659	42,457	42,000
F10: S10	Low	28,814	37,458	37,000
F10: S10	High	44,870	58,331	58,000
F10: S50	Low	72,657	94,454	94,000
F10: S50	High	109,923	142,900	140,000
F5: W	Low	38,734	50,354	50,000
F5: W	High	60,863	79,122	79,000
F5: S10	Low	39,802	51,743	52,000
F5: S10	High	61,863	80,422	80,000
F5: S50	Low	86,317	112,212	110,000
F5: S50	High	130,840	170,092	170,000
F0: W	Low	121,151	157,496	160,000
F0: W	High	187,857	244,214	240,000
F0: S10	Low	126,554	164,520	160,000
F0: S10	High	195,484	254,129	250,000

Appendix F Uplifted values to account for overflows with permits that could not be included in the analysis

November 1, 2021

Policy option and delivery scenario		CAPEX Main report value (£mn)	CAPEX 30% increase value (£mn)	Rounded value for use in Executive Summary (£mn)
F0: S50	Low	141,576	184,049	180,000
F0: S50	High	215,841	280,593	280,000
F10 Sensitive Waters: W	Low	11,960	15,548	16,000
F10 Sensitive Waters: W	High	19,072	24,794	25,000
F10 Sensitive Waters: S10	Low	16,630	21,619	22,000
F10 Sensitive Waters: S10	High	25,915	33,690	34,000
F10 Sensitive Waters: S50	Low	41,453	53,889	54,000
F10 Sensitive Waters: S50	High	62,730	81,549	82,000
F10 RNAG related to storm overflows: W	Low	9,866	12,826	13,000
F10 RNAG related to storm overflows: W	High	15,712	20,426	20,000
F10 RNAG related to storm overflows: S10	Low	12,837	16,688	17,000
F10 RNAG related to storm overflows: S10	High	20,036	26,047	26,000
F10 RNAG related to storm overflows: S50	Low	29,785	38,721	39,000
F10 RNAG related to storm overflows: S50	High	45,121	58,657	59,000
F5 Rivers used for bathing: W	Low	5,990	7,787	8,000
F5 Rivers used for bathing: W	High	9,415	12,240	12,000
F5 Rivers used for bathing: S10	Low	6,164	8,013	8,000
F5 Rivers used for bathing: S10	High	9,584	12,459	12,000
F5 Rivers used for bathing: S50	Low	13,387	17,403	17,000
F5 Rivers used for bathing: S50	High	20,293	26,381	26,000
Full separation	Low	338,000	n/a	350,000
Full separation	High	593,000	n/a	600,000

Table F2 Uplifted bill impact values to account for overflows with permits that could not be included in the analysis

Policy option and delivery scenario		Bill impact Main report value (£/household/year)	Bill impact 30% increase value (£/household/year)
F40: W	Low	7	9
F40: W	High	11	14
F40: S10	Low	20	26
F40: S10	High	30	39
F40: S50	Low	76	99
F40: S50	High	110	143
F40 - 10: W	Low	23	30
F40 - 10: W	High	37	48
F40 - 10: S10	Low	38	49
F40 - 10: S10	High	58	75
F40 - 10: S50	Low	110	143
F40 - 10: S50	High	160	208
F20: W	Low	19	25
F20: W	High	30	39
F20: S10	Low	35	46
F20: S10	High	53	69
F20: S50	Low	112	146
F20: S50	High	163	212
F10: W	Low	35	46
F10: W	High	56	73
F10: S10	Low	52	68
F10: S10	High	79	103
F10: S50	Low	138	179
F10: S50	High	201	261
F5: W	Low	66	86
F5: W	High	103	134
F5: S10	Low	71	92
F5: S10	High	108	140
F5: S50	Low	162	211
F5: S50	High	237	308
F0: W	Low	205	267
F0: W	High	317	412
F0: S10	Low	217	282
F0: S10	High	333	433

Appendix F Uplifted values to account for overflows with permits that could not be included in the analysis

November 1, 2021

Policy option and delivery scenario		Bill impact Main report value (£/household/year)	Bill impact 30% increase value (£/household/year)
F0: S50	Low	256	333
F0: S50	High	381	495
F10 Sensitive Waters: W	Low	20	26
F10 Sensitive Waters: W	High	32	42
F10 Sensitive Waters: S10	Low	30	39
F10 Sensitive Waters: S10	High	46	60
F10 Sensitive Waters: S50	Low	79	103
F10 Sensitive Waters: S50	High	115	150
F10 RNAG related to storm overflows: W	Low	17	22
F10 RNAG related to storm overflows: W	High	27	35
F10 RNAG related to storm overflows: S10	Low	23	30
F10 RNAG related to storm overflows: S10	High	35	46
F10 RNAG related to storm overflows: S50	Low	57	74
F10 RNAG related to storm overflows: S50	High	83	108
F5 Rivers used for bathing: W	Low	10	13
F5 Rivers used for bathing: W	High	16	21
F5 Rivers used for bathing: S10	Low	11	14
F5 Rivers used for bathing: S10	High	17	22
F5 Rivers used for bathing: S50	Low	25	33
F5 Rivers used for bathing: S50	High	37	48