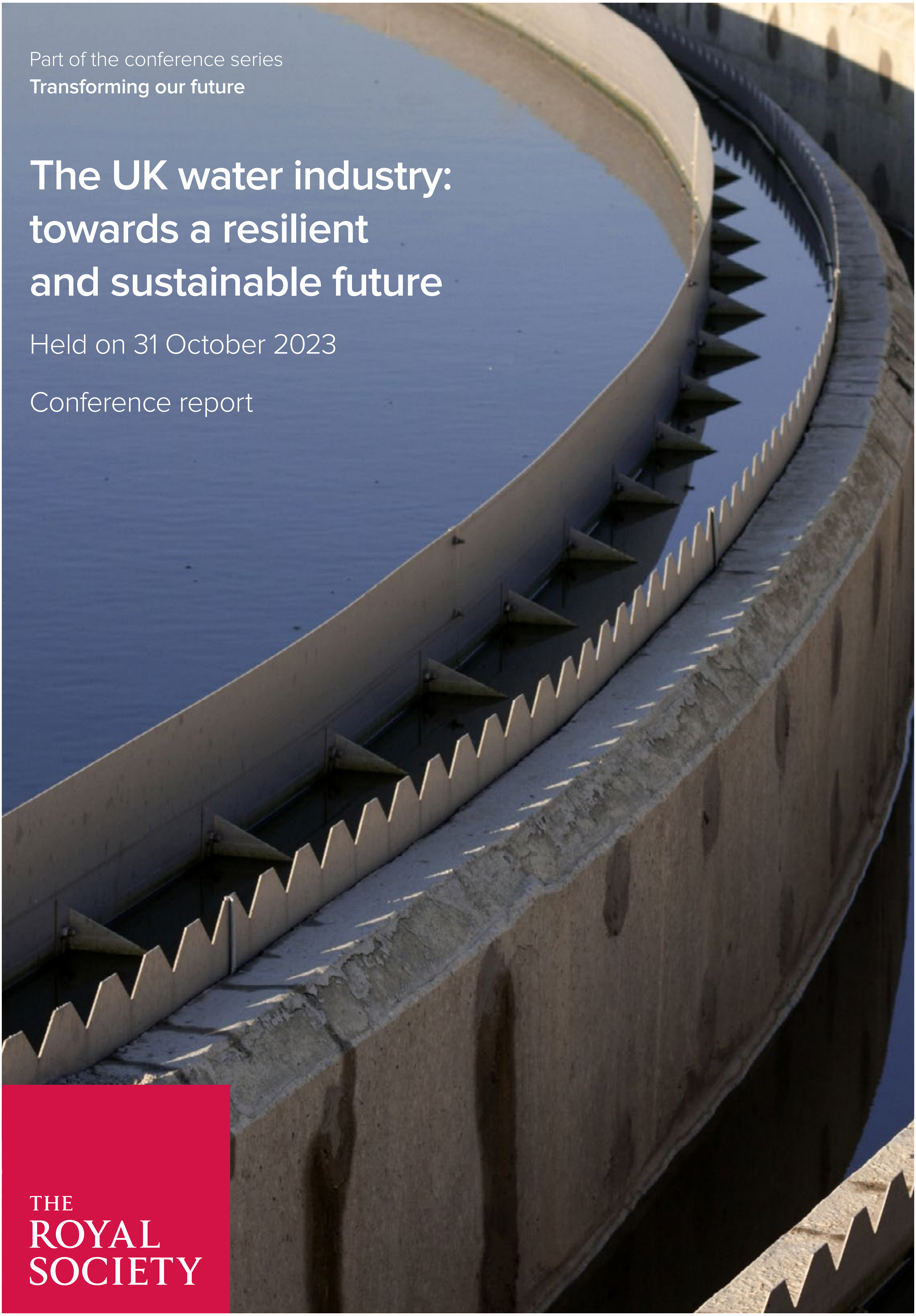
Part of the conference series
Transforming our future

The UK water industry: towards a resilient and sustainable future

Held on 31 October 2023

Conference report



THE ROYAL SOCIETY

Introduction

On 31 October 2023 the Royal Society hosted a hybrid conference on *The UK water industry: towards a resilient and sustainable future*. This meeting forms part of the Royal Society's Transforming our future series.

Image: Delegates networking during the conference.

The Transforming our future conferences are unique, high-level meetings featuring cutting-edge science. They bring together experts from industry, academia, funding bodies, the wider scientific community and government to explore and address key scientific and technical challenges of the coming decade. These conferences are organised with the support of the Royal Society Science, Industry and Translation Committee.

The conference series forms part of the Royal Society's Science and Industry programme which demonstrates the Society's commitment to integrate science and industry across its activities, promote science and its value, build relationships and foster translation.

The programme for this meeting focused on the water sector and was organised by Dr Mar Batista, Anglian Water, Professor Sir John Beddington CMG FRS, former Chief Scientific Advisor to the UK Government and Professor Guangtao Fu, University of Exeter.

"We want to discuss how collaboration, innovation and a more circular and sustainable economy can help address water quality challenges."

Dr Mar Batista, Anglian Water

An opening keynote from Professor Louise Heathwaite CBE FRS, Lancaster University, set the scene for the day by outlining the key challenges facing the UK water sector and highlighting actions needed. Three sessions of talks focused on climate resilience, water pollution and quality and decarbonisation and energy, respectively. The conference concluded with a panel discussion that addressed how the UK water sector could improve in terms of both sustainability and uptake of innovation.

This report is not a verbatim record, but a summary of the discussions that took place and the key points raised. Comments and recommendations reflect the views and opinions of the speakers and not necessarily those of the Royal Society.

Executive summary

The sector is facing significant challenges in terms of climate variability and uncertainty, poor water quality and the need to reduce greenhouse gas emissions and energy use.

Image: The conference opened with remarks from Dame Sue Ion GBE FREng FRS, Chair of the Royal Society Science, Industry and Translation Committee

"We are all aware of the very difficult problems there are within the UK in the water industry. The focus of this conference is finding solutions and innovations."

Professor Sir John Beddington CMG FRS, former Chief Scientific Advisor to the UK Government

In recognition of the high likelihood of future water shortages in the UK, the National Infrastructure Commission's Preparing for a drier future report[1] defined a range of measures to be taken by government, water companies and regulators to promote efficient water use and encourage investment in supply infrastructure.

While progress has been made, further action is needed. Further collaboration and scientific innovation are needed to build a more resilient and sustainable UK water sector. Key themes that emerged from the talks and panel session during this conference include:

Climate resilience

- Innovative modelling approaches are being used to examine the effects of different adaptation interventions and supply infrastructure in a range of possible future drought conditions.
- Well-designed sustainable drainage systems can enhance climate resilience in urban areas while also providing refuge for wildlife.
- New technologies for recycling and reusing water can help address the disparity between water supply and demand in the UK.

1. National Infrastructure Commission. 2018. *Preparing for a drier future*. See https://nic.org.uk/app/uploads/NIC-Preparing-for-a-Drier-Future-26-April-2018.pdf (accessed 18 January 2024).

- Strategic operational management and the use of flexible pipeline materials can help reduce water leakages. Earth observation and artificial intelligence approaches may help with future leak detection.

Water pollution and quality

- Water management is closely linked with public health. Developing frameworks now for how we might respond to potential water-borne disease outbreaks should mean we are better able to manage any future crisis.
- Innovations in processing manures, pelletising biosolids, and improving water testing on farms have the potential to drive future improvements in water quality.
- Innovative technologies are needed to remove two emerging classes of micropollutants: per- polyfluoroalkyl substances (PFAS) and pharmaceuticals.
- Novel wastewater treatment solutions such as membrane-aerated bioreactors, anaerobic membrane bioreactors and cellulose recovery technologies show promising results in trials and have potential to be deployed widely.
- Artificial intelligence and machine learning approaches can provide water quality assessments and predictions, optimise treatment processes and guide water management decision-making.
- When developing new tools for the water sector, innovators must answer three questions: What is needed? How will the innovation get to customers? How can data be transformed into action?

Decarbonisation and energy

- To accelerate the decarbonisation of the water sector, an understanding of whole life carbon must be embedded in decision-making, policy and regulation. Tools and processes are being developed to enable the sharing of best practice.
- The production of nitrous oxide emissions from wastewater treatment processes is highly complex. Emerging artificial intelligence and machine learning approaches are being used to monitor and potentially mitigate these emissions.
- Water services, energy generation and climate change are deeply interconnected. Innovative technologies such as the ultralow flush toilet and zero-energy rainwater harvesting show promise in reducing both water and energy demand.

> "We expect our water infrastructure systems to provide high quality water and wastewater services. This has carbon, energy and cost implications."
>
> Professor Guangtao Fu, University of Exeter

KEYNOTE

Towards a resilient and sustainable future

Professor Louise Heathwaite CBE FRS, Lancaster University, reflected on the global issues facing the water sector. She highlighted three challenges: our changing water cycle, the quality of our water environment, and the road to net zero.

Image: Professor Louise Heathwaite CBE FRS, Lancaster University provided the opening keynote.

"Everything we thought about the way we could engineer water in the environment for long-term sustainably was knocked on its head because of the changes imposed by climate change."

Professor Louise Heathwaite CBE FRS, Lancaster University

The water sector is facing a crisis. Increasing climate variability together with an intensified hydrological cycle, misuse of water resources and water quality changes will have serious environmental, health and social consequences if swift action is not taken.

Global water inequalities

There are striking imbalances between where water resources are located and where water is used. Reliance on large and potentially unsustainable international transfers of 'embedded water' (water used in the production of goods, processes and services) has environmental, economic and geopolitical implications. Lack of access to safe drinking water and public sewerage has serious implications for human health, particularly in lower income countries.

A wholescale rethink of water management is needed to address the impacts and uncertainties associated with climate change. The sector must address three key challenges, described below.

Challenge 1: The changing water cycle

Human actions affect the way water flows through the atmosphere, oceans, land surface and subsurface. Extracting water for drinking, food production, manufacturing, construction and other activities directly impacts the water cycle. There are also indirect effects from land use change and temperature increases due to the greenhouse gas emissions. As temperatures increase, the capacity of the atmosphere to hold moisture is enhanced. This intensifies the water cycle through rising precipitation and evaporation rates, as well as changes in the risks of droughts and floods. Holistic thinking is needed to develop our understanding of the changing complexities of the water cycle and what this means for sustainable water management.

Challenge 2: Quality of our freshwater environment

The global nitrate time-bomb is a critical water quality issue. Modelling work shows that in certain geologies, nitrogen applied at the soil surface (eg through agricultural activities) can take decades to move through the subsurface[2]. The application of synthetic nitrogen fertilisers in excess of crop needs starting in the twentieth century has led to a massive build-up of nitrate in the vadose zone (the area between the surface and the groundwater table). As a result, even if nitrogen application rates are restricted through better farm management and increased regulation, there will be a lag of many years between changing land management practices and seeing a substantial drop in the nitrate concentrations in groundwater.

Challenge 3: The road to net zero

The myriad net zero emissions policies proposed in recent years have largely been developed in isolation without serious consideration of their interactions with other policy outcomes. The Royal Society's Multifunctional landscapes report[3] established that significant land use changes will be required to accommodate the diverse policies that impact our landscapes. For example, the net area used as farmland would need to decrease from 75% to 67% to accommodate proposed housing, woodland, agroecological, and peatland requirements. Notably, these changes are predicted to result in a net positive in terms of water flows and quality. However, navigating land use change is further complicated by the diversity of stakeholders involved and the tension between their potentially disparate needs.

Net zero policies and environmental monitoring efforts have largely focused on carbon. This fails to recognise that human activities have also dramatically enhanced global cycles of nitrogen and phosphorus. We need to understand how the changing fluxes of different macronutrients impact the ability of ecosystems to sequester carbon, moderate temperatures and maintain biodiversity.

2. Ascott MJ, *et al.* 2017 *Global patterns of nitrate storage in the vadose zone. Nature Communications,* 8(1416). See https://doi.org/10.1038/s41467-017-01321-w (accessed 18 January 2024).
3. The Royal Society. 2023 *Multifunctional landscapes.* See https://royalsociety.org/-/media/policy/projects/living-landscapes/DES7483_Multifunctional-landscapes_policy-report-WEB.pdf (accessed 18 January 2024).

Looking ahead

To begin to address the above challenges, the water sector must focus on:

- **Creative spatial planning of water management interventions:**
  There is a move towards spatial planning of water resources for improved climate resilience. The Environment Agency's Meeting our future water needs report[4] brought together England's water industry to move beyond traditional water company boundaries and develop strategic regional planning. Future development of the subsurface is another spatial consideration in terms of water management. Underground assets (eg data centres, transportation routes, energy storage) are proliferating as urbanisation increases. Additional water pipes, sewers and drainage are likely to be needed to accommodate a growing population and reduce flooding risks at the same time as dealing with increased heat stress. As space is limited, this will require careful planning.

- **Improved sharing and interoperability of data for the water sector:**
  More data is needed to better monitor and understand factors impacting water quality. While there is improved data on water quantity via earth observation and modelling approaches, innovations in more effective water quality measurement and monitoring are needed.

- **Scaling innovation:**
  There is an opportunity to reduce water scarcity via wastewater treatment and subsequent reuse. Globally, currently only a small fraction of wastewater produced is reused; this is an important area for future development. Another emerging area of interest is the use of nature-based solutions to restore or imitate natural processes, for example improving water storage by creating ponds or restoring wetlands. More evidence is needed to understand how to scale these and other emerging water management interventions and monitoring approaches.

> "'Dilution is the solution to pollution' no longer works."
>
> Professor Louise Heathwaite CBE FRS, Lancaster University

4. Environment Agency. 2020 *Meeting our future water needs.* See https://assets.publishing.service.gov.uk/media/5e6e478ed3bf7f26963789f3/National_Framework_for_water_resources_main_report.pdf (accessed 18 January 2024).

Strategic systems analysis of infrastructure options to ensure water supply resilience in extreme droughts

Professor Jim Hall FREng, Environmental Change Institute at the University of Oxford, discussed current state of the art approaches to national drought risk analysis. He then highlighted areas for future research in climate modelling, hydrology, systems analysis and demand management.

Image: Professor Jim Hall FREng, Environmental Change Institute at the University of Oxford.

> "Scientific understanding needs to inform [water resource] governance frameworks which are much better at navigating trade-offs and making decisions for the benefit of people and the environment."
>
> Professor Jim Hall FREng, Environmental Change Institute at the University of Oxford

Management of water resources in the UK has evolved considerably over the last decade. Previously, planning was done at the water company level and was deterministic in approach.

Growing awareness within the industry that this was not fit for purpose led to the National Infrastructure Commission's Preparing for a drier future report[1], which predicted a one in four chance of a severe water shortage event by 2050. The cost of dealing with a water shortage was estimated to be £40b, while the cost of proactively mitigating the risk was estimated at £21b. To achieve the latter, three approaches were proposed: reducing demand, reducing leakage, and building new infrastructure.

The report raised some pointed questions for the water industry:

- How resilient are our water supplies?
- How might that resilience change in the future?
- What are the options for enhancing resilience, and how much will they cost?
- What are the robust adaptive strategies that can respond to changing risk levels?

Water resource systems analysis

Simulation modelling is required to address the above questions. This involves running simulations of variable climate conditions and putting that information into models of rainfall, streamflow and groundwater. These can then be combined to produce a more holistic water resource system model that simulates where water is coming from, where it is being stored and how it is being used.

Water flows, changing demand, and water use restrictions can be included in simulations. In thinking about possible interventions to deal with water shortages, there is a trade-off between the risk of a water shortage and the cost of adaptation. A water resource systems model is needed to test out the impact of potential interventions.

The Water Resources England and Wales model

To analyse water resource resilience at the national level, the Water Resources England and Wales (WREW) model was created. This combined many climate simulations with a hydrological model, a water demand for irrigation model, and operational rules for extraction. For each water resource zone, simulations of the frequency and duration of shortages can be plotted.

This has allowed for the quantification of the risks of water shortages and regional and national analysis. It is driven by an understanding of spatiotemporal variability and enables robust prioritisation of strategic interventions. The aim is to create an open-source version of WREW that will be openly accessible to regulators and researchers.

Looking ahead

Future water systems analyses should aim to:

- Increase the number of credible future climate patterns used in simulations;
- Quantify the amount of water needed for resilient aquatic ecosystem functioning;
- Integrate water quality into analyses;
- Examine the effectiveness of nature-based solutions;
- Include continuous learning about catchment behaviour;
- Inform an integrated governance framework that over-arches all catchment actors and incentivises good outcomes for people and the environment.

Sustainable drainage systems: future innovations

Jo Bradley, Director of Operations at Stormwater Shepherds, discussed how improved design and development of sustainable drainage systems could enhance climate resilience in towns and cities while also providing refuge for urban wildlife.

Image: Jo Bradley, Director of Operations, Stormwater Shepherds.

> "We desperately need to think more about what long, dry, hot spells mean for wildlife across the UK, particularly in urban areas."
>
> Jo Bradley, Director of Operations, Stormwater Shepherds

In urban environments, the presence of buildings, roads and other paved areas prevents the effective absorption of rainwater. Extensive networks of pipes and sewers are typically used to divert excess surface water to local water bodies. However, these transfers of water can cause issues with flooding and pollution, particularly during storms.

Sustainable drainage systems

Over the past 20 years, sustainable drainage systems (SuDS) have been increasingly used to help mitigate these issues by attempting to manage rainwater where it falls. SuDS imitate natural drainage systems and are diverse in form as they are tailored to the local context. Ponds, basins and swales (shallow channels) are commonly used. These devices capture and hold water where it falls, reduce flooding, decrease flow rates into watercourses, create habitats for wildlife, provide urban greening and improve water quality.

Despite many successes, a rethink of SuDS design and development is needed to better mitigate against the effects of climate change in towns and cities. They must be planned in a way that benefits both people and wildlife. There is potential for every SuDS device to do more in terms of effectively managing stormwater and serving as a sustainable, resilient habitat for wildlife.

Increasing temperature and rainfall variability have caused issues with many existing SuDS. During the drought of 2022 in England, some SuDS devices died back and thus lost functionality. Urban wildlife dependent on these devices likely died as well. Plant species under drought conditions stop producing pollen and nectar, thus pollinator species lost their food sources. Hard, dry soils become impenetrable and cannot sustain insect life, thus limiting food availability for birds. Small mammals would similarly have lost access to food, water and shelter. If rainwater had been captured nearby (eg in water butts) and used to irrigate the SuDS during the drought, this loss might have been prevented.

> "We need to get much better at capturing rainwater, and sharing that water, and using it."
>
> Jo Bradley, Director of Operations, Stormwater Shepherds

Looking ahead

Improved design features for SuDS may include:

- Ground-level planting to provide food and habitats for wildlife while also preventing soil erosion.
- Use of organic mulches to minimise evaporation from the soil and provide inputs of organic matter thus improving soil health and fertility.
- Mechanisms to keep soils aerated and damp so micro-organisms and invertebrates can thrive and provide food for other animals.
- Limited lighting for the benefit of wildlife. Artificial light at night can negatively impact animal vision, navigation, physiology and health.
- Planting of fruit trees and bushes to provide food for wildlife as well as local communities.
- Rainwater capture. This can then be used in the home or garden to reduce tap water use. It can also be used in SuDS irrigation and to provide drinking water for wildlife.
- Capture, storage, use and sharing of rainwater has the additional benefit of reducing the risk and impact of fires. When wildfires broke out in Argentina in 2022, the necessary use of water for firefighting meant that water was not available for urban animals. This resulted in staggering wildlife losses. Environmental wetting via sustainable, irrigated drainage systems reduces the presence of dry plant matter which can be a serious fire hazard.
- SuDS must both function as stormwater management devices and deliver a mosaic of wildlife habitats. Improving the design and increasing uptake of SuDS will help our urban environments to cope with the impacts of climate change.

Innovations in water re-use and recycling

Professor Bruce Jefferson, Cranfield University, described what can be done to address the disparity between water supply and demand in the UK. In addition to reducing demand, recycling and reusing water must be part of the solution.

Image: Professor Bruce Jefferson, Cranfield University.

"Doing things at the household level can actually start to change people's thinking."

Professor Bruce Jefferson, Cranfield University

Despite long-term efforts to encourage reduction in water use, per capita demand has not substantially changed since 1990[5]. Average water use remains around 145 litres per person per day[6]. However, the use of data averages masks diversity in water use.

Demand management for water supplies

People in the centre of urban environments tend to use less water. There is a need to work with the social sciences to develop demand management approaches that target specific areas where excessive water use is a problem. For example, garden irrigation is a major source of water demand during dry summer months. The most severe ecological challenges tend to exist in smaller rivers near small population centres.

Reducing average water demand has many benefits. It will decrease the likelihood of sewer overflows and result in lower water volumes going through wastewater treatment facilities. This will produce more concentrated sewage that is more cost effective to treat and easier to use in resource recovery activities. Still, demand management will not be enough to address the gap between water demand and supply.

5. Artesia Consulting. 2020 *Artesia's first Waterwise newsletter article!* See https://artesia-consulting.co.uk/artesias-first-waterwise-newsletter-article/ (accessed 18 January 2024).
6. Ofwat. 2023 *Water company performance report 2022-23*. See https://www.ofwat.gov.uk/wp-content/uploads/2023/09/Water-Company-Performance-Report-2022-23.pdf (accessed 18 January 2024).

Water reuse via wastewater treatment

Increased and improved water reuse will also be needed to ensure sufficient water is available to meet demand. Indirect reuse involves treating sewage effluent and putting it back into water bodies for future extraction. This typically uses two types of membrane: ultrafiltration and reverse osmosis.

The technologies that are required for wastewater treatment are largely the same as those required to produce feed water for hydrogen production. Co-location of wastewater treatment and hydrogen production facilities could be valuable in future infrastructure planning to enable efficient use of resources. Promising synergies include:

- The electrolyser used in hydrogen production can be fed with water from the treatment centre.
- Oxygen created as a by-product in hydrogen production could be used in water treatment.

Looking ahead

Three emerging innovations in wastewater treatment are generating excitement in the water sector:

1 Ceramic membranes:

The high energy requirements for wastewater treatment is linked to salt concentration. Membrane separation can be effective at separating salts from water, however the need for frequent membrane replacement creates a large carbon footprint. The use of ceramic membranes is a potential game-changer. Ceramic membranes have a longer lifespan than traditional porous membranes, are easier to aggressively clean, and allow for high fluxes. However, ceramic membranes are expensive. A further promising area of development is coating porous membranes with thin layers of ceramic to achieve similar benefits.

2 Heat separation:

Small molecular weight uncharged molecules (eg urea) are difficult to remove via reverse osmosis membrane separation. Heat separation is being explored as an alternative treatment method, as sewage treatment generates ‘waste’ heat that could be collected and used for this process.

3 Nature-based solutions (NbS):

These approaches use ecosystem services to manage water quantity and improve water quality. NbS are increasingly used in wastewater treatment and can be particularly effective at the household-scale in reducing water demand and improving environmental awareness. However, NbS is a broad church. Before employing NbS, it is important to examine the strengths and weaknesses of different approaches in relation to the specific treatment problem that needs to be addressed.

These innovations are at the brink of large-scale commercial availability. However, their widespread deployment requires new thinking and ambition in designing treatment facilities.

The UK water industry: towards a resilient and sustainable future – leakage research

James Curtis, Head of Leakage at Affinity Water, discussed the challenges water companies face in reducing leakages. He described the work being done to overcome these issues and shared examples of emerging innovations that may prove useful in detecting and stopping water losses.

Image: James Curtis, Head of Leakage, Affinity Water.

"I've seen more innovation in the past five years than I have in the previous 15 years of my career in the water industry."

James Curtis, Head of Leakage, Affinity Water

Water companies in the UK are all dealing with the same intractable challenge: how to reduce water losses in their vast networks of pipes. In 2018, the National Infrastructure Commission called for the water industry to halve leakage by 2050[1]. Water companies subsequently came together to agree a roadmap towards this goal.

While progress has been made, there is still a long way to go. Below-ground leakage in England in the 2021 / 2022 regulatory reporting year was nearly 3000 megalitres per day, which is enough water to meet the needs of 20 million people[7]. To solve this problem, water companies must develop effective methods for both detecting and reducing leakages.

Climate change has made this more difficult. Rapid changes in ground water levels cause compaction and / or expansion of the soil and are correlated with increased leakages. There are two leakage peaks each year, as both consistently drier periods in the summer months and consistently wetter periods in winter months are linked with pipe bursts.

7. Ofwat. 2022 *Price Review 2024*. See https://www.ofwat.gov.uk/regulated-companies/price-review/2024-price-review/ (accessed 18 January 2024).

Possible solutions

Operational strategies can be used to tackle some leaks and offer short-term solutions. Water companies continually monitor water pressure in their networks and use control devices on their pipes to manipulate pressure as needed. For example, water pressure tends to be higher at night when demand is low, so water companies may actively lower pressure in the network to reduce the potential for leakages.

A longer-term solution is the proliferation of more flexible materials. Polyethylene pipelines have increased flexibility in comparison with traditional metal pipes. High-density polyethylene pipes can bend to a radius 20 – 30 times the diameter of the pipe dependent on wall thickness. This means they are less likely to burst in response to ground movement. They have been used since the 1990s in network growth and pipe replacement schemes, and the system will continue to adapt over time.

Changing the materials used for pipes has consequences in terms of detecting leaks. Currently, the most common method for detecting leakages is via acoustics. When water exits a pressurised metal tube, it creates noise and vibrations. Switching from metal to plastic pipelines results in difficulties detecting leaks using traditional approaches as noise does not transmit in same way. Current technologies must be used much closer to plastic pipelines to detect leaks which is not always possible depending on the depth of the network.

Looking ahead

Several emerging innovations may help with future leak detection:

1. **Earth observation approaches:**
   These techniques have been used to great effect. Satellite data can be used to highlight points of interest to be followed up via ground-truthing. This is particularly useful in urban areas where high levels of background noise make acoustic detection approaches difficult.

2. **Use of fibre optic networks:**
   There are promising proof-of-concept results indicating that the existing fibre optic network can detect the noise of leakages in plastic pipes. They are located proximal to many pipelines in the subsurface, making detection easier.

3. **Artificial intelligence (AI) solutions:**
   Water companies are installing more sensors across their networks to detect flow and pressure. AI tools may be useful in integrating the vast reams of data produced to find points of interest that may correspond to leakages.

Nurturing innovation and experimentation for long-term collaboration and relevance in large organisations

Steve Hanslow, Head of Water & Waste Water at Siemens UK & Ireland, outlined several barriers to innovation in the water industry. He identified three areas of focus in overcoming these barriers.

Image: Steve Hanslow, Head of Water & Waste Water at Siemens UK & Ireland.

"If we are going to talk to our customers about innovation, what is it we're trying to do? What is the exam question we're looking to answer?"

Steve Hanslow, Head of Water & Waste Water at Siemens UK & Ireland

The water industry has a well-defined product (water) and customer base. Innovation is needed to ensure safe, quality water is delivered to customers in a cost-effective way that minimises losses through leakages. New tools including power electronics, process automation, software systems and digital twins will be increasingly useful in sustainable water management.

The Net Zero Hub

The Ofwat Innovation Fund is supporting change in the water industry. One project being delivered through this fund is 'The Net Zero Hub'. A consortium of water companies and industry stakeholders, including Siemens, have been awarded £10 million to develop the world's first carbon neutral wastewater treatment plant. An additional £28 million will be invested by Severn Trent Water, the project lead. The project aims to use a suite of cutting-edge technologies to capture and reduce emissions produced during wastewater treatment. Innovations to be used on the Net Zero Hub site include digital twin technologies, cellulose recovery processes and a sludge plant cover that reduces greenhouse gas emissions.

Barriers to innovation in the water sector

Numerous emerging technologies show promise in addressing the sustainability challenges facing the water industry, as demonstrated by the Net Zero Hub project. However, there are several barriers to their widespread, large-scale deployment:

- **Water industry infrastructure is extensive and aging.** Maintaining and updating water treatment facilities and networks of pipelines is expensive and may limit funds available for rolling out new technologies. Expensive technologies are unlikely to be adopted without convincing evidence that they will generate substantial cost-savings in the short-term.

- **Water companies tend to be large organisations with established processes that are difficult to alter.** Effective change management strategies and strong leadership are needed to overcome the inertia of existing practices.

- **Data management and cybersecurity concerns require careful development.** There is the potential to collect data from thousands of assets across water networks. However, this will generate massive datasets that are likely to be in several formats that may not be easily interoperable. Secure offsite data handling is needed.

- **Navigating regulatory, compliance and legal frameworks adds additional complexity and time to innovation projects.** Unless the benefits are clear and compelling, the additional work required to deal with these frameworks often means companies choose not to pursue innovative projects.

Looking ahead

To develop effective new tools and deploy them at scale, innovators in the water sector must be able to answer three questions:

1. **What is needed?**
   Understanding why business as usual is no longer sufficient provides clarity of ambition. Examining the potential costs of a project and comparing them with the benefits and / or savings they may generate is integral to predicting whether a solution is likely to be adopted.

2. **How will the product or service get from the shelf to customers?**
   An understanding of the supply chain and delivery partners is essential. When delivering at scale, there is a need to move away from tailoring to individual customer needs.

3. **How can data be transformed into action?**
   Successful use of digital technologies requires knowing which stakeholders need what data and ensuring they have the tools and skills to use it.

Integrated catchment management – working with others on-farm to help improve water quality

Richard Bramley, Yorkshire farmer and Chair of the National Farmers Union Environment Forum, provided examples of work being done by farmers and their catchment partners to improve water quality. He described what more can be done and what support is needed for sustainable on-farm water management.

Image: Richard Bramley, Yorkshire farmer and Chair of the National Farmers Union Environment Forum.

"Ultimately, it's about not bringing new nutrients into a system. It's about trying to make better use of the nutrients we've got and protecting that most vital asset, our soil."

Richard Bramley, Yorkshire farmer and Chair of the National Farmers Union Environment Forum

Farmers face a complex challenge: they must deliver food to meet the demands of a growing population while also maintaining high environmental standards. Farm management is intrinsically linked with the quality of our water courses.

Agricultural pollutants

The twentieth century was characterised by a boom in the use of fertilisers following the invention of the Haber-Bosch process, which made nitrogen fertilisers relatively cheap to produce. Nitrogen and other nutrients in fertilisers (notably phosphorus) improve soil fertility and crop yields. They have enabled the production of more food per unit of land and have reduced the starvation risk for millions.

However, not all the nutrients in fertilisers are absorbed by crops – working in the natural environment has its challenges. Excess nitrogen and phosphorus in the soil may run-off the land or leach into groundwater. These nutrients along with plant protection products used to prevent crop disease are key sources of pollution linked with agricultural activity. However, these products are also valuable to farmers. There is a clear benefit to farmers in working to find ways to keep these potential pollutants on-farm and out of our water courses.

Improved management

Progress has already been made towards reducing some of the negative water quality impacts associated with farming. There has been a 42% reduction in the use of nitrogen fertilisers and a 69% decrease in the use of phosphate fertilisers since the 1980s[8]. However, as these nutrients may take decades to move out of groundwater, there is a long lag between changing land management strategies and seeing corresponding environmental impacts.

Partnerships between farmers and the water industry have driven improvements in water quality. The Sustainable Landscapes programme run by Yorkshire Water and Future Food Solutions supports farmers in exploring sustainable farm management practices. The programme encouraged farmers to rethink their use of metaldehyde as a slug control product. Whilst an effective method of control, the product could get into drinking water and was hard to remove during water treatment. Ferric phosphate is an alternative control product. However, until recently there was limited evidence for its effectiveness and its high cost meant farmers were disinclined to try it. The Sustainable Landscapes programme subsidised the use of ferric phosphate and asked farmers to share effectiveness data to build a case for its widespread use. Metaldehyde use has subsequently been phased out in the UK.

The promotion of the wider use of cover crops has also been successful in addressing nutrient loss over winter, improving soil structure, enhancing organic matter content and reducing sediment run-off.

Looking ahead

Further improvements in water quality will be driven by the development and widespread uptake of several innovations on farms, including:

- **Processing manures:**
  The sustainable collection, storage, treatment and application of manures could reduce the use of synthetic fertilisers.
- **Pelletising biosolids:**
  Treated sewage sludge (biosolids) can be applied to agricultural land to improve fertility and reduce fertiliser use.
- **Improved water testing on farms:**
  Monitoring water quality frequently and in many locations will improve real-time understanding of what is happening at the farm and catchment level.

Defra's Environmental Improvement Plan[9] has set ambitious nutrient management for the agricultural community. A push to meet these targets without a well-defined strategy could lead to a reduction in domestic food production and an increased reliance on imports. This raises food security concerns and increases the likelihood that of the UK merely 'off-shoring' its emissions and environmental impacts. Plans to improve environmental quality must be jointly developed with a range of stakeholders to ensure they are achievable.

8. Defra. 2023 *The British survey of fertiliser practice: fertiliser use on farm crops for crop year 2022*. See https://assets.publishing.service.gov.uk/media/64b7b4550ea2cb000d15e5b5/fertiliseruse-annualreport2122pdf-20jul23.pdf (accessed 18 January 2024).
9. Defra. 2023 *Environmental Improvement Plan 2023*. See https://assets.publishing.service.gov.uk/media/64a6d9c1c531eb000c64fffa/environmental-improvement-plan-2023.pdf (accessed 18 January 2024).

Novel technologies and innovation addressing micropollutants

Fabio Bacci, Innovation Manager at Glanua, discussed the challenges associated with preventing micropollutants from reaching our water courses. He described the need for innovative technologies to remove two emerging classes of contaminants: PFAS and pharmaceuticals.

Image: Fabio Bacci, Innovation Manager, Glanua.

> "We need to ensure we think holistically and provide technological solutions that will see us through the next 20 – 30 years."
>
> Fabio Bacci, Innovation Manager, Glanua

Concern is growing about micropollutants and their impact on water quality, ecosystem integrity and human health. Although these compounds can be captured through wastewater treatment facilities, their presence at low concentrations in water courses can still cause serious issues.

There are several broad classes of micropollutants: pesticides and herbicides; surfactants and personal care products; veterinary drugs and pharmaceuticals; and per-polyfluoroalkyl substances (PFAS). Of these, PFAS and pharmaceuticals pose the biggest challenges in terms of water quality.

Image: The session on water pollution and quality was chaired by Dr Mar Batista, Anglian Water.

Persistent PFAS

PFAS are long-chain carbon-based molecules with versatile applications. Because of their high thermal stability and repellence characteristics, these compounds are used in firefighting foams and textile coating; more diverse applications also include their use in munitions as binding agents. These compounds are extremely persistent, with a half-life of decades. They bioaccumulate and biomagnify through the food chain and transfer atmospherically. Efforts are being made to phase out PFAS; however, their persistence means the environmental impacts will continue for decades to come.

PFAS are difficult and expensive to remove from water and generally require a phased process. Separation can be achieved using adsorption via granular activated carbon or ion exchange resins. Alternatively, they can be subjected to physical separation via membrane, novel polymeric adsorbents, or electrocoagulation, flocculation and precipitation. However, all these processes concentrate PFAS into a waste stream that must undergo a subsequent degradation treatment.

Several degradation and destruction technologies exist:

- **Thermal treatment:**
  There is evidence that incineration at >1200˚C is effective at degrading PFAS. Pyrolysis uses lower temperatures (350 – 600˚C) and produces biochar, which stores high amounts of carbon and can be applied as soil conditioner. However, it is still unclear whether PFAS persist in this biochar and might be reintroduced in the environment.

- **Advanced oxidation processes:**
  Sonochemical oxidation uses soundwaves to generate microbubbles, and the cycle of bubbles forming, growing and collapsing creates localised pyrolysis conditions. Electrochemical oxidation is a standard water treatment process that uses two electrodes to produce oxidising species that degrade contaminants.

- **Emerging thermal oxidation treatment:**
  Supercritical water oxidation requires high temperature and pressure conditions. This process is exothermic (generates heat) and can reach a steady state, at which point energy input requirements are substantially reduced.

Uniqueness of pharmaceuticals

There are over 3000 pharmaceuticals present in the global market with very different modes of action and impacts. While some active pharmaceutical ingredients are effectively removed by standard wastewater treatment processes, some compounds are difficult to detect and remove. The separation treatments described above for PFAS are also effective for pharmaceuticals.

The presence of pharmaceuticals in water courses is of particular concern because many of these compounds are pseudo-persistent (always present because they are continuously discharged in the environment). Also, they have been designed to have a biological effect on humans at defined doses. However, the effects of chronic exposure to low dosages of these compounds on humans and other organisms remains largely unknown, as are the impacts of the myriad of drug-to-drug interactions. Fundamentally, human welfare depends on the availability of pharmaceuticals. Consequently, it is ethically impossible to simply phase out pharmaceuticals based on environmental impact alone until viable substitutes become available.

Looking ahead

A quote attributed to Albert Einstein states, 'We can't solve problems by using the same kind of thinking we used when we created them'. We must be cognisant that technological myopia can lead to speedy but transient solutions. Cost-effective water treatment solutions are needed to ensure that micropollutants are removed from water courses and legislation can impel the supply chain to develop commercially viable technologies. However, technology alone is remedial in nature and not a warrant to pollution; radical changes will be required to replace these compounds with greener solutions.

> "We can't keep relying on technology… Eventually we need to face the sources of these pollutants."
>
> Fabio Bacci, Innovation Manager, Glanua

Implementing next-generation wastewater treatment technologies to meet new challenges

Peter Vale, Carbon & Circular Economy Architect at Severn Trent Water, highlighted several trials undertaken to test the feasibility, viability and desirability of novel wastewater treatment technologies. He discussed how some of these technologies are now being implemented at scale.

Image: Peter Vale, Carbon & Circular Economy Architect, Severn Trent Water.

"We're very lucky in the UK… there is a lot of innovation in this space. Technology providers and academics have lots of potential solutions."

Peter Vale, Carbon & Circular Economy Architect, Severn Trent Water

There is a need for transformative wastewater innovation. While there have been incremental improvements, current treatment processes are similar to what was used one hundred years ago. These approaches are largely effective at removing contaminants. However, they are also highly energy intensive. A transition to wastewater management processes that are circular and carbon neutral will be key to the long-term sustainability and effectiveness of water treatment.

To this end, Severn Trent Water have established the Resource Recovery and Innovation Centre at Spernal Wastewater Treatment Plant to test new technologies. Recent trials are discussed below.

Membrane-aerated bioreactors (MABR)

Wastewater treatment processes use bacteria to break down organic material. These bacteria are aerobic, meaning they require oxygen. This is typically provided by pumping compressed air into wastewater. Air bubbles rise rapidly, so bacteria must act quickly to use the oxygen in these bubbles.

MABRs are a potential alternative to compressed air. In this approach, membrane modules are submerged in treatment tanks. The membranes introduce oxygen in a molecular ("bubbleless") form that is less transient and thus more easily used by bacteria. This approach expands treatment capacity and there is evidence that it also reduces greenhouse gas emissions produced during wastewater processing.

Following trials, Severn Trent has begun to incorporate MABR technologies into its wastewater treatment sites. While the benefits are myriad, this approach still requires energy inputs to provide the bacteria with oxygen. It also still produces some nitrous oxide, a long-lived greenhouse gas.

Anaerobic membrane bioreactors (AnMBR)

The use of anaerobic bacteria in wastewater treatment is now being explored to remove the need to supply oxygen. This would reduce energy requirements as well as costs. In AnMBR, anaerobic bacteria convert organic material to carbon dioxide and methane (biogas), which can then be used to generate renewable electricity. In theory, this could make the process energy neutral. Ultrafiltration membranes are then used to separate bacteria from the treated effluent, which is important for water reuse. Next, a degassing membrane unit is used to remove dissolved methane enabling its capture and reducing the release of methane into the environment post-treatment. While bench-scale experiments and pilot demonstrations show promising results, this process is not yet fully proven.

Cellulose recovery

Toilet paper is approximately 80% cellulose. An estimated 100,000t of cellulose is present in sewage from Severn Trent region alone. Recovery of this material is an exciting area of innovation, as it is a valuable resource that can be used in biocomposites or as a feedstock to produce fine chemicals. A technology being trialled uses a fine screen followed by a rotating belt filter to produce a sludge. This is dewatered and dried to produce a sterilised recovered cellulose 'fluff' (see Figure 1). By isolating cellulose for recovery rather than degrading it, this process has the added benefit of reducing emissions associated with wastewater treatment plants by up to 15%.

FIGURE 1

The cellulose recovery process (left) produces a 'fluff' (right) with numerous potential uses.

Source: Severn Trent.

Looking ahead

Some of the above technologies are now being implemented at scale at Strongford Wastewater Treatment Plant in Stoke-on-Trent, Severn Trent Water's net zero hub site. Other emerging approaches that could further revolutionise wastewater treatment include:

- Recovery (rather than destruction) of ammonia in sewage for use in fertiliser or energy production
- Identification of bacteria that convert ammonia into nitrates while producing no nitrous oxide
- Use of pyrolysis units designed initially for home energy recovery to manage domestic or commercial wastewater solids on site, producing renewable energy and byproducts that could be used in construction.

There are many circular wastewater treatment solutions. Widespread and rapid adoption requires collaboration between innovators and water companies, as well as access to funding and expertise.

Potential applications of AI and other emergent technologies to the water industry

Professor Julie McCann, Head of the Adaptive Emergent Systems Engineering group at Imperial College London, described how emerging computer science technologies may be useful in addressing the sustainability challenges faces by the water industry.

Image: Professor Julie McCann, Head of the Adaptive Emergent Systems Engineering group, Imperial College London.

"We're starting to see a lot of work on explainable AI… We've got this big black box telling us an answer, we now want to know why it's told us that answer."

Professor Julie McCann, Head of the Adaptive Emergent Systems Engineering group, Imperial College London

The water sector is underpinned by data. Measuring how water moves through diverse water courses and vast networks of water pipelines produces large datasets. Wastewater treatment facilities must detect a broad range of contaminants and monitor the function of numerous technologies. The processes governing how water flows through landscapes and industrial systems are highly complex.

Computer science approaches are increasingly being used to better understand these processes. Computers use artificial intelligence (AI) to simulate human problem-solving. By employing machine-learning (ML) methods, they can use datasets to learn autonomously and make predictions about the future. These approaches can identify relationships that are difficult for humans to notice.

How AI / ML has been used by the water sector

AI / ML can provide water quality assessments and predictions for surface water, groundwater, wastewater and seawater[10]. They can also be used to optimise treatment processes and guide water management decision-making. Examples of these applications include:

- **Seawater quality prediction:**
  ML methods were trained with thirty years of historical data to predict algal growth and eutrophication in marine waters around Hong Kong[11]. ML models have the potential to improve understanding of the relationship between algal growth and coastal environmental variables, which could inform future management decisions.

- **Contaminant identification:**
  In this proof-of-concept project, the Clean Water AI system[12] has been trained to recognise harmful compounds and bacteria using ML methods. Connected sensors can then monitor water quality in real-time.

- **Sewer blockage detection:**
  A cloud-based AI system was designed to identify obstructions in sewer pipelines[13]. This technology predicts water depths using precipitation data and compares these with water depth data from sensors deployed throughout the sewer network. Higher than expected water depth may signify a blockage. Early detection and rectification can prevent unnecessary spillages through combined sewer overflow systems.

- **Irrigation advice:**
  A cloud-based water management system[14] was developed to support precision irrigation and reduce water use amongst farmers in Australia. Sensors were used for real-time monitoring of water use and weather conditions, and data were analysed to provide advice on optimal irrigation strategies.

Looking ahead

Emerging areas of interest include:

- **Adaptive learning in dynamic environments**:
  'Edge analysis', where ML is undertaken locally by sensors as opposed to in a cloud network, is being investigated as an approach that enables real-time data processing, close-term predictions and quick responses.

- **Joint sensing and communication:**
  The possibility of including sensing capabilities within future 6G wireless networks is being explored. The higher frequencies likely to be accessible through 6G infrastructure will allow for high spatial resolution and speed of data transfer. Using network infrastructure for additional sensing functionality has diverse applications (eg condition monitoring of machinery, traffic monitoring and precision agriculture).

- **Security:**
  Sensor-based systems can be vulnerable to interference. Developing strategies to detect and prevent malicious activities (eg signal jamming, eavesdropping, energy draining, data integrity attacks, etc) is a priority.

- **Explainable AI:**
  This growing area of development helps humans to understand why ML methods have provided a given solution. It can be useful in checking the validity of the outputs and to see what parameters have heavily influenced the results.

- **Cyber-physical interaction**:
  As we increasingly use digital systems together with physical infrastructure, we need to know how they interact with and impact one another.

10. Zhu M, *et al.* 2022 *A review of the application of machine learning in water quality evaluation. Eco-Environment & Health*, 1(2): 107-116. See https://doi.org/10.1016/j.eehl.2022.06.001 (accessed 18 January 2024).
11. Deng T, *et al.* 2021 *Machine learning based marine water quality prediction for coastal hydro-environment management. Journal of Environmental Management*, 284. See https://doi.org/10.1016/j.jenvman.2021.112051 (accessed 18 January 2024).
12. https://cleanwaterai.com/
13. Shepherd W, *et al*. 2023 *Cloud-based artificial intelligence analytics to assess combined sewer overflow performance. Journal of Water Resources Planning and Management*, 149(10). See https://dx.doi.org/10.1061/JWRMD5.WRENG-5859 (accessed 18 January 2024).
14. Horizon 2020. 2019. Copernicus applications and services for low impact agriculture in Australia. See https://cordis.europa.eu/project/id/870518 (accessed 5 February 2024).

Perspectives on the effects of water quality on health

Sir Christopher Whitty KCB FMedSci FRS, Chief Medical Officer for England and Chief Medical Adviser to UK Government, shared his thoughts on the intersection between public health and water management.

Image: Sir Christopher Whitty KCB FMedSci FRS, Chief Medical Officer for England and Chief Medical Adviser to UK Government.

"We should think seriously about what is an appropriate and proportionate response in terms of reducing human pathogens [in our water bodies]."

Sir Christopher Whitty KCB FMedSci FRS,
Chief Medical Officer for England and Chief Medical Adviser to UK Government

Human health and water quality have always been closely entwined. The position of Chief Medical Officer for England was created in the mid-nineteenth century to manage cholera and typhoid epidemics. These diseases are closely linked with water quality, and subsequent engineering improvements to separate sewerage from drinking water have been highly effective at improving water sanitation and thus reducing outbreaks. However, sewage in rivers and public waterways where people may come into contact with it is a growing problem in some areas of the country[15].

Disease transmission via faeces

There are five main routes of transmission for infectious diseases: respiratory, sexual, touch, vector-borne, and faecal / oral. Faecal / oral has historically been very important as cholera, typhoid, hepatitis A, hepatitis E, and rotavirus are all spread via faecal / oral transmission. This transmission may occur person to person but can also occur via contaminated food or water. Cholera is the archetypal water-borne infectious disease.

Although faecal matter of any origin can pose a risk to public health, human faeces are of particular concern. They are likely to harbour pathogens that have evolved to infect humans and that may have been exposed to commonly used antibiotics and survived, and may be resistant to antibiotics commonly used in medicine.

15. Whitty C, *et al.* 2022 *Sewage in water: a growing public health problem.* See https://www.gov.uk/government/news/sewage-in-water-a-growing-public-health-problem (accessed 18 January 2024).

Sewage in public waterways

Both storm overflows and continuous discharge from wastewater treatment facilities as part of routine operations can introduce pathogens from human faeces into waterways, which are increasingly being used for recreational purposes. The scale of the problem is difficult to quantify as small outbreaks (eg norovirus amongst wild swimmers) may not be reported. In periods without major rainfall, when water levels are lower, continuous discharge is often more important as a contributor of sewage in waterways than the more widely debated storm overflows. These sunny and dry periods without major flooding are also times when people commonly use fresh water for recreational purposes.

This is an issue that the public cares about, reasonably. The current public attention this issue is receiving represents an opportunity to consider how we approach a growing problem.

Looking ahead

Most water quality legislation is focused on environmental impacts. However, it is important that the implications for human health are equally recognised. First, the size of the public health risk must be determined. The number of viable human faecal organisms present in effluent discharge from sewage treatment plants in particular is not well understood. In addition, efforts to reduce pathogens in water have historically focused primarily on bacteria. It will be important to explore how to prevent potential future faecal / oral viruses of concern from getting into our drinking water supplies. Developing frameworks now for how we might respond should mean we are better able to manage any future crisis.

Innovation will be required to address the current challenges faced by our sewage system, and climate adaptation should be integrated into any developments.

Decarbonising existing and new infrastructure: future challenges

Maria Manidaki, Technical Director for Decarbonisation at Mott MacDonald, identified the main decarbonisation challenges for UK water sector. She also shared current decarbonisation activities being undertaken, and discussed what future action is needed.

Image: Maria Manidaki, Technical Director for Decarbonisation, Mott MacDonald.

> "Technologies are important, solutions are important, but it is also important to bake whole life carbon into decision-making."
>
> Maria Manidaki, Technical Director for Decarbonisation, Mott MacDonald

Water companies in England have committed to achieving net zero operational carbon emissions by 2030[16]. However, capital carbon emissions associated with infrastructure construction are not generally seen as fitting under this 2030 pledge. For these emissions, different water companies have their own commitments, targets and timelines.

Data from the Sixth Carbon Budget[17] puts water sector emissions into a broader context. This report provides recommendations on the volumes of greenhouse gas emissions the UK should seek to produce in the future. Across all sectors, there is a call to cut emissions by 78% by 2035 from 1990 baseline levels. As of 2021, a 42% reduction in emissions from 1990 levels had already been achieved, largely due to the increased use of renewable energy to power the electricity system. Much more work is left to do.

16. Water UK. 2019 *Public interest commitment.* See https://www.water.org.uk/sites/default/files/wp/2019/04/Public-Interest-Commitment-2.pdf (accessed 18 January 2024).

17. Climate Change Commission. 2020 *Sixth carbon budget.* See https://www.theccc.org.uk/publication/sixth-carbon-budget/ (accessed 18 January 2024).

Image: The session on decarbonisation was chaired by Professor Guangtao Fu, University of Exeter.

Capital carbon emissions

Recent work has examined the sources of capital carbon emissions in the water sector in more detail[18]. Looking at the relative emissions contributions of different factors (eg earthworks during excavation, materials, fuels) involved in construction can provide evidence to underpin future reduction strategies. Building infrastructure involves complex global supply chains, making it difficult to predict how drivers of emissions might change over time.

To meet new regulatory requirements and introduce innovative water treatment and management technologies, a great deal of new infrastructure must be built. This is a cause for concern in terms of emissions produced during asset creation. There is a need for evidence-based dialogue between policy makers, regulators, water companies and other stakeholders to understand how different policy levers may impact whole life carbon emissions.

Operational emissions include process emissions

Operational emissions in the water sector include those associated with energy use. They also include process emissions, which comprise gases like methane and nitrous oxide that are produced by wastewater treatment techniques. As energy requirements are increasingly being met by renewable sources, it is estimated that by 2030 process emissions will account for over 70% of total operational emissions in the water sector.

Areas of progress

There are four areas where the UK water sector is making important progress in decarbonising:

1. **Whole life carbon reduction targets:** Many UK water companies have set targets for both operational and capital carbon emissions reductions.
2. **Regulatory requirements and enablers:** It is anticipated that water companies will soon be asked to report on their whole life carbon emissions.
3. **Leadership in research and innovation:** The UK has an active water sector research base and water companies are trialling innovative solutions.
4. **Recognising importance of behaviours:** Water companies and regulators recognise that actions across the whole value chain influence emission management.

Looking ahead

The following actions may help accelerate decarbonisation in the water sector:

- **Carbon in decision-making:** the entire supply chain should be empowered to reduce emissions in the areas they can influence.
- **Integrated policy and regulation:** it is important to understand how environmental and water policies and regulations may impact future decarbonisation.
- **Strategic and adaptive planning:** an improved understanding of whole life carbon emissions and the key drivers of emissions must underpin strategic planning.

18. All Company Working Group. 2022 *ACWG carbon ambition.* See https://www.wrse.org.uk/media/muvl5thv/acwg-low-capital-carbon-alternatives.pdf (accessed 18 January 2024).

The water-energy-climate cycle: from vicious to virtuous?

Professor David Butler FREng, University of Exeter, explained the links between water services, energy generation and climate change. He discussed both interactions and interventions within an urban water services context.

Image: Professor David Butler FREng, University of Exeter.

> "Act now and work together to ensure that the vicious cycle of today becomes the virtuous cycle of tomorrow."
>
> Professor David Butler FREng, University of Exeter

Managing the inherent links between water, energy and climate is a key challenge for the UK water sector and society more broadly. As we generate and use energy, we produce more carbon. This has climate implications, which in turn causes extremes and increased variability in the water cycle (eg more frequent and severe drought and flooding events). Water services require energy inputs, and energy generation requires water. These complex interrelationships can be framed as the water-energy-climate cycle.

‘Vicious’ interactions

There are considerable water use implications associated with energy generation. Globally, there has been an almost linear rise in energy demand since 1990, with most of the increase in demand coming from Asia[19]. The amount of water used is highly dependent on the technology employed. Using biomass as a fuel is the most water-intensive energy generation approach, and using wind turbines is among the least water-intensive[20]. Most technologies use between 10^3 and 10^4 L / MWh.

Similarly, the provision of water services requires high levels of energy consumption. Globally, there was an inflection point in water extraction between 1950 and 1960, at which point demand increased dramatically[21]. In terms of the energy required for water use, demand is particularly high for producing bottled water. Desalination and water recycling also require substantial energy inputs, while energy demand for river and reservoir management is comparatively low.

Within the UK, the water industry consumes an estimated 8 TWh annually to produce potable water and treat wastewater. This corresponds to approximately 3% of total UK energy consumption.

‘Virtuous’ interventions

Innovative household-level approaches to water demand management are arguably where the biggest decarbonisation gains can be made. Approximately 89% of greenhouse gas emissions associated with urban water services are linked to water usage within the home. When examining individual appliances, changing toilet design and use can substantially reduce water use but has little impact on reducing energy demand or carbon emissions[22]. Alternatively, changing shower design and use has the potential to reduce water use, energy demand and emissions.

Looking ahead

New technologies showing promise in reducing both water and energy demand include:

- **Ultralow flush toilet:**
  uses a pneumatic flush that uses 1.5L per flush vs 6L in a standard toilet. This has the potential to generate water savings of 86% and energy savings of 76%.

- **Zero-energy rainwater harvesting:**
  most household rooftop rainwater collection systems use more energy than they save. New designs allow for passive water collection, allowing for maximum energy efficiency.

- **Heat recovery from wastewater:**
  A heat exchanger shower design from Zypho® recovers heat from warmer discharged water to reduce the amount of energy needed to heat inflow.

Measures taken to drive down household water usage must be considered carefully, as they could have the unintended consequence of driving up energy usage. Water and energy efficiency must be promoted together.

19. Enerdata. 2023 *Global Energy Trends – 2023 Edition.* See https://www.enerdata.net/publications/reports-presentations/world-energy-trends.html (accessed 22 January 2024).
20. Jin Y, *et al.* 2019 *Water use of electricity technologies: A global meta-analysis. Renewable and Sustainable Energy Reviews,* 115. See https://doi.org/10.1016/j.rser.2019.109391 (accessed 22 January 2024).
21. Boretti A and Rosa L. 2019 *Reassessing the projections of the World Water Development Report. npj Clean Water*, 2(15). See https://doi.org/10.1038/s41545-019-0039-9 (accessed 22 January 2024).
22. Fidar A, *et al. 2010 Environmental implications of water efficient microcomponents in residential buildings. Science of the Total Environment*, 408(23): 5828-5835. See https://doi.org/10.1016/j.scitotenv.2010.08.006 (accessed 22 January 2024).

Reducing emissions from wastewater treatment: recent innovations and future priorities

Professor Evina Katsou, Imperial College London, discussed the complex pathways leading to nitrous oxide emissions from wastewater treatment processes and highlighted several emerging technologies being used to monitor and mitigate these emissions.

Image: Professor Evina Katsou, Imperial College London.

"Reducing nitrous oxide emissions is a market priority."

Professor Evina Katsou, Imperial College London

Biological nutrient removal processes in the wastewater sector involve complex communities of microorganisms that produce large volumes of nitrous oxide, a potent greenhouse gas. This can account for up to 80% of the total carbon footprint for a wastewater treatment plant[23].

Monitoring and estimating nitrous oxide emissions

There is high seasonal and diurnal variation in nitrous oxide emissions[24], indicating that both long-term and continuous monitoring is needed.

There are several techniques for plant wide and point source monitoring of emissions that have been developed over the years. They include hoods placed in one or multiple locations in the plant, liquid sensors, remote sensing and the use of sniffer drones.

23. Daelman MRJ, *et al.* 2013 *Methane and nitrous oxide emissions from municipal wastewater treatment – results from a long-term study. Water Science & Technology*, 67(1), 2350-2355. See https://doi.org/10.2166/wst.2013.109 (accessed 22 January 2024).
24. Daelman MRJ, *et al.* 2015 *Seasonal and diurnal variability of N2O emissions from a full-scale municipal wastewater treatment plant. Science of the Total Environment*, 536: 1-11. See https://doi.org/10.1016/j.scitotenv.2015.06.122 (accessed 22 January 2024).

There are currently several methods used for estimating nitrous oxide emissions using monitoring data. A comparison of six methods was undertaken using activity data from two wastewater treatment plants[25]. The resulting emissions estimates were widely varied, highlighting the need for a standardised approach to both data collection and emissions estimations.

Mitigation using real-time explainable artificial intelligence (AI)

A range of operational interventions can be used to help mitigate emissions from wastewater treatment processes[26]. However, different factors affect nitrous oxide production depending on the time of year and the time of day. Different interventions may be needed to manage emissions at different times, thus it is important to develop adaptive and dynamic control strategies.

Real-time explainable AI can be a useful tool for mitigation. This machine learning (ML) approach is underpinned by four core principles:

1 **Domain knowledge:**
incorporate known biological and physical processes into every stage of model development. This aligns models with the practical realities of wastewater treatment.

2 **Data quality:**
A robust sensor fault detection and diagnosis system was developed. This protects against inaccurate monitoring which, unchecked, can cause issues with the models.

3 **Interpretability:**
Model outputs can be turned into accessible, actionable advice. The system highlights which controllable parameters can be adjusted in real-time to reduce emissions.

4 **Continuous learning:**
The models are not static. They adapt to new data and events.

These principles were used to develop an AI system for monitoring and controlling nitrous oxide emissions from a wastewater treatment plant in Spain[21]. The research team aimed to develop a tool that could predict near-time nitrous oxide emissions as well as determine which factors influence emission generation during different periods.

The first step was to clean the data. Algorithms were applied to identify sensor faults. Historical data was analysed to identify abrupt changes in emissions and these were compared with rainfall and temperature records to see what influence these parameters may have had on emission levels.

Following data cleansing, prediction algorithms were deployed. After confirming that the prediction model adequately aligns with what is observed, the predictions themselves can be analysed to see what parameters (eg dissolved oxygen levels in wastewater) are influencing the results. This analysis can inform short-term management decisions and uncover consistent system behaviour patterns. By understanding these dynamics in a few wastewater treatment plants, we can potentially apply these findings to others, ensuring more efficient and environmentally friendly operations. There are plans to test the model in real-time conditions in 2024.

The system described above is a data-driven model. To further improve interpretability, reliability and predictive performance, there is growing interest in combining data-driven models with mechanistic expert knowledge in hybrid modelling approaches.

Looking ahead

To continue to reduce nitrous oxide emissions from wastewater treatment, several things are needed:

- Standardised sampling and monitoring methods
- Standardised data collection and processing approaches
- The integration of microbial analysis (eg relative abundances) into monitoring studies
- Research on explainable AI and hybrid models to increase trust
- Long-term, on-site emission reduction research
- Solutions that can be transferred between wastewater treatment plants
- Collaboration between industry, academia and government to tackle digital illiteracy in the water sector and support evidence-based policy-making

25. Katsou E, *et al.* 2024 [unpublished data].
26. UK Water Industry Research. 2020 *Quantifying and reducing direct greenhouse gas emissions from waste and water treatment processes – Phase 1.* See https://ukwir.org/quantifying-and-reducing-direct-greenhouse-gas-emissions-from-waste-and-water-treatment-processes-1 (accessed 22 January 2024).

Moving to a whole life carbon approach through innovation and collaboration

Alex Herridge, Carbon & Sustainability Manager at Anglian Water @One Alliance, provided an overview of the Enabling Whole Life Carbon in Design project. This work developed a best-practice approach to integrating whole life carbon into decision-making and governance.

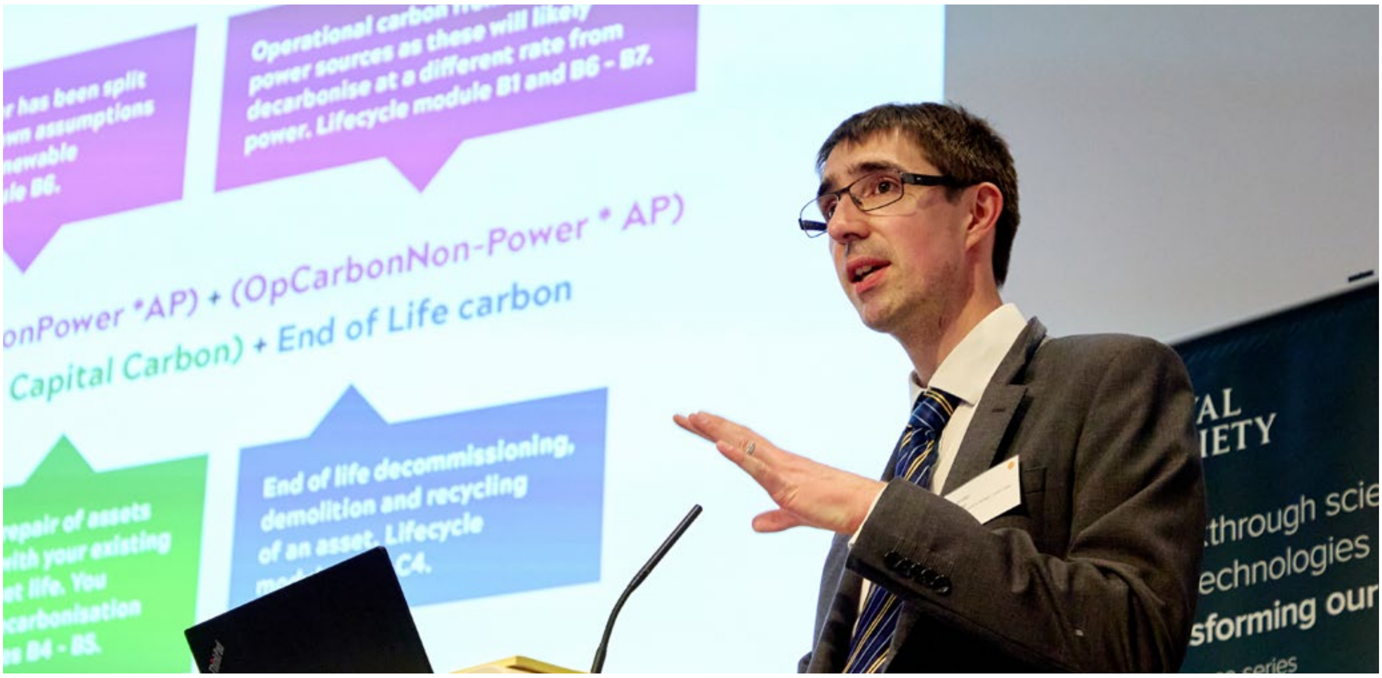


Image: Alex Herridge, Carbon & Sustainability Manager at Anglian Water @One Alliance.

> "We want to move the dial with this project to make it quicker, more intuitive and more useful to calculate carbon."
>
> Alex Herridge, Carbon & Sustainability Manager at Anglian Water @One Alliance

The Enabling Whole Life Carbon in Design project aims to develop the tools and processes needed to enable lower carbon and cost solutions across the water sector. The project is led by Anglian Water with support from Dŵr Cymru – Welsh Water, Affinity Water, the @OneAlliance, Sweco and Skanska.

Objectives and challenges

The partners wanted to: develop an approach to measuring whole life carbon, bringing together existing data into a water sector-specific context; produce a guide for creating a visualisation tool; and create a framework for embedding the concept of whole life carbon into policy and decision making.

Five factors make it difficult to examine whole life carbon in the water sector:

1. **Lack of whole life carbon metrics.**
   The industry has traditionally focused on operational and to a lesser extent capital carbon emissions.

2. **Carbon and cost cause-and-effect relationship is not fully understood.**
   There is a need to understand which are the most cost-effective carbon interventions.

3 Lack of integration between data and systems.
Cost systems, carbon systems and engineering systems have not been designed for interoperability.

4 Carbon data is not easy to interpret.
Visualisation tools and simpler carbon calculations should allow for easier interpretation.

5 Project governance focuses on capital and operational carbon.
Decision making does not currently incorporate whole life carbon data.

The playbook

The main project output has been 'the playbook'[27]. Organisations move through a series of development stages, outlined below.

Building a carbon data library and calculating whole life carbon

The playbook simplifies whole life carbon calculations. It uses a formula that includes capital carbon (split into initial construction, maintenance and repair sources), operational carbon (split into power and non-power sources) and end-of-life carbon (eg associated with decommissioning of assets).

Aligning carbon, cost and data models

This has been done manually and provides a proof-of-concept model for what can be achieved if you spend the time aligning datasets. Learning from the alignment process should inform future system design decisions to ensure easier integration.

Visualising carbon and cost data

The playbook provides guidance on using Building Information Modelling (BIM) to produce three-dimensional models of infrastructure and processes. BIM can depict a system's carbon footprint and give live feedback on carbon and cost impacts of design changes.

Embedding data into data and governance processes

The playbook has synthesised information on best practices across project stages based on data from interviews with water companies and guidance from PAS 2080, which provides standards on managing carbon in infrastructure.

Managing organisational change

Success requires that all actors understand why an organisation is developing a whole life carbon strategy and what benefits are likely to result. A change consultant advised on best practice. Carbon literacy underpins this process.

Looking ahead

The playbook is intended to support water sector companies on their journey towards incorporating whole life carbon into their governance and decision-making processes. Technical surgeries will also be offered in collaboration with Spring to support dissemination. The playbook is intended to be useful to organisations outside the water sector as well, as most of tools and guidance are sector-agnostic.

27.WAnglian Water. 2023 *Enabling whole life carbon in design.* See https://awinnovationhub.co.uk/wp-content/uploads/2023/09/Whole-Life-Carbon-Playbook.pdf (accessed 22 January 2024).

PANEL DISCUSSION

Improving sustainability and innovation in the UK water sector

Professor Sir John Beddington CMG FRS, former Chief Scientific Advisor to the UK Government, chaired a discussion on improving sustainability and innovation in the UK water sector.

Image: from left to right, Mike Woolgar, Professor Tom Stephenson FREng, Professor Carolyn Roberts, Professor Gideon Henderson FRS and Beth Corbould.

> "How can we get people in their households to understand we need to use water differently?"
>
> Beth Corbould, Director of Policy and Outcomes, Ofwat

Panellists included: Beth Corbould, Director of Policy and Outcomes at Ofwat; Professor Gideon Henderson FRS, Chief Scientific Advisor for Defra and Professor of Earth Sciences at the University of Oxford; Professor Carolyn Roberts, Emeritus Professor of Environment at Gresham College London; Professor Tom Stephenson FREng, Professor of Water Sciences at Cranfield University; and Mike Woolgar, Water Strategy Director at WSP in the UK.

The panel were asked to identify their key takeaways from the event, and questions from the audience further stimulated the discussion. The main themes are summarised below:

Integrated and collaborative water management

- There is a need for collaborative environmental planning created by and for the entire sector (water companies, landowners, farmers, policymakers, etc) rather than individual plans for each actor.
- Integrated water management is a key ambition for the water sector. This approach brings together diverse stakeholders, usually at the catchment-level, to collaboratively consider the environmental, social and economic factors influencing decision-making. However, the stakeholders involved in integrated water management often must respond to numerous demands, not just those linked with water. The necessary trade-offs between competing needs makes catchment-level collaborative management highly complex.

- Lessons on working collaboratively could perhaps be learned from the telecommunications sector, which has digitalised and uses information collectively to provide services.

Data and AI

- There is capacity to increase the range and scope of monitoring in the water sector.
- Better measurements can support better management. Planning of data collection should focus on how it can be used and who can use it to take appropriate action.
- Use of AI and ML to understand increasingly large datasets could revolutionise water and wastewater management.
- There is a role for citizen science in engaging the public in the water sector. AI tools could potentially be used to refine data collected in this way.
- Data sharing between the public, private and charity sectors should be prioritised.

Emissions, pollutants and nutrient flows

- Although wastewater treatment processes can be optimised to reduce emissions, there is still a need for mitigation interventions including capture technologies.
- Clear information about appropriate disposal routes for pollutants (eg pharmaceuticals, items containing PFAS) could reduce the presence of these compounds in our water courses.
- Circular nutrient use is an emerging area of technology development and management decision-making. There is scope for improved nutrient recovery from wastewater treatment facilities.

> "Organisations are making plans, but they are making plans on their own. If you are genuinely trying to be resilient, you need to understand where your vulnerabilities are and how they arise."
>
> Mike Woolgar, Water Strategy Director, WSP in the UK (in reference to flood management strategies).

> "We in the UK are pretty good at innovation at the level of devices… [however], we need a systematic analysis of the barriers to take-up of innovation in the water sector."
>
> Professor Carolyn Roberts, Emeritus Professor of Environment, Gresham College London

Nature-based solutions (NbS)

- There are many types of NbS, each with its own benefits and disadvantages.
- NbS can be particularly difficult to deploy in urban environments due to tight space constraints.
- It is difficult to know if a given NbS will work in a specific context, thus a willingness by companies and regulators to tolerate potential failure will be key to improving uptake.

Disaster management and governance

- Water management, particularly during floods and droughts, requires enormous collaboration between numerous actors (eg local authorities, water companies, households, fire brigades, transport providers, etc). However, each organisation typically has its own rules and disaster management plans that have been developed in isolation.
- An overarching governance structure could support cohesive, genuine resilience. Thoughtful development is needed to ensure future governance frameworks and / or policies reduce (rather than increase) complications in collaborative management.

> "There should be more focus, when it comes to the water sector and preserving the environment or mitigating climate change, on nitrogen."
>
> Professor Tom Stephenson FREng, Professor of Water Sciences at Cranfield University

Collaboration with the social sciences

- Improving the sustainability of the water sector will require behaviour change at various scales, from individual households to the industrial level.
- Analysis of factors influencing behaviours, barriers to change and possible interventions could be undertaken in partnership with social scientists.
- Engaging households and companies in discussions about storing and sharing water is one clear step that can be taken to reduce water demand.

Investment to support innovation and adoption:

- Longer, consistent public sector funding cycles are needed to support large-scale sustainability efforts across the water sector.
- Substantial investment by Ofwat via their £200 million Innovation Fund is driving technological and environmental improvements in the water sector. Ofwat is also developing a future £100 million Water Efficiency Fund to support projects that focus on reducing demand for water.
- The £12 million Innovation in Environment Monitoring programme from Defra and Innovate UK will fund the development of innovative sensors and sensing systems. These tools have the potential to support improved water management and could boost compliance with water quality regulations.

"[The need for] a systems approach is what came through today, a systems approach to the whole raft of issues that are facing us in terms of how we can have a sustainable water system going forward. The conference demonstrated that there are very significant opportunities for innovation across most of the issues discussed and the benefits of bringing the water companies, the supply chain and academics working in the field together."

Dame Sue Ion GBE FREng FRS, Chair of the Royal Society Science, Industry and Translation Committee

Image: The panel discussion was chaired by Professor Sir John Beddington CMG FRS, former Chief Scientific Advisor to the UK Government.

"What has come through from this meeting is how important it is to get different sectors all talking to each other. That has been very valuable."

Professor Sir John Beddington CMG FRS, former Chief Scientific Advisor to the UK Government

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