Civil engineering insights into combined sewer overflows (CSOs)

This paper discusses the use of combined sewer overflows as part of the UK's wastewater infrastructure system, and what policymakers and practitioners must consider in managing and preventing excessive discharges into waterways.

Overview

England has a combined sewage system made up of hundreds of thousands of kilometres of sewers, much of which was built by the Victorians, in many urban centres. This means rainwater and wastewater from toilets, bathrooms and kitchens are conveyed in the same pipe to sewage treatment works.

During heavy rainfall, the capacity of these pipes can be exceeded. This means possible inundation of sewage works and the potential to back up and flood homes, roads, and open spaces unless it is allowed to spill elsewhere. Combined sewer overflows (CSOs, also known as storm overflows) were developed as overflow valves to reduce flooding during heavy rainfall.

Overflows of diluted sewage during heavy rainfall are not a sign that the system is faulty. CSOs are a necessary part of the existing sewerage infrastructure system, preventing sewage from flooding homes and businesses.

However, the topic of sewage discharges onto UK beaches and rivers has attracted a significant amount of attention. In 2022, sewer overflows discharged a mix of raw sewage and rainwater into rivers and seas 301,091 times – or 825 times a day on average (a 19% reduction in the number of sewage discharges from 2021, largely driven by 2022's below-average rainfall).[1] Untreated sewage contains bacteria such as E. coli and viruses like hepatitis, which can be harmful to the public and wildlife.

The issue has resonated very strongly with the public, who are facing the prospect of ongoing sewage discharges and increased bills to fix or mitigate the problem.

The UK government published its storm overflows discharge reduction plan in August 2022. It commits water companies to spend £56 billion between 2025 and 2050 to reduce spills from CSOs that discharge to inland waterways and designated bathing waters.

Reducing discharges from sewer overflows on the scale planned in an environmentally sensitive way is a huge challenge. Professionals and policymakers must now ensure that the additional investment delivers the intended improvements to rivers, waterways and the infrastructure system. However, attempting to rush the process will likely result in ineffective solutions that may do more harm than good.

This insight paper, which draws on views and evidence from experts on the ICE's Water & Sanitation Community Advisory Board, asks: what is the true impact and scale of the problem? What are the solutions and timescales to implement solutions? And what are the challenges to overcome for policymakers and professionals?

[1] Department for Environment, Food & Rural Affairs (2022) Event Duration Monitoring - Storm Overflows - Annual Returns

CSOs in context

While it is fair to say that the views on CSO discharges expressed by the press, public and politicians are universally negative, it is important to make sure that there is an understanding of why CSO discharges happen so that solutions to the problem can be found.

From the Victorian era until well into the second half of the 20th century, it was standard practice in the UK and most of the developed world to provide combined sewers. The legacy of this combined infrastructure remains:

- Combined sewers carry wastewater from toilets, sinks, baths, and showers, alongside rainwater (surface water), combining both into a single pipe.
- When it rains very heavily, the volume of rainwater can become too great for the pipes. An overflow arrangement is needed to ensure that properties are not flooded.
- There are approximately 22,000 CSOs in the UK (with 15,000 in England) discharging to inland rivers, estuaries, the sea, and other water bodies.[2]
- Many of these have been in operation since the first sewers were built over 150 years ago. Across Europe, there are 650,000 overflows. As such, CSOs are not new, and nor are they unique to the UK.

The rollout of comprehensive monitoring of CSOs in England and Wales, which started in 2016, has revealed their frequent use as part of the day-to-day operation of the UK's wastewater infrastructure system, with the water sector apologising and admitting that rivers and beaches are often not at the standard the public rightly expect.

However, this gradual rollout of monitoring means that comparing data on CSO discharges over time can be misleading, primarily as more CSOs are monitored today than at any point previously.

The impact of CSOs

CSOs can cause problems for the health of people, wildlife and the environment, particularly if the overflow spills too often or discharges to a sensitive location.

In periods of heavy rain, the overflows should primarily be rainwater and could be discharged into the swollen river harmlessly. Rainwater from approximately 62% of properties drains into combined sewers.[3]

However, while the effluent (liquid waste or sewage) discharged from CSOs should be mainly rainwater, there will still be a quantity of untreated sewage. This can affect the health of rivers as the discharges can introduce ammonia and reduce the levels of dissolved oxygen in the rivers.

Storm discharges can contain high levels of bacteria, which impacts public health. Swimming in water where untreated sewage is discharged can lead to gastrointestinal illnesses, as well as respiratory, skin, ear, and eye infections. Wildlife, including fish and insects, can also be harmed, primarily due to a lack of oxygen in the water.[4]

These discharges can also have a significant 'social impact' as the effect on the public of seeing untreated flows from sewers being discharged into waterways causes concern.

In recent years, discharges from CSOs have increased in many areas. In some locations, this is due to increased population and a phenomenon called 'urban creep'.

[2] Department for Environment, Food & Rural Affairs (2022) Storm Overflows Evidence Project
[3] Sayers and Partners (2022) Surface Water Future Risk and Investment Needs
[4] Natural History Museum (2021) The Deadly Effects of Sewage Pollution on Nature

Urban creep describes the impact of issues such as gardens being paved over to provide space to park cars or the addition of conservatories and patios in gardens that were previously grass, resulting in more rainwater passing into the combined sewers rather than soaking into the ground.

Changing weather patterns due to climate change are bringing more intense rainfall, which is not only harmful to rivers and lakes, but also increases the risk of surface water flooding.

In other areas, ageing sewerage infrastructure allows more infiltration (groundwater) to enter the pipes, increasing the flows within them and causing them to spill more frequently. These trends are likely to continue unless greater emphasis is placed on maintenance to reduce the problem.

What are the solutions?

CSOs exist as a safety valve, which helps to prevent flooding when the flows in combined sewers exceed the capacity. When considering solutions, care must be taken to ensure that interventions do not result in increased flooding.

Recognising the importance of accurate data, the water companies and their regulators agreed to install event monitors in CSOs so the frequency of their operation could be accurately recorded, and trends and impacts studied. The installation of monitoring equipment is a work in progress. It is set to be completed by the end of 2023, with the data on overflow discharges made available to the public by 2025.[5]

There are a variety of interventions that can be made to reduce the problem, such as blue-green infrastructure, nature-based solutions and examining how clean, healthy rivers can be achieved by considering the catchment as a whole (i.e. if the main source of pollution in a particular catchment is agriculture, it may be more sensible to improve the river quality by working with farmers to reduce their impact rather than only focusing on the CSO). When considering CSOs alone, simplistically, there are two solutions: to either store or separate, as summarised below.

Storage	Separation
Store storm flows in large tanks until the storm has passed, then empty the tank back into the sewer.	**Separate the surface water and discharge the surface water in a way that does not harm the environment and does not result in unacceptable flooding.**
This represents the most widely used approach.	These solutions have been used and trialled around the world, attempted at scale in 'sponge cities' (China and elsewhere)
Pros ■ This type of solution is understood and is known to work. ■ The costs associated with this type of solution can be estimated with some confidence. ■ Delivery of these solutions is within the current powers of the water companies.	Pros ■ Separating foul and surface water on new developments is relatively easy, and the solutions can provide green spaces, improved habitats and involve less water being pumped (reducing carbon impact). ■ In the right conditions, these solutions can help to recharge aquifers. ■ Working with nature to reduce the impact of developments.
Cons ■ If there is too much storage in the network, tanks can remain partially full for weeks or months and the sewage becomes septic. This leads to corrosion, odours, and difficulties at treatment works. ■ As the tanks do not empty in wetter periods, the volumes of storage required to reduce spills can become unrealistically large. ■ Concrete storage tanks have a high carbon emission impact. **Storage tanks will be part of the solution but cannot drive discharges down to the levels required.**	Cons ■ Separating foul and surface water systems in existing urban areas is technically challenging and disruptive. ■ Finding a space and point of discharge for the water that meets the requirements of blue-green infrastructure without making flooding worse can be very challenging and is arguably impossible in some locations. ■ Many stakeholders are involved in this process, and guidance on implementation for both engineers and these stakeholders is very limited. ■ Water companies do not currently have the powers to deliver these projects on the scale needed. **Effective, but takes a long time to plan and implement**

[5] Environment Agency (2021) Event Duration Monitoring – Lifting the Lid on Storm Overflows

A UK government-led taskforce, including Ofwat, the Environment Agency, water companies, the Consumer Council for Water, and other environmental groups was established, producing the Storm Overflows Evidence Project in 2022. A range of options were considered, and costs and benefits were assessed.

The report concluded that eliminating CSOs would cost between £350 billion and £600 billion, increasing household bills between £569 and £999 per year.[6] Water companies would need access to an additional 118.43 million m^3 of storage to achieve zero spills, equivalent to 40,000 Olympic-sized swimming pools.

Getting to zero spills would also emit over 19 million tonnes of carbon dioxide equivalent through embodied carbon in construction activity and materials – approximately 20 times the embodied carbon estimated to result from the construction of HS2.[7]

A whole range of options, which involved retaining CSOs in some capacity but reducing spill frequency, were also evaluated and presented. Costs here range from £5 billion to £280 billion and would impact accordingly on household bills.

The research that the costs were based on was the first of its kind; there were many unknowns and uncertainties in deriving the numbers. As such, care must be taken when applying the estimates generated.

Reducing rainwater flows in sewers will contribute to reducing the risk of CSO spills. The National Infrastructure Commission has concluded that some CSO investment could be co-designed to address surface water flooding, reducing the total investment needed.[8] Recent successful schemes in Llanelli and Barcelona have been designed to address both goals.[9] [10]

The scale and size of the challenge

Since privatisation in 1990, the water companies in England and Wales have invested approximately £160 billion.[11]

On 26 August 2022, the UK government published its storm overflows discharge reduction plan, which commits the water companies to spend £56 billion between 2025 and 2050 to reduce spills from CSOs that discharge to inland waterways and designated bathing waters.[12] This is in addition to the work that has already been committed to. By 2025, the aim is for water companies to have reduced overflow discharge from 2020 levels by 25%.

In May 2023, Water UK, the membership body representing the UK water industry, announced plans to publish a National Overflows Plan in summer 2023, setting out each water company's approach to improving their sewage spills performance and when those improvements can be expected, how they will be delivered, and the expected results. This includes £10 billion of investment with an expectation that, by 2030, this will cut sewage discharges by up to 140,000 each year compared to 2020 levels.[13]

These funds are based on the assumption that the primary solution will be large storage tanks. Opposition parties are pushing for the challenge to be tackled sooner than 2050.

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[6] Department for Environment, Food & Rural Affairs (2022) Storm Overflows Evidence Project
[7] Department for Environment, Food & Rural Affairs (2022) Storm Overflows Discharge Reduction Plan
[8] National Infrastructure Commission (2022) Reducing the Risk of Surface Water Flooding
[9] *Proceedings of the Institution of Civil Engineers - Civil Engineering*, Christopher Ellis et al. (2016) Transforming Water Management in Llanelli, UK
[10] *Sustainability*, Luca Locatelli et al. (2020), Socio-Economic Assessment of Green Infrastructure for Climate Change Adaptation in the Context of Urban Drainage Planning
[11] House of Commons Library (2020) Economic Regulation of the Water Industry in England and Wales
[12] Department for Environment, Food & Rural Affairs (2022) Storm Overflows Discharge Reduction Plan
[13] Water UK (2023) Water and Sewage Companies in England Apologise for Sewage Spills and Launch Massive Transformation Programme

Engineers are tasked with driving down embodied and operational carbon; doubling the capital programme with investment in concrete storage tanks will result in higher emissions. This raises questions about whether there is a net environmental benefit in reducing spills from overflows to the extent required in all locations. The installation of monitors to automatically record spills from CSOs started by agreement in 2016. The Environment Act 2021 requires water companies to install monitors at CSOs to measure the impact of the overflow on the river. This is a large and complex programme of works. If this is successful, it will provide a much better understanding of the impacts of sewer overflows.

As of July 2023, the Department for Environment, Food and Rural Affairs (Defra) is consulting on how best to address the remaining 9% of CSOs that have coastal or estuarine discharges that are not designated bathing waters[14]. Including these remaining CSOs will add to the costs.

Reducing discharges from sewer overflows on the scale set in an environmentally sensitive way is a huge challenge and will involve many stakeholders. The challenge is vast, and attempting to rush the process will likely result in ineffective solutions that may do more harm than good.

Additional guidance could make a big difference if the key stakeholders were involved in its development. There is currently minimal guidance for engineers, regulators, or other stakeholders (such as town planners) attempting to separate existing foul and surface water flows.

There are also wider issues, such as that surface water (particularly highway run-off) is often too contaminated to be discharged to the environment and requires the design, construction, and adaptation of treatment works.

There is a need to better understand what the pollutants are, what the design criteria are for the treatment works intended for highway run-off, and who will own and operate them. In some circumstances, it may be better to extract the foul flows from the combined system and construct an entirely new vacuum foul system and foul treatment works. However, this could prove very expensive to build and operate.

In addition, there remains a skills shortage in the water sector that must be addressed. Increased investment in addressing discharges will see greater demand for people who understand sewerage and drainage at all levels, along with the wider implications.

[14] Department for Environment, Food & Rural Affairs (2023) Storm Overflows Discharge Reduction Plan Consultation

Next steps

Ensuring that the additional investment delivers the desired improvements to rivers, waterways and the wider infrastructure system is vital. In debating the next steps, policymakers and practitioners must consider the following issues:

- The public is rightly concerned about the impact of CSO spills, but much of the emotion and finger-pointing must be stripped out of the debate.
- Reducing spills from CSOs must be debated based on sound principles and an understanding of the implications of the decisions made. Above all, interventions must not result in increased flooding.
- The cost of completely separating wastewater and stormwater infrastructure, effectively eliminating CSOs, has been estimated at £350 billion to £600 billion, increasing household bills by £569 to £999 per year.
- Limiting spills to 40 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.
- All scenarios for eliminating or limiting spills carry a significant cost in embodied carbon through construction activity and materials.
- Long-term, low-carbon solutions will take decades to plan, design and deliver.
- CSOs are not the only cause of river pollution; solutions must be considered in parallel with other issues, such as agricultural and highway run-off pollution.
- Guidance is required if the water sector is to successfully implement blue-green infrastructure solutions and separate surface water from foul flows on a large scale. This guidance is needed for the regulators as well as the designers.
- It is vital that solutions deliver cleaner rivers in a sustainable way. This means resisting undertaking work to resolve spills that are found to be doing no harm and looking for whole-catchment, nature-based solutions wherever possible.
- Policymakers must be very careful in navigating a route to the cleaner, greener future that is needed. All parties must collaborate to find the solutions which are right for the UK public.

About the ICE

Established in 1818 and with over 96,000 members worldwide, the Institution of Civil Engineers exists to deliver insights on infrastructure for societal benefit, using the professional engineering knowledge of our global membership.

The ICE's strategy is focused on the decarbonisation of the infrastructure system, building resilience against the effects of climate change, and transforming productivity in infrastructure delivery, recognising the interlinking effects of water, transport and energy in achieving these goals.

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Appendix: case studies

St. Louis, Missouri, USA

Project details

Location: St. Louis, Missouri, USA [catchment serves 1.3 million people]
Value: $4.7 billion
Date of completion: 2013 (planning), ongoing (implementation)
Duration: 10 years (planning), 23 years (implementation)
Client: Metropolitan St. Louis Sewer District (MSD)

Challenge summary: Protecting public health by reducing overflows into streams and rivers, eliminating illegal discharge points in the collection system, and meeting the Environmental Protection Agency Consent Decree requirements to reduce the discharge of pollutants from the city's wastewater infrastructure.

Challenge solution: $4.7 billion, 400+ projects, 23-year long capital improvement replacement programme.

Combined sewers dominate in St. Louis City and older inner suburbs. MSD is conducting an expansive overhaul of the city's sewerage infrastructure. It requires a 23-year timeline to achieve these goals, periodic reporting requirements, sewer improvement and maintenance plans, and expansion of sewer capacity.

Not only will this work reduce the discharge of pollutants into waterways, but it will also prevent backups of sewage in basements and some areas of localised flooding. The programme also requires $100 million of investment in 'green' stormwater technologies to reduce rainwater volume in the combined sewer system.

The programme facilitates the reduction of almost 13 billion gallons of overflows into local waterways per year and significantly reduces CSO volumes leaving the collection system. In addition, it eliminates more than 200 illegal discharge points within the sanitary sewer system.

International Perceptions of Urban Blue-Green Infrastructure: A Comparison across Four Cities

by Emily C. O'Donnell, Noelwah R. Netusil, Faith K. S. Chan, Nanco J. Dolman and Simon N. Gosling

This study approaches the issue of blue-green infrastructure (BGI) perceptions. It does so in a unique way by exploring perceptions of BGI in four cities at the forefront of their implementation through an online survey with professionals from a range of disciplines (engineers, environmental managers, designers, planners, and those involved in strategy, policy, finance and implementation) and organisations (public, private, academia, non-profit).

BGI is defined as an interconnected network of landscape components, both natural and designed, that includes open, green spaces and water bodies. Examples are green roofs and walls, swales, rain gardens, street trees, ponds, urban wetlands, restored watercourses, reconnected floodplains, and re-naturalised and de-culverted rivers.

Often referred to as 'green infrastructure' or 'nature-based solutions', BGI is subtly different in that it is specifically designed to turn 'blue' during rainfall events to manage stormwater and reduce flood risk.

This is the first multi-country comparison of professional stakeholders' perceptions of BGI, supported by a detailed online survey and supplementary analysis of open-source plans, reports, and city strategies.

Several case studies examine professionals' perspectives of the barriers and challenges to implementing BGI and how they have been overcome (in Australia; Portland, Oregon; Sweden; Semarang City, Indonesia, China, and Newcastle, UK).