Government
Office for Science

Future of the Subsurface: Urban Water Management in the UK

June 2024

Foresight

Government Office for Science

Artwork credit: Cleo Zhang

Foresight

Overview

This document is an annex to the *Future of the Subsurface* report completed by the Foresight team in the Government Office for Science. It has been informed by a review of literature and stakeholder engagement and draws on a series of UK and international case studies to highlight current issues and potential solutions for urban water management.

- **Background**: the review begins by introducing water management in urban areas. Over 80% of the UK's population lives in urban areas, and relies on water management systems for essential services such as provision of drinking water, wastewater removal and treatment, and flood protection.[1] These water systems, which exist both within urban areas and across the wider water catchment, comprise both built and natural components, including pipes and other distribution infrastructure, wastewater treatment works, groundwater, and rivers.
- **Current UK status**: the review then describes different aspects of urban water management in more detail. These include challenges associated with managing urban water systems and the crucial services they provide. Water supply, for example, is challenged by drought, demand, and water leakages. The management of flood risk, groundwater, wastewater and pollution are also considered. In the UK, the responsibility for managing urban water systems is shared by multiple bodies, and the policy landscape varies by location.
- **International examples of innovative urban water management**: the review then considers some international examples. These include a rainwater harvesting system in Australia, a smart city with smart urban water management in South Korea, and the Cloudburst Management Plan in Denmark.
- **Future challenges and opportunities in urban water management**: the review then highlights some challenges and opportunities in urban water management in the UK. Many problems faced by urban water management are likely to

become exacerbated in the future, as urbanisation increases, climate change brings more extreme weather, and water infrastructure increasingly competes for subsurface space with other uses. There are also opportunities to innovatively manage urban water, that utilise emerging technologies or take a more holistic approach. These can be efficient in targeting more than one urban water management issue at once, whilst providing benefits for the citizens of urban areas.

- **Interactions with the wider subsurface system**: the review ends by considering how urban water systems interacts with the wider subsurface system. Examples of these interactions include groundwater flooding affecting other subsurface infrastructure, tree roots interfering with buried infrastructure, and competition for space between subsurface water infrastructure and other assets. The review also considers a specific subsurface interaction relating to urban water management – the potential implications of an increase in the installation of sustainable drainage systems (SuDS).

Background

Water systems, both within the urban footprint and across the wider water catchment, have a crucial role providing essential services for cities, and comprise both natural and built systems. Over 80% of the UK's population live in urban areas, and rely on these essential services including the delivery of drinking water, removal of wastewater, management of surface water and flood protection. This case study focuses on parts of water systems that fall within the urban catchment specifically ('urban water systems'), and primarily their subsurface aspects. However, urban water systems form part of the wider water catchment which includes rural areas, and activity at the surface strongly influences the subsurface.

The natural water system comprises a variety of components, including rainfall, moisture in the soil, groundwater, blue infrastructure[i] such as rivers and ponds, and supporting green infrastructure[ii] such as trees. Blue-green infrastructure provides a multitude of benefits, including improving an area's natural flood resilience, and increasing biodiversity. Components of the natural water system have often been altered in urban areas, for example, many rivers in urban areas have been culverted or heavily modified over a period of many years, for purposes such as supporting industrial processes or to free up surface space.

Groundwater is both a source of water and can be used to provide heating and cooling. It stores geothermal energy which can be extracted from the ground by either open or closed loop geothermal heating systems. Open loop systems pump groundwater from aquifers directly, utilising a heat pump to extract low-grade heat and upgrade it to higher temperatures (>40˚C) required for the heating of buildings. They then return the colder groundwater to the subsurface. Closed loop systems use a carrier fluid, rather than the groundwater itself, to exchange heat. For a more detailed description of

[i] Blue infrastructure is urban water infrastructure, which includes rivers, canals and ponds.
[ii] Green infrastructure refers to natural spaces in urban areas, such as hedges, fields, parks and gardens.

geothermal energy and heating, please see the evidence review *Geothermal energy in the UK*.

Engineered water systems consist of infrastructure such as pipes and other distribution elements, and water treatment and storage facilities, which provide services such as the provision of water supply, wastewater treatment and flood protection. Water is supplied by pipes which pump water to urban areas from reservoirs, and wastewater is carried away from buildings through a different set of pipes to sewers. In urban areas, rainwater often cannot drain naturally due to high levels of impermeable surfaces, so positive drainage is required to manage surface water runoff.

Traditional drainage systems form part of the built water system and are designed to remove water as quickly as possible where it falls, by directing it into public sewers. Around a third of sewers in the UK are 'combined sewer systems', which carry both wastewater and surface water. The volume of surface water entering the wastewater system puts it under significant pressure, which is often alleviated through 'combined sewer overflows'.[2] These discharge excess water (diluted sewage) directly into watercourses at times of high flow and are regulated, for example by the Environment Agency (EA) in England under the Permitting Regime.[3] Otherwise, wastewater from sewers is cleaned in water treatment facilities before being returned to rivers.

Current status in UK

This section covers different aspects of urban water management in the UK, including the management of water supply, flood risk, urban groundwater, wastewater and pollution. It also covers information on the policy landscape of urban water systems and urban water management in Manchester.

Water supply

The delivery of safe drinking water is a crucial function of the urban water system, and is challenged by drought, increasing demand and ageing infrastructure. The daily household usage of water increased from 85 litres per person in the 1960s to 143 litres per person in 2020.[4]

Leaks exacerbate water demand issues, causing around one fifth of public water supply to be lost each year.[5] They can be caused by ageing pipes or ground movement, which results from ground water abstraction, loading from construction, or temperature changes. As shown in Figure 1, the volume of water lost from leaks decreased during the 1990s, then remained relatively constant in the 2000s and 2010s. Although the amount of water lost from leaks has recently started to decline again, leaks remain frequent and difficult to detect.

Challenges from these issues can exist in parallel. For example, London experiences significant water loss through leaks (around 500 megalitres of water per day in 2019), whilst being in the South-East which is currently classified as 'seriously water stressed'.[6] Significant portions of its pipes are over 60 years old, with some being older than 150 years.

Water companies are responsible for the delivery of water supply, as well as manging the supporting infrastructure. Ofwat, the Water Services Regulation Authority, are the economic regulator of water companies, and are responsible for ensuring that water companies properly carry out their functions and can finance their functions.[7]

Current status in UK

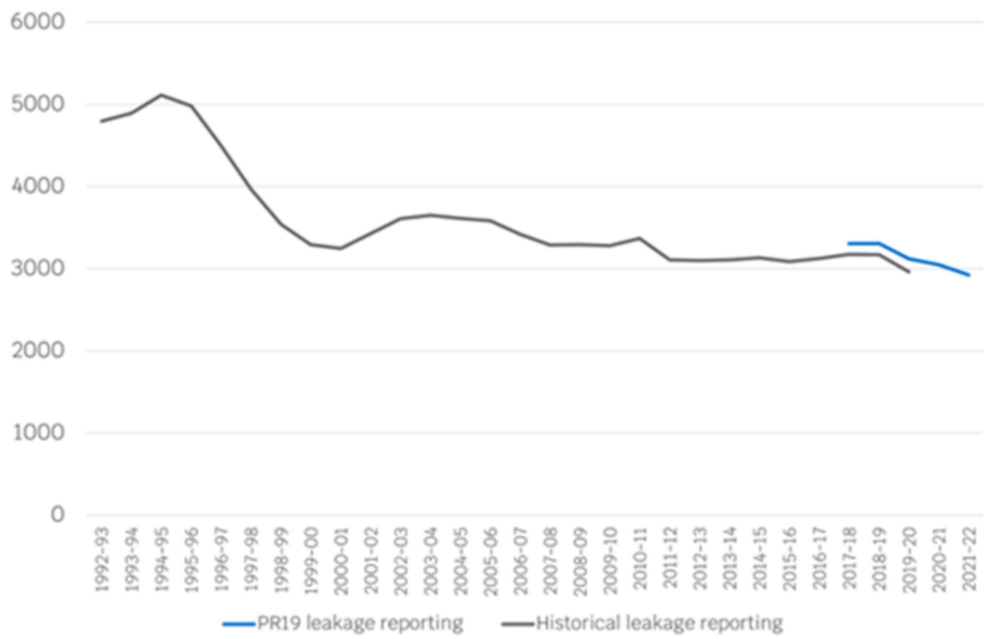

Figure 1: Graph showing water leakage from pipes in ML/day in England and Wales. Source: © Crown Copyright ([Ofwat](#))

Flood risk

Flood risk is one of the main hazards faced by urban areas, and can be dangerous to life, as well as causing infrastructural and economic damage. For example, annual losses from flood damage are around £700 million,[8] and over 60% of properties in England use services supplied by infrastructure sites and networks located in (or dependent on others located in) areas at risk of flooding.[9]

Permeable surfaces such as grass and soft landscaping help absorb rain and allow it to infiltrate into underlying soils, but in urbanised areas these surfaces are often replaced with less permeable or impermeable materials, such as concrete. This results in rain collecting on the surface, which requires formalised drainage systems to remove. 'Surface water flooding' is a type of flooding which occurs when urban drainage systems become overwhelmed by severe or extended rainfall or as a result of localised failures or blockages. Approximately 3.4 million properties in England were at risk of surface water flooding in the year 2022-2023, with over 900,000 of these having an annual probability of flooding greater than 1%.[10,11]

'Groundwater flooding' is another type of flooding, in which groundwater emerges from the ground at the surface or causes the flooding of buildings or infrastructure below ground including basements. This also affects urban areas, with an estimated 122,000-290,000 properties estimated to be at risk in England in 2021-2022.[10] Fluvial (river) flooding[iii] and sea flooding can also affect urban areas.

There have been recent changes to legal drainage requirements for new developments to help mitigate the flood risk in urban areas. Schedule 3 of the 2010 Flood Water Management Act has a provision for the approval and adoption of drainage systems, in which drainage approval is required from a SuDS approval body (SAB) before commencing any construction work which has drainage implications. This was adopted by Wales and came into force in 2019.[12] A recent review by Defra recommended making SuDS mandatory for new developments, and there will likely be new standards on the design, construction, operation and maintenance of SuDS.[13] Schedule 3 is currently in the process of being enacted in England, however the way it will be implemented is still being determined by Defra.

Urban groundwater

Groundwater refers to water found beneath the Earth's surface in spaces between rocks and soil and is a key element of the urban water system. Whilst accounting for a third of public water supply in the UK, and up to two thirds in some regions, groundwater is sensitive to human interference with a multitude of factors determining pollution and water table levels. Regulation and coordination of these various factors is sparse, and without adequate risk management, can lead to issues including subsidence and groundwater flooding.

Groundwater has been referred to as "both an asset and a problem",[14] because it's a very valuable resource, but can also pose health risks. As well as being used for human consumption, it has other applications such as being used in industrial processes and

[iii] When rivers and streams break their banks causing water to flow out onto adjacent low-lying areas.

for the cooling of air.[15] Compared to other water sources, groundwater is typically more resilient to the effects of climate change although groundwater drought does occur.[16]

The interaction between groundwater and buried urban infrastructure can be a significant problem. Groundwater can infiltrate and flood buried infrastructure such as basements and tunnels, and the prolific construction of underground infrastructure can impede groundwater flow and lead to higher water table levels. This can be considered during the planning stages of basement construction, for example through Basement Impact Assessments.[17]

The balance between natural groundwater recharge and the abstraction of groundwater also affects water table levels and leads to issues if not monitored. Over-abstraction, where the amount of groundwater being abstracted is greater than the amount being replenished by the rain, can cause negative effects including the deterioration of groundwater quality, increased salinity concentrations and declining water table levels, which can lead to subsidence issues.[18] Groundwater rebound, where abstraction decreases and groundwater levels recover, can result in ground uplift, and flooding of buried infrastructure.[19,20] This has been a particular issue in cities such as Birmingham, Nottingham, Liverpool and London.[21]

In the late 1980s in London, groundwater rebound was identified as a potential problem as the water table was rising by up to 3m per year following decreases in groundwater abstraction. However, this was addressed via the GARDIT strategy which was devised between Thames Water, the EA and London Underground. Now groundwater levels in London are continuously monitored and are broadly stable.[22]

Waste

Managing and treating wastewater is a crucial function of urban water systems. A huge volume of wastewater requires treatment in urban areas each year, for example Thames water, which supplies areas in the South of England, treated 4.6 billion tonnes of wastewater between March 2021 and March 2022.[23] Around a third of sewers in the UK are combined, in which wastewater and surface water are discharged to the same piped network.

Water companies often discharge dilute raw sewage into rivers via storm overflows to alleviate pressure on combined sewer systems, for example in 2021, discharged raw sewage was discharged into rivers 372,533 times over a period of 2.75 million hours (over 300 years).[24] The EA regulates the use of sewage overflows by water companies through Environmental Permitting Regulations,[25] however overflows occur regularly and outside of these permitted events, increasing pollution. Recent analysis has attributed sewage overflow events to insufficient infrastructure capacity and highlighted that investment into water infrastructure has not kept up with demand over a prolonged period of time, with most wastewater treatment works receiving a volume of flow much greater than they are designed to manage. This demand increase is partly attributable to urban population growth, whilst urbanisation has also increased surface run-off volumes into combined sewers.[26]

Recent upgrades to urban sewer systems include the construction of the Tideway Tunnel in London. This is a 25km long tunnel underneath the Thames to reduce sewage overflows and is due for completion in 2025.[27] Water companies have recently pledged to invest £10bn this decade to modernise sewers and reduce sewage overflows into England's waterways, tripling their current investment plans. This will fund a significant upgrade to the sewer system, which Water UK has stated will reduce sewage overflows by up to 140,000 per year by 2030, compared with 2020.[28]

Pollution

Aside from storm overflows discharging diluted sewage into watercourses, other areas of the natural water environment in urban areas which are susceptible to pollution include groundwater and other bodies of water such as ponds. Pollution can enter the natural water environment directly from the source, such as phosphorous from water mains leaks or wastewater treatment works.[29] Similarly, thermal pollution from infrastructure can pollute natural water environments by raising their temperature.[30] For example, ground source heating and cooling systems can thermally pollute groundwater, altering microbe growth rates and chemical concentrations.[31]

The natural environment can also become polluted by diffuse sources, including pollutants relating to both industrial and municipal activities, such as run-off from impervious surfaces and built areas, and pollutants from leaking sewers.[32] The adverse impacts of these effects on water can include harmful impacts to aquatic life,[33] and increases in the cost of purification of groundwater to produce drinking water.[34] Government have committed to producing plans to mitigate against diffuse pollution.[35]

Policy landscape

In the UK, the responsibility for managing urban water systems is shared by multiple bodies, and the policy landscape varies across different locations.

For example, water supply management involves Defra which oversees the policy landscape, Ofwat which economically regulates water companies and water companies who are responsible for water delivery infrastructure. Groundwater abstraction is primarily controlled through a licensing system. This is overseen by the Environment Agency in England,[36] the Environment Agency Wales in Wales,[37] the Scottish Environment Protection Agency in Scotland[38] and the Northern Ireland Environment Agency in Northern Ireland.[39]

Other aspects of urban water management are also regulated by multiple authorities and bodies. For example, a number of bodies have joint responsibility to manage flood risk, and this varies by devolved administration. In England, Defra are the policy lead on flood risk, and national policies are delivered by Risk Management Authorities (RMAs). These include the Environment Agency, Lead Local Flood Authorities, District and Borough Councils and Water, Sewerage Companies and Internal Drainage Boards.[40] In Wales, Flood and Coastal Erosion Risk Management involves organisations including National Resources Wales and 28 RMAS. In Scotland, bodies involved in flood risk management include local authorities and SEPA which is responsible for national flood risk forecasting. In Northern Ireland (NI), multiple organisations are involved in planning for risk of flooding, including NI water, NI Environmental Agency and NI Rivers. See Table for a list of authorities involved in urban water management in Manchester.

UK example: Greater Manchester

Greater Manchester is the third most populated county in the UK and has a variety of different authorities and organisation managing its water, as described in Table 1. It faces many of the water management risks and challenges described above. Some of these relate to:

Floods and flood risk: Several parts of Greater Manchester are Zone 2 (0.1% - 1%)[iv] or Zone 3 (>1%)[v] flood zones,[41] with 15,000 properties in Greater Manchester having a medium or high flood risk. The 2015 Boxing Day floods caused £11.5 million in infrastructure damage and left 31,200 properties without power.[41]

Upgrading ageing infrastructure: The aqueduct which supplies most of Greater Manchester with its drinking water from the Haweswater reservoir is almost 100 years old and 100km in length.[41] This is currently undergoing significant upgrades with a £1.75 billion investment to replace six sections of pipeline.[42] Many of Manchester's buried, culverted rivers are uncharted and at risk of collapse and blockage.

Combined drainage systems: Like many urban areas, Greater Manchester has a higher proportion of combined sewers compared with the UK average, with 54% of public sewers combining surface and wastewater.

Leakage and water loss: Leaks caused United Utilities (which is the water supplier for the North-West including Greater Manchester) to lose 133 litres per day per person in 2017-2018.[41]

Water usage: Domestic usage has increased from 106 litres per day per person in 2013-2014 to 123 litres per day per person in 2017-2018.[41]

[iv] 0.1% - 1% annual probability of flooding
[v] >1% annual probability of flooding

Current status in UK

Table 1: Some authorities and organisations roles involved in urban water management in Greater Manchester.[41]

Provision of basic services	Managing flood risk	Protecting the environment	Economic and socio-cultural
• **United Utilities** – responsible for drinking and wastewater services • **Environment Agency** (EA) – developed an operating framework for reservoirs supplying water • **Ofwat** (Water services regulatory authority) – economic regulator of privatised water and sewerage industry • **Drinking Water Inspectorate** – checks drinking water is safe for consumers and meets legal water quality requirements	• **Greater Manchester Combined Authority** – holds the Greater Manchester Resilience Unit, which holds secretarial responsibility for the GMRF[43] • **Greater Manchester Resilience Forum (GMRF)** – partnership of emergency services with responsibility for coordinating emergency planning[44] • **EA** – has strategic overview of managing flooding from sources including sea and rivers. • **Department for Levelling Up, Housing and Communities** – issues guidance to councils on managing flood risk • **10 Lead Local Flood Authorities** – lead on local flood risk management • **United Utilities** – manage the risk of flooding from public sewers and utility pipes • **The Met Office** – provides services to help authorities respond to flooding, such as those offered by the flood forecasting centre, run in collaboration with the EA • **Insurance Companies** – affected by widespread increases in claims following damage from flooding	• **National Farmers' Union** • **EA** – Regulates water quality and quantity, and ecological protection • **Defra** – creates policy to protect and improve the environment • **Mersey River's Trust** – A charity which works with others to improve rivers and waterways • **Greater Manchester Ecology Unit** – provides advice to 10 local councils on environmental issues such as biodiversity • **Natural England** – Advises the government on protecting the natural environment • **United Utilities** – Has responsibility as a water company to protect the natural environment, including having a role in achieving the goals of the 25 Year Environmental Plan	**Local governance -** Greater Manchester Combined Authority & 10 Greater Manchester Local Authorities **Transport** - Highways England, Network Rail and Transport for Greater Manchester **Housing and property** – private developers and the Peel Group **Environment**: Environment Agency, Natural England, Groundwork, and Canal & River Trust,

International examples of urban water management

This section covers international examples of urban water management. Examples from Australia, South Korea and Denmark are highlighted as innovative solutions or approaches to urban water management challenges.

Australia – Rainwater harvesting in tanks for irrigation in parks

Australia is the 17th most water-stressed nation globally. Up to 90% of the rainwater which falls in its cities runs off hard surfaces and enters waterways, carrying pollutants with it. To help re-use this water efficiently and prevent pollutants entering waterways, some parks are installing huge water tanks beneath them to store and process rainwater.[45]

One example of this is the Fitzroy Gardens Harvesting System in the city of Melbourne. It uses wetland principles and underground water storage tanks to collect rainwater. Stored rainwater goes through a filtration process to remove waste, sediment and other pollutants, before being disinfected with UV to remove bacteria and viruses. Processed water is sprayed at night to limit any potential health risks to park users. The system has been operating since 2013 and captures around 30 million litres of storm water per year for irrigation.[46]

South Korea – Smart cities with smart urban water management

Busan is the 2nd most populated city in South Korea, where the metropolitan government are currently developing an adjoining waterfront city, located between two rivers, called the Busan Eco Delta City. Within this area, a region called the Busan Eco Delta Smart City (BEDSC) is being piloted as a smart city. This is currently in the testing phase in which citizens are experiencing living with smart technologies to provide feedback. Technologies include radar, sensors and automated drains to restore the natural water cycle and reduce flood risk. BEDSC utilises water from its adjacent river, both as a drinking water supply and to generate hydropower.[47]

Denmark – Cloudburst Management Plan

Following extensive flooding in Copenhagen in 2010 and 2011, Copenhagen City Council adopted a Cloudburst Management Plan.[48] This plan aims to protecting against cloudbursts (very heavy rainfall), whilst creating more recreational urban green spaces. Once fully implemented, it will combine sewer-based drainage solutions such as tunnels with around 300 surface projects. These surface projects will facilitate drainage and storage of rainwater near to the surface and utilise it to develop green and blue infrastructure.

The plan will be implemented over twenty years and each year the city decides which projects to undertake, prioritising projects which are in high-risk areas, areas where they will be easy to implement, or areas where new investments can be connected to ongoing urban development projects. Tunnel solutions should only be used where there are no opportunities for drainage solely at ground level.[48] Infrastructural changes have been presented as 'improved city green spaces', which has helped generate acceptance and enthusiasm for the upgrades.[49] Currently, the project is ongoing, with 11 major surface projects and 2 major cloudburst tunnels already having been constructed, and 60 more surface projects under development.[50]

Future challenges and opportunities for urban water management

This section considers future challenges for urban water management in the UK, and potential opportunities, reflecting on the examples shown above. Whilst urban water systems face significant challenges currently, many will be exacerbated in the future by changes such as increased urbanisation and climate change. However, there are also opportunities to innovatively manage urban water, in ways that utilise emerging technologies or take a more holistic approach. These can be efficient in targeting more than one urban water management issue at once, whilst providing benefits for the citizens of urban areas.

Future challenges

Urban populations: Urban populations are increasing, and at a faster rate than rural populations. Population projections show that city region populations will increase by 7.6% between 2015 and 2025, compared with the UK average of 6.7%.[1] This will put more pressure on infrastructure to deliver water supply and remove and treat wastewater.

Climate – flood risk: Flood risk is likely to increase in the future, with the number of properties in England at high risk of surface water flooding expected to increase by 230,000 by 2055.[51] This is partly due to climate change causing increases in extreme daily rainfall events.[52] Analysis has shown that in a 'worst-case' scenario where carbon reduction targets are missed and climate sensitivity is high, 1% annual probability flood losses could increase by up to 37% from 1990 levels.[53] Urbanisation also contributes to increased flood risk. New developments are also expected to increase the number of properties in areas at high risk of surface flooding, whilst increases in areas covered by impermeable surfaces, such as front gardens being paved over, may also cause increases. Groundwater flood risks are also likely to change in the future too, as changes to rainfall patterns affect groundwater recharge and rising sea levels cause the water table level to increase.

Climate – water supply and demand: Water supply is set to face increased pressures in the future, with reports suggesting that parts of the South of England will run out of water within the next 20 years unless greater action is taken.[54] Total water supply is forecasted to decrease by 7% between 2020 and 2045 due to drier weather, and the need to abstract water more sustainably. However, an additional supply of 4 billion litres of water per day is expected to be needed by the 2050s.[54] In cities in particular, water can have a role in climate change adaptation, as it can be used in cooling to help cope with heat waves, through water fountains or spraying water onto streets.[55] Options for increasing water supply are limited, time-consuming and expensive, so reductions in water demand will be needed, which will likely require a combination of methods.[54]

Changes in groundwater recharge will also place increasing stress on water supply. Groundwater accounts for a third of the UK's water supply and this is far higher in some regions, such as over 75% in South East England.[56] Groundwater recharge is the process by which surface water moves downwards and replenishes groundwater. Modelling has suggested that compared to today by the 2080s the groundwater recharge season will be shorter, and that recharge potential over summer will be lower, but that the annual recharge potential will be broadly unchanged. This is due to likely changes in rainfall and evaporation caused by climate change, and could lead to more variable groundwater levels and heighten risk of drought.[57] Understanding how these changes could affect groundwater recharge can help ensure future water supplies are resilient.

Ageing infrastructure: Leaks and challenges with infrastructure associated with urban water systems may also increase with time, as infrastructure becomes increasingly old. Climate change may also exacerbate leakage, as it is expected to cause greater variation in the levels of moisture in the soil, leading to increased ground movement which damages pipes.[58]

Future opportunities

Integrated water management: Integrated water management can help address the combination of issues surrounding water management including high and low flows, and water pollution. This process involves treating different uses of water as interdependent, and uses a coordinated water management approach, rather than the traditional fragmented sectoral approach. This can involve using modelling to create a water management strategy for a particular area and to create mechanisms to deliver this.[59]

Smart urban water systems and emerging technologies: Smart urban water systems could be used in the future to integrate digitalisation into the water systems in a way which would reduce water demand and flood risk. Smart urban water systems combine novel techniques of data collection and transmission, modelling, analysis and automation to increase flexibility within the water system. For example, data from smart water meters and noise loggers could be used to detect leaks and identify their location. Then automated infrastructure could control the water pressure to reduce water loss. However, smart water systems can carry potential risks, especially around privacy and security.[60]

Another emerging technique being developed uses unused optical fibre strands to detect leaks from water and wastewater networks. In this technique, lasers would detect noise at regular intervals along the strand, providing data on the location of leaks, ground stability and activity on network assets.[61] Pipebots are another new technology being developed, in which high-accuracy sensing technology is installed in micro-robots able to enter pipes and ducts. These may help utility companies to monitor their infrastructure, reducing the need for road excavations.[62]

Rainwater harvesting: Rainwater harvesting is a technique which treats water as a natural resource by collecting and using it for purposes such as irrigating parks and gardens, toilet flushing and firefighting, but not typically as a supply of drinking water. This can provide direct benefits such as improving water security and mitigating against pollution from surface runoff, and can also lead to further benefits such as improving natural spaces.[63,64] Additionally, another benefit of rainwater harvesting is that generally water can be collected near to the location where it is required.[63]

Sustainable drainage systems: There are also future opportunities in urban water management surrounding sustainable drainage systems (SuDS) and working with natural processes (WWNP). SuDS aim to imitate the natural drainage system of an undeveloped site to allow the infiltration of surface water into the ground where possible and manage surface water in an alternative way to traditional drainage systems. They comprise a variety of features and interventions, depending on the site-specific constraints. These can include a mixture of green and engineered components used for both the storage and conveyance of surface water, such as retention ponds, permeable paving and geocellular drainage systems, which are storage tanks which contain honeycomb-shaped structures.[65] SuDS can also include measures above ground, such as green roofs which can reduce surface run-off by up to 70%.[66]

Analysis of an urban area in London has shown that retrofitting SuDS would be a cost-effective method of managing flood risk, if all wider benefits are considered.[67] The most significant wider benefits were shown to be from reduced flood risk, rainwater harvesting effects and decreasing surface water charges, which are fees paid by property owners to account for the water that drains from their property into public sewers.[68] Studies have also been carried out in Greater Manchester which show that retrofitting SuDS and incorporating urban nature-based solutions can provide extensive benefits in addition to reducing flood risk, including cost savings and creating new green and blue spaces.[69,70] SuDS can also improve groundwater recharge, which as described above is likely to reduce as a result of climate change.[71]

There are challenges associated with the implementation of infiltration SuDS, including specific issues relating to adoption. They are not suitable for all locations, and if installed inappropriately can lead to issues such as sinkhole formation and subsidence issues. For example, the installation of infiltration-based SuDS in gypsum karst (a type of soluble rock) areas may wash fine minerals from the ground, increase geohazard frequency and lead to sinkhole formation.[72] This demonstrates the importance of understanding the physical system when incorporating SuDS into urban areas.

Interactions with the wider subsurface system

The urban water system is affected by, and linked to, many other parts of the subsurface system. Additionally, external factors can affect or change the requirements of the urban water system. This section outlines some of these subsurface elements and external factors.

Flooding affecting other subsurface infrastructure: Between October 2019 and August 2021, there were 55 incidents of Transport for London stations being closed due to flooding, including flooding from surface water, and from water mains bursts and leaks.[73] Damage to water and energy infrastructure typically accounts for 3-10% of the total cost of floods.[74]

SuDS interactions: Infiltration SuDS could change the subsurface properties due to facilitating increased infiltration.

Net zero: Interactions between urban water systems and net zero include the groundwater system, which could provide renewable heat. This includes water in disused coal mines, which 25% of UK homes and businesses are located over.[75] Heating currently accounts for one third of the UK's annual carbon footprint,[76] with geothermal heating offering potential for heating more sustainably. For example, a recent analysis estimated that all sources of geothermal heat combined could fulfil UK residential heating demand for 100 years.[77]

Competition for space with other uses: Increasingly deep infrastructure is being developed for urban water management, such as the Tideway Tunnel in London for sewage at up to 70m deep.[27] Construction and tunnelling can require dewatering of subsurface space, and conversely water can be used in construction.

Interaction with tree roots: Proximity of buried infrastructure and tree roots in urban areas means interactions are frequent. Tree roots can break into water or sewage pipes with minor cracks or loose joints, causing extensive damage, blockages and subsequent flooding.[78] However, there are mitigation measures which allow tree roots and utilities to co-exist nearby to each other, such as providing tree roots with good quality uncompacted soil, meaning they don't need to seek out water and nutrients from other areas.[79]

Ground movement damaging infrastructure: Heavy rain and leaking pipes can cause ground movement which damages infrastructure. For example, in 2015 in Manchester a sinkhole opened up following heavy rain, believed to be caused by a collapsed water pipe.[80] This caused a carriageway to collapse and damaged a major sewer beneath.[81] Ground movement typically costs the utility sector £300-500 million/year.[82] Climate change is expected to exacerbate subsidence issues caused by varying moisture levels in soil, with 10% of UK properties expected to be at risk by 2070.[83]

Example systems interaction

To illustrate some specific subsurface interactions, we have isolated and refined three example interactions, chosen in consultation with stakeholders as particularly interesting and illustrative of subsurface challenges, one of which is shown below. These include both ‘feedback loops’ and linear chains of interactions, described below. Further information about the example interactions, including their development, is shown in the main *Future of the Subsurface* report.

Figure 2 shows one set of interactions developed, which includes the installation of SuDS to mitigate flood risks, the occurrence of surface floods, and how these interact over time.

As shown, installing SuDS will reduce surface runoff, thus decreasing surface flood risk. When flood risk is reduced, less new flood mitigation measures need to be installed. Depending on the specific site and scale of installation, reduced surface runoff could also entail a reduction in sewage overflow events, reducing pollution of open waters. This would also reduce the need for investment in new wastewater infrastructure.

SuDS installations have to be planned carefully not only to maximise their benefits but also to prevent negative effects such as the potential to trigger geohazards such as sinkhole formation. For simplicity, these side specific effects have not been included in the included in Figure 2.

Interactions with the wider subsurface system

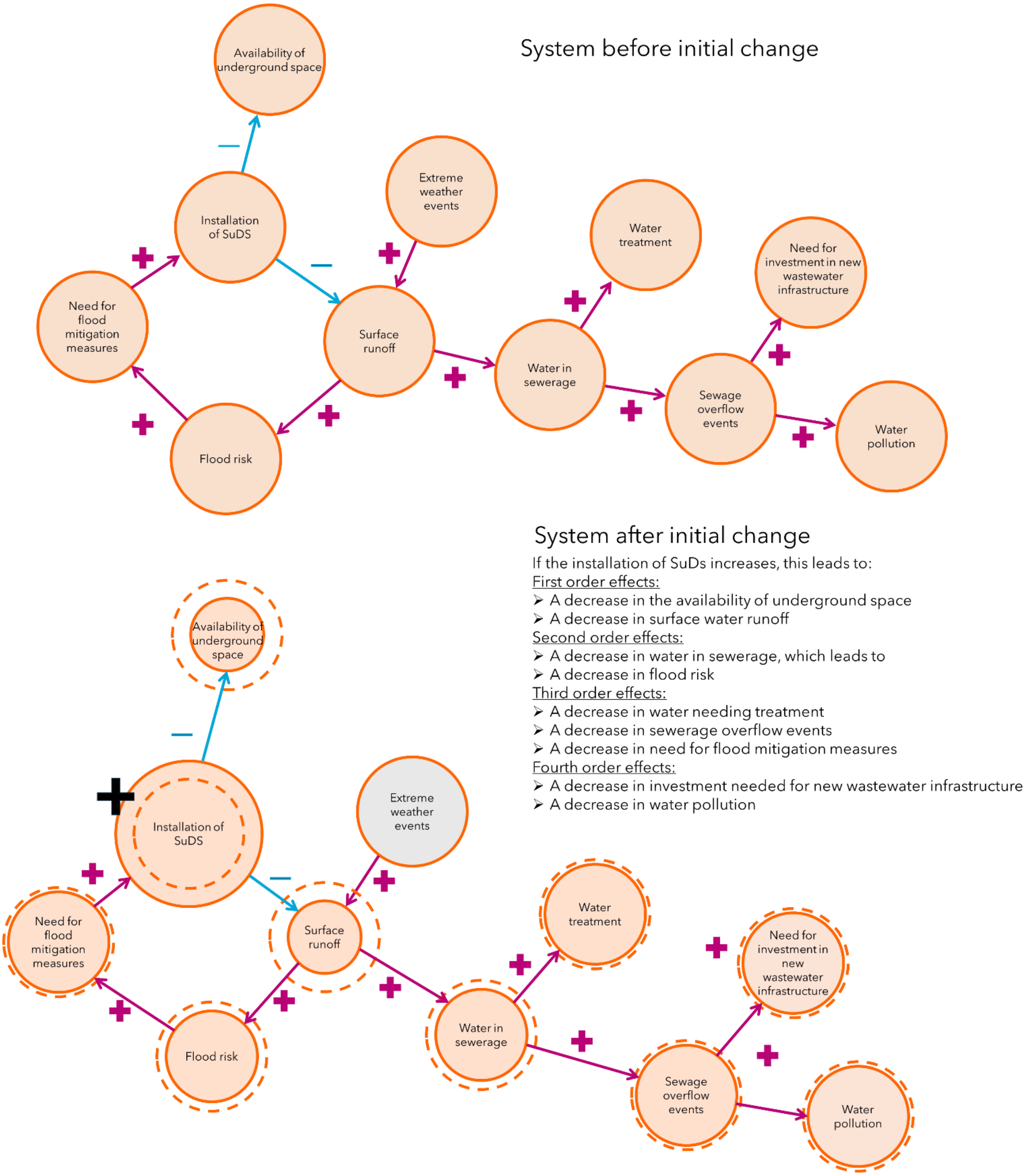

Figure 2: This figure shows an example interaction of the installation of SuDS and other aspects of the subsurface system. After the installation of SuDS is increased, this decreases surface runoff, which decreases flood risk as well as the volume of water in sewerage.

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