Water in Crisis

Delivering urban and natural water cycle symbiosis

The Water Research Group in the Department of Civil and Structural Engineering at the University of Sheffield is the UK's largest urban water research team. Their research encompasses the entire water service provision including assessing the environmental impact and protection of groundwater and rivers, stormwater management and flooding, green and urban water infrastructure engineering, and management of buried assets to optimise performance and safeguard drinking water quality. Their pioneering work is internationally recognised and aims to continue delivering sustainable engineering solutions that promote active urban and natural water cycle symbiosis.

Water is in crisis. The Water Research Group in the Department of Civil and Structural Engineering at the University of Sheffield is at the forefront of resolving worldwide problems and pioneering innovative solutions. Water is a fundamental need of life and critical to society, global economies and the natural environment. When we turn on a tap, we see a clean and safe supply of water that we take for granted. We rarely consider how it got there, how our wastewater is removed or how integral this urban water cycle is to our everyday lives and well-being.

Covid-19 has brought public health concerns to the forefront, but viruses exist everywhere, even in our drinking water. This should not be a cause of fear, but is an example of something we must embrace and work with in harmony to ensure resilience in the quantity and quality of our water. The Water Research Group at the University of Sheffield provides essential research and services facilitating this synergy.

The Sheffield Water Research Group is the UK's largest urban water research team. Their research encompasses the entire water service provision including assessing the environmental impact and protection of groundwater and rivers, stormwater management and flooding, green and urban infrastructure engineering, and management of buried assets to optimise performance and safeguard drinking water quality. Their research spans fundamental aspects to application, with a focus on challenge-driven issues. They work with water utilities, consultants, contractors and other stakeholders internationally and advise governments and policy-makers. In addition to Civil and Structural Water Engineering, they collaborate across the University of Sheffield and with other leading international researchers to deliver trans-disciplinary research that is essential to make a difference in the water sector, with particular strengths in integrating social science to deliver transformative socio-technical change. The group includes many disciplines, drawing on expertise in Computer Science, Earth Science, Environmental Science, Geography, Geoscience, Hydrogeology, Mathematics, Microbiology and Social Science. Research is coordinated across five themes: Environmental Fluid Mechanics, Groundwater Protection and Restoration, Sustainable Drainage Systems and Urban Drainage, Water Distribution Systems and Infrastructure, and Catchment and River Flooding.

The urban water cycle encompasses the engineered systems that protect water resources, form green infrastructure, provide essential and safe drinking water, ensure wastewater and sewage removal and manage stormwater to prevent flooding. The Sheffield Water Research Group's strategy focuses on both the current and future needs of these engineered systems, ensuring they operate to the benefit of all: supplier, consumer and environment. Here, we outline just a few examples of the research being undertaken.

BIOFILMS IN DRINKING WATER

Drinking water treatment works to protect public health through the provision of high-quality, safe consumable water that complies with prescribed standards. However, water quality can degrade on its journey through the immense, yet hidden world of drinking water distribution systems. Central to this are the water's interactions with the pipe walls, which are governed by the complex microbial biofilms that cover them. Biofilms are inevitable within aquatic environments as it is not possible to create sterile conditions. In fact, natural biofilms provide essential safety features resisting pathogens, yet unmanaged they can lead to aesthetic and health issues. Researchers at Sheffield are developing techniques to investigate these ecosystems and the relationships between communities including bacteria, viruses and fungi and the structures holding them together. This understanding is promoting ever better pro-active management, ensuring beneficial community colonisation and safe adaptation to issues such as climate change or changing water sources required to tackle increasing worldwide water scarcity.

We rarely ever question how integral the urban water cycle is to our everyday lives.

WATER DISTRIBUTION SYSTEMS AND INFRASTRUCTURE

Safeguarding water quality in order to protect public health underpins our water supply systems. Satisfying customers' expectations while managing ageing and deteriorating distribution systems, however, presents challenges to water utilities. The most common complaint relating to drinking water quality concerns discoloured water appearing from consumers' taps. Researchers working on the Prediction of Discolouration in Distribution Systems (www.PODDS.co.uk) project explain, with the aid of in-house developed modelling tools, how the accumulation of organic and non-organic material on pipe walls can cause discolouration and other issues such as taste and odour problems.

The PODDS team explore how hydraulic conditions in our drinking water distribution systems can both impact, and be used to manage, this risk. Results show how the low-level background material concentrations in transmitted water accumulate on pipe walls in conjunction with ubiquitous biofilms creating an inevitable and endemic discolouration risk. By understanding the hydraulic characteristics, however, significant cost savings can be made over traditional cleaning methods by working in harmony with this engineered ecosystem. One strategy is Flow Conditioning that uses managed flow increases together with quality monitoring to safely remove excess material without disrupting the natural biofilms, leading to cleaner systems with improved resilience. Along with real-time network monitoring, water quality samples are routinely collected but the resulting data has typically been archived rather than analysed. Researchers are using machine learning approaches to analyse historical water quality databases to identify dominant discolouration mechanisms driving discolouration risk, such as nitrification and cast iron mains. This approach is being used to inform interventions and justify investments to help safeguard drinking water quality.

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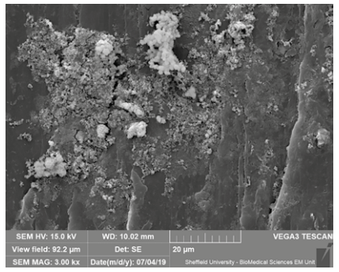
TWENTY65: A NEW TAKE ON THE ENERGY-WATER NEXUS

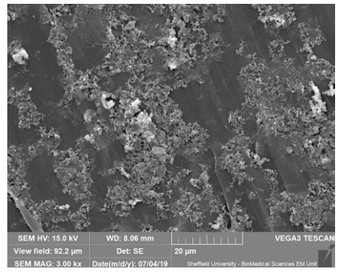
The Sheffield Water Research Group leads the EPSRC-funded Grand Challenge consortium TWENTY65 (www.twenty65.ac.uk) that is looking to the future of water supply. Interdisciplinary teams are researching and developing innovative long term synergistic and sustainable ways of delivering clean water while also having a positive impact on our health, the environment, economy and society. As an example of one of the eight themes of disruptive research within TWENTY65, researchers at Sheffield are taking a novel approach to the energy-water nexus as they integrate renewable energy generation and storage with the distribution of drinking water and wastewater collection. Simulations have combined the energy produced by turbines in drinking water reservoirs and heat recovered from the sewer network with wind turbines and solar photovoltaic panels. Results reveal that such an integrated system could satisfy the heat demand for up to 63% of the time over the course of a year. At the same time, carbon emissions could be reduced by 55% and the associated CO_2 reduced by 60% compared to heating with natural gas. Implementing such systems in neighbourhoods could help governments meet carbon emission obligations.

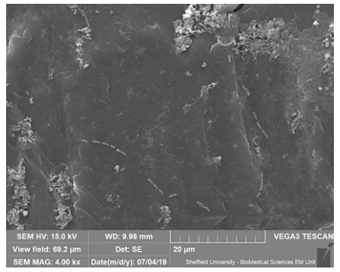
PIPEBOTS

Deploying autonomous robots to inspect the buried pipelines of sewer

To safeguard drinking water, the research group analyses discolouration mechanisms.







Natural biofilms in water pipes provide essential safety features resisting pathogens. However, unmanaged they can lead to aesthetic and health issues.

and drinking water systems has the potential to provide effective non-destructive methods for examining internal pipe structure and identification of performance issues. The Water Research Group at Sheffield are leading the EPSRC-funded Pipebots project (www.pipebots.ac.uk) in partnership with researchers from three other UK universities. The project aims to transform the capabilities of utilities, moving them towards failure-free operation and preventing unplanned road excavation by developing pipe-scale robots. These Pipebots need to be capable of inspecting and working in inaccessible pipes, which incorporates a range of challenges, such as high pressures and potentially explosive gases. Simulations using biologically inspired behaviour, which take into account network length, topology, the number of robots and their speed, highlight the potential to monitor entire networks.

Robotic sensing enables Pipebots to extract accurate and relevant information concerning the condition of pipes together with location and fault diagnosis in real time with minimal human interaction. Artificial Intelligence (AI) and machine learning techniques are being used to refine performance and given the energy contained in moving fluids, energy-harvesting hardware is also being developed. The Pipebots team have the advantage of being able to use the facilities at the National Distributed Water Infrastructure Facility at ICAIR (the Integrated Civil and Infrastructure Research Centre, www.icair.ac.uk) to develop and perform controlled testing of the robots at full scale before moving onto field testing.

PROTECTING GROUNDWATER QUALITY

Since 2000, research funded by EPSRC, the Environment Agency and private industry has facilitated long-term investigation of the fate and behaviour of gasoline ether oxygenates (GEO) that pollute European groundwaters. The research has advanced fundamental understanding of microbial transformation of these petroleum additives (used to improve combustion and reduce vehicle emissions), with innovative monitoring strategies and restoration concepts developed that underpin strategies helping to reduce the environmental risk posed by GEOs in groundwater.

Researchers are developing pipe-scale robots that are capable of inspecting and working in underground pipe networks and sites deemed dangerous for humans.

URBAN FLOODING

The recently completed H2020 funded CENTAUR project developed an innovative and cost-effective local autonomous sewer flow control system to reduce urban flood risk. The CENTAUR system uses control gates operated by local AI-based control software to store water in upstream parts of the catchment to reduce flood risk at downstream locations. It is now being exploited by commercial partners to allow existing infrastructure to be better utilised, either reducing the need for large capital schemes, or buying time before such schemes can be delivered. Supporting this are advanced flood modelling approaches developed at the Sheffield Water Research Group that can be used to estimate the impact of flooding on building damage, potential loss of life, and highlight countermeasures to ensure safety.

The EPSRC-funded Urban Green DaMS project takes a different, but complementary approach to reducing flood risk by conducting research to enhance the understanding of the performance of bioretention cells. These are sustainable drainage systems that retain and detain rainwater before it enters drainage networks while also delivering a positive impact on water quality, amenity and biodiversity. The improved knowledge of these devices allows numerical models to be developed to give drainage engineers confidence in performance allowing them to be incorporated in urban planning.

URBAN WATER AND NATURAL WATER CYCLE SYMBIOSIS

Engineered systems that protect water resources, deliver a supply of continuous clean water and remove wastewater are complex and ageing with operation and management incurring significant energy, chemical and capital costs. The Water Research Group at Sheffield is delivering sustainable solutions to reduce these costs while fulfilling industry needs and improving the urban water infrastructure and environment. The example innovations highlighted here give a flavour of how their work is using a symbiosis between the natural water and urban water cycles to optimise delivery of these essential assets.

Behind the Research

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References

- Liu, F., Tait, S., Schellart, A., Mayfield, M., and Boxall, J. (2020). Reducing carbon emissions by integrating urban water systems and renewable energy sources at a community scale. *Renewable and Sustainable Energy Reviews*, [online] 123, 109767. Available at: https://doi.org/10.1016/j.rser.2020.109767
- Thornton, S.F., Nicholls, H., Rolfe, S.A, Mallinson, H.E.H., and Spence, M.J. (2020). Biodegradation and fate of ethyl tert-butyl ether (ETBE) in soil and groundwater: a review. *Journal of Hazardous Materials*, 391, 122046. Available at: https://doi.org/10.1016/j.jhazmat.2020.122046
- Sunny, I., Husband, P.S., and Boxall, J.B. (2020). Impact of hydraulic interventions on chronic and acute material loading and discolouration risk in drinking water distribution systems. [online] *Water Research*, [online] 169, 115224. Available at: https://doi.org/10.1016/j.watres.2019.115224
- Douterelo, I., Dutilh, B.E., Arkhipova, K., Calero, C., and Husband, S. (2020). Microbial diversity, ecological networks and functional traits associated to materials used in drinking water distribution systems. *Water Research*. Available at: https://doi.org/10.1016/j.watres.2020.115586
- Parrott, C., Dodd, T.J., Boxall, J., and Horoshenkov, K., (2020). Simulation of the behavior of biologically-inspired swarm robots for the autonomous inspection of buried pipes. *Tunnelling and Underground Space Technology*, [online] 101, 2020, 103356. Available at: https://doi.org/10.1016/j.tust.2020.103356
- Speight, V., Mounce, S.R., and Boxall, J.B. (2019). Identification of the Causes of Drinking Water Discoloration from Machine Learning Analysis of Historical Datasets' Environmental Science: *Water Research & Technology*, 5, 747–755. Available at: https://doi.org/10.1039/C8EW00733K
- De-Ville, S., Menon, M., and Stovin, V. (2018). Temporal variations in the potential hydrological performance of extensive green roof systems, *Journal of Hydrology*, 558, 564–578. Available at: https://doi.org/10.1016/j.jhydrol.2018.01.055
- Abdel-Aal, M., Schellart, A., Kroll, S., Mohamed, M., and Tait, S. (2018). Modelling the potential for multi-location in-sewer heat recovery at a city scale under different seasonal scenarios. *Water Research*, 145, 618–630. Available at: https://doi.org/10.1016/j.watres.2018.08.073
- Fish, K., Osborn, A.M., and Boxall, J.B. (2017). Biofilm structures (EPS and bacterial communities) in drinking water distribution systems are conditioned by hydraulics and influence discolouration. *Science of the Total Environment*, 593–594, 571–580. Available at: https://doi.org/10.1016/j.scitotenv.2017.03.176
- Sonnenwald, F., Hart, J.R., West, P., Stovin, V.R., and Guymer, I. (2017). Transverse and longitudinal mixing in real emergent vegetation at low velocities. *Water Resources Research*, 53(1), 961–978. Available at: https://www.doi.org/10.1002/2016WR019937

Research Objectives

The Water Research Group at the University of Sheffield aims to deliver sustainable engineering solutions promoting urban and natural water cycle symbiosis.

Detail

Bio
Joby Boxall is Professor of Water Infrastructure Engineering at the University of Sheffield, and Head of Department of Civil and Structural Engineering.

Ian Guymer is an EPSRC Established Career Research Fellow.

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UKRI in general, EPSRC specifically and critically our longstanding trusted collaborative partnerships across the water sector.

Personal Response

What has been the most rewarding outcome of the Water Research Group's work?

Stewart Husband: It is truly exciting and rewarding to know that by respecting and working with the natural water cycle we are able to deliver pioneering engineering solutions that supports society and helps protect the entire planet. Water is fundamental to life, so investigating and working in harmony with this essential resource for everyone's benefit is a privilege.