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Back to the future: A personal perspective on water and climate change*

Mark Fletcher

Perspective

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Corresponding author:
Mark Fletcher;
Email: Mark.Fletcher@arup.com

Executive summary

This paper is a personal perspective following my journey into systems thinking initially through the water cycle at school as a geographer and geologist. It records my progression and understanding through working on many aspects of the water cycle in my early career through to embracing what sustainable development is and a realisation that our climate is rapidly changing. As a geologist, I was aware that this change had occurred in geological time but became increasingly concerned about the impact of human development and how it has contributed to an acceleration, something that we all now recognise as 'anthropogenic climate change'. This creates more extreme and more frequent extremes. It also brings greater uncertainty to our status quo which has provided the basis for human development. The bulk of the impacts of climate change are felt across the water cycle (UN Water, n.d.) – the first 'system' I learned about.

The timing of our increased awareness of the human contribution to climate change has coincided with more people living in cities than rural areas (Open University, n.d.), an acceleration in urbanisation. Cities are made up of systems of systems, and so a natural progression in my thinking has been the application of systems thinking to develop an approach to assess how to improve the resilience of the water system to shocks (short-duration events, e.g., storms), and stresses (incremental events, e.g., sea-level rise) from a systems perspective and in an urban context (Resilience Rising & Arup, n.d.). I have always tried to make sense of the way our landscape and underlying geology has evolved from a perspective of knowledge and understanding of natural processes. When I think of a problem I peel away human development and think about the water cycle and try to develop solutions that are more in-tune with nature. This is one way in which we can increasingly consider the potential for restoring parts of the water cycle and ultimately think about regenerating our natural system. There are recommendations provided to address some of the practical barriers to water resilience and nature-based solutions and opportunities for further research.

To gain a different perspective on this subject, Arup commissioned the artist Peter Coates (2017) to undertake an exploration into one of the main causes of anthropogenic climate change, the Industrial Revolution. During this period of unprecedented technological development, we accelerated our knowledge of science and engineering. With hindsight, we also unknowingly lit a fuse and are now realising the residual negative consequences of that period of human development. This took place without due consideration of the impact on our natural systems. This has caused an imbalance in the natural processes affecting our world which is solely protected by a fragile band of gas (Tim Peake, Astronaut, 2017). This 'phrase' is now being progressed at the heart of an innovative creative collaboration between the artist and Arup to form the basis for a major public art installation to highlight these issues. The fate of humanity may indeed rest on whether we are able to arrest the imbalance caused by anthropogenic climate change.

Impact statement

This paper provides a personal perspective on systems thinking through a water lens. It builds on the principles of sustainable development in a world affected by 'anthropogenic climate change' resulting in more extreme and more frequent extremes. The timing of our increased awareness of the human contribution to climate change has coincided with more people living in cities than rural areas, an acceleration in urbanisation. Cities are made up of systems of systems, and so a natural progression has been the application of systems thinking to develop an approach to assess how to improve the resilience of the water system to shocks (short-duration events, e.g., storms), and stresses (incremental events, e.g., sea-level rise) in an urban context. This helps consideration of the potential for restoring parts of the water cycle and ultimately regenerating

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Mark Fletcher is the Global Water Leader at Arup, an international consultancy. He is an Arup Fellow and RAEng Visiting Professor in Engineering Design for Sustainable Development. He is also Chair of British Water.

our natural system. There are recommendations provided to address some of the practical barriers to water resilience and nature-based solutions including: governance, scale, systems thinking, total value; procurement, and funding. There are also opportunities identified for further research associated with these themes.

To gain a different perspective on this, Arup commissioned the artist Peter Coates to undertake an exploration into one of the main causes of anthropogenic climate change, the Industrial Revolution. During this period of unprecedented technological development, we accelerated our knowledge of science and engineering. With hindsight, we also unknowingly lit a fuse and are now realising the residual negative consequences of that period of human development. This took place without due consideration of the impact on our natural systems. This has caused an imbalance in the natural processes affecting our world which is solely protected by a fragile band of gas.

My personal introduction to systems thinking

The first cycle I learned at school was the water cycle. It seemed so simple yet so sophisticated and made a lot of sense. Water could exist as a solid, a fluid and a gas and could be experienced in all its forms in nature in a visual state through ice, sleet and snow; water in our rain, lakes, rivers and oceans and vapour in our clouds. The cycle was easy to draw and was my introduction to systems thinking. It was a natural system. I could imagine the development created by man being peeled away to reveal this earth system. These natural processes operating at a catchment scale in a logical way. This system underpins how we look at urban development and how a trend in urban growth needs to be considered at that scale. What I did not realise at that young age was that my body was made up of about 60% water (Michell et al., 1945) and that water is fundamental to life itself.

The earth is made up of many systems that inter-act. Understanding the dynamics of these dependent and inter-dependent systems was fascinating, and the geological flexing of this system of systems made sense. Sea levels have varied with geological time, my A-level geography project on the Flandrian Transgression (Kaplin, 1982) and its impact on the South West Lancashire coastal plain provided me with evidence of dynamic processes affecting the landscape in which I grew up. The Flandrian Transgression is divided into two stages: the Upper Pleistocene (17,000–6,000 years Before Present [BP]) – rapid rising sea level at a rate of ~9 m in a thousand years, and the Holocene (6,000 years BP to present) – progressive reduction in the rate of sea-level rise from ~4 to ~1 m in 1,000 years.

When I then studied Engineering Geology at university it enabled me to fill in some more gaps in my understanding of the evolution of our pre-industrial landscape. My career in Arup has continued to put flesh on the bones of my formative education-based knowledge particularly with the relevance of concepts like sustainability and sustainable development. My work has furthered my understanding of the impacts of human activity on those increasingly familiar natural processes, fuelling my interest and helping me make-sense through my systems lens. The significance of the industrial revolution as a 'fuse that was lit' that initiated human impact on the climate became a key point of interest and one I wanted to explore further.

The progress made through Integrated Water Resource Management (IWRM) approaches has led to management of natural processes at a system scale (catchment/watershed/river basin). Good practices like the EU Water Framework Directive River Basin Plans and Catchment Flood Management Plans are more advanced in the UK and European Union than in many other parts of the world. The insight from these policies led to catchment scale understanding of governance.

Climate change through the water cycle

Water is essential for life and is at the cutting edge of climate change. In practical terms water has a role mitigating the causes of climate change, adapting to the impacts, helping to connect with nature and building resilience for people, places and the environment. The impact of climate change is growing significantly with more frequent and extreme extremes, for example, Europe's 500-year drought; the national flooding in Pakistan and Peru; the cloudbursts in New York, London and Copenhagen; extreme heat events in Europe during 2023; and increased pollution from combined sewer overflows in the UK.

The equitable distribution of water in the face of a growing population, combined with the trend to global urbanisation and increasing uncertainty of a changing climate, is moving water security to the top of the political agenda around the world, especially the global south. Building greater resilience into the water supply system is also becoming increasingly important. Alongside this there is growing interest in augmenting water supply, for example, stormwater harvesting, wastewater recycling, desalinating saline and brackish water. On the water demand side, for example, reducing leakage, the 50 l home (World Business Council for Sustainable Development, 2021) and smart agriculture. All are within the context of other global drivers like the biodiversity crisis and net zero carbon targets.

Systems thinking and climate change

In 2017, I was approached by Arup to develop a Master's Course on the 'resilience of urban systems' (Arup & MIT Sloan Management School, 2020) with my colleague Dame Jo da Silva. This was intended to help build better understanding of resilience from a cities and 'system of systems' perspective across the senior leadership of Arup. It was developed with an external focus. Client and partner organisations were invited to send their senior representatives to participate.

The importance of the water cycle when considering the impacts of climate change should not be understated. The United Nations Framework Convention on Climate Change (UNFCCC) consider 'more than 90% of the impacts of climate change are felt through the water cycle'. The dependence and inter-dependence of the water system with other systems such as energy, transport and food has been recognised by thought-leading global bodies like the World Economic Forum (Waughray, 2011). This systems-based thinking and its impact are fundamental for understanding cities and climate change.

We explored resilience from a systems perspective, that is, 'a water cycle lens'. This wasn't just about survival and recovery but we also considered the potential for 'thrival' – that is, realising a 'resilience dividend' as a result of the system being more resilient. In fact, in 2014, Judith Rodin, President, The Rockefeller Foundation, 2005–2017 and President Emerita, University of Pennsylvania wrote a book that sought to better explain the added returns that resilience planning, projects, and practices offered, entitled: The Resilience Dividend (Rodin, 2014).

While the field of resilience is now more widely recognised, and the dividends that resilience concepts and planning provide are more widely appreciated, we have lacked a systematic, comprehensive way to measure and quantify the true value of those returns.

Restorative and regenerative development

In the 1980s there was more enlightened thinking about sustainable development, and it was defined in the World Commission on Environment and Development's 1987 Brundtland report (Brundtland Commission, 1987) as 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. I became a RAEng Visiting Professor in Engineering Design for Sustainable Development in 2003. I used to present this definition to my students. It was relevant in helping me to look at the world through a different lens. However, over the years I became increasingly uncomfortable with the definition as it did not address unsustainable development from the past and the residual associated problems. I have since expanded my thinking on this to consider the role of restorative and regenerative development, thanks to some insightful research included in the Arup Sustainability Strategy – 'A Better Way' (Arup, 2020). In order to better understand how to think about the use of the terms sustainable, restorative and regenerative, I consulted the Concise Oxford English Dictionary (2022):

> **Sustain (able)** *adjective:* able to be maintained at a certain rate or level; to be upheld or defended. It is also a *verb:* strengthen or support physically.
> **Restore (ative)** *adjective:* bring back or re-establish (a previous right, practice or situation).
> **Regenerate (ive)** *verb:* grow after loss or damage (of a living organism); bring new and more vigorous life to an area; revive.

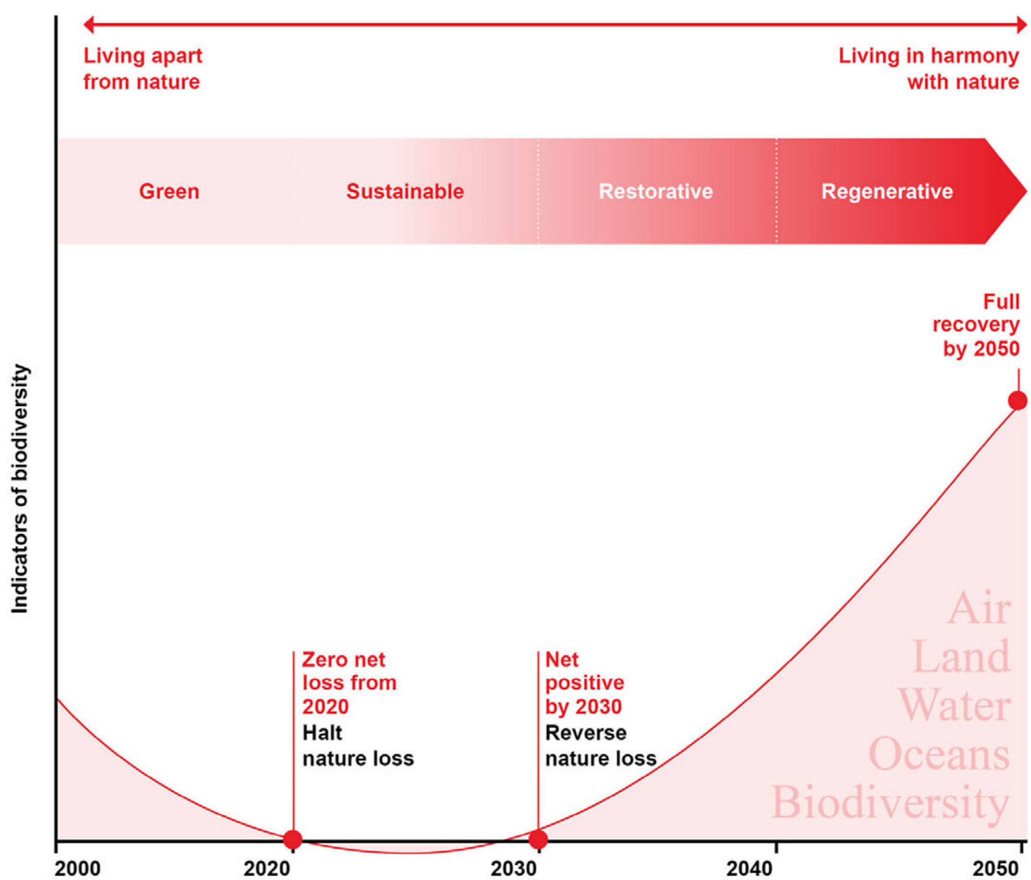
This provided me with simple language to explain these concepts. The diagram below helped in making sense of our journey back to working in-tune with natural processes and hence increasing biodiversity/ecological gain. These natural processes help to mitigate the causes of climate change and are essential in adapting to the impacts. This also provides a framework of understanding to help bring the broader community of organisations and individuals engaged across catchments together with greater common purpose.

A projection of how we can achieve a nature-positive future by 2030, as set out in the Global Goal for Nature (Locke et al., 2020).

Example: Shanghai drainage masterplan

Arup won an international competition in 2017 to provide a stormwater masterplan for the city of Shanghai. A digital tool – Terrain – was used to map land use types and typologies, and provide a forward-thinking solution to the introduction of a wide range of substantial blue and green infrastructure measures – natural and semi-natural landscape elements within the city – in combination with optimising its necessary grey infrastructure measures. The rosetta stone that unlocked the understanding of the drainage of the city was governance mapping across the water cycle looking at roles and responsibilities of agencies who had inter-dependencies.

Systems-thinking as part of the Shanghai Urban Drainage Masterplan (Rodin, 2014) (image copyright Arup).



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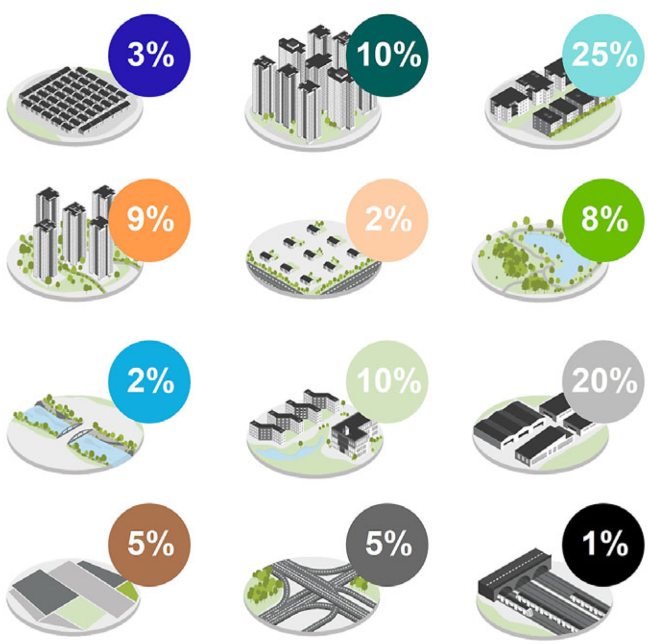

Diagrams showing the digital land-use typology assessment for Shanghai (images copyright Arup) (Arup, 2017).

Optimising the existing drainage (blue) system through maximising existing systems and modelling potential for ephemeral storage on the surface in public areas, maximising the use of natural and semi-natural vegetated areas (green) and expanding these nature-based solutions significantly reduced the need for residual (grey) infrastructure systems (pumping stations, underground storage tanks and tunnels). A $43B grey infrastructure 'single-system' solution was significantly revised through a 'blue/green/grey/governance' system of systems approach with potential savings of over $10B and the promotion of solutions much more in-tune with the natural systems and processes. These multi-faceted solutions go beyond the single benefit of traditional grey infrastructure solutions.

Back to nature

Our natural systems have become depleted, degraded and out of balance due to human development. In many areas, our human, social and financial systems are also struggling to provide a resilient and equitable social foundation. The failure of financial systems to recognise or account for the value of services provided by nature or natural capital (natural assets) has led to the loss, degradation and mis-management of nature. The pandemic highlighted again how poverty and inequality increases vulnerability to shocks and stresses. This framework of understanding provides an opportunity to think about how we can work in-tune with our natural system and processes. It can help mitigate the causes of climate change, for example, carbon sequestration, soil recovery; and can contribute to support adaptation to the impacts of climate change, for example, natural flood management, and mangrove restoration.

We need to restore and enhance streams, rivers and existing green spaces in order to leave them in a better place for future generations. Within the water sector, for example, we must consider how restoring, protecting and enhancing across the water cycle can become a catalyst for increasing the resilience, health and wellbeing of our human and natural systems. This could mean restoring a river to sustain greater biodiversity, increase the value of place, encourage greater social interaction with the river and stimulate economic regeneration.

Regenerative nature-based solutions (IUCN, n.d.) (NbS) use the power of functioning ecosystems as infrastructure to provide services that benefit the environment and society. All NbS involve common elements, they

- work with and are based on natural systems and contribute to environmental protection, sustainable management or restoration of natural resources;
- deliver value to society by addressing societal challenges (e.g., reducing biodiversity loss or providing biodiversity net gain; mitigating impacts of climate change);
- provide significant social value providing amenity and recreation and contributing to a natural landscape;
- benefit nature by preserving and enhancing biodiversity and ecosystem services.

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They play a key role in mitigating and adapting to climate change, and in improving the resilience of the built environment. They are affordable, available and scalable and need to be integrated with traditional engineering responses to deliver 'next generation infrastructure'. There are opportunities to consider NbS across a wide range of solutions given their role in addressing, for example, air quality, water management, temperature regulation, biodiversity, food security and carbon sequestration.

Example: Mansfield nature-based solutions

In 2020, Defra and water regulators put out a call for ideas for a green recovery post pandemic by driving bolder environmental ambition, creating jobs and stimulating the economy. Arup was appointed to help Severn Trent Water develop the business case, design and implement an urban flood resilience scheme based on biodiversity interventions instead of traditional drainage systems. The Mansfield sewer system is susceptible to overflow in extreme storm conditions and intercepting, storing and slowing down surface water from entering the combined system can significantly reduce the risk of sewage pollution.

In developing the business case, we made the conscious decision to consider the benefits nature-based solutions can bring beyond flood resilience. Applying a total value approach to the economic appraisal of the scheme, we were able to not only demonstrate the diverse range of values the scheme can bring to different stakeholders, but also generate insights on the total value return on investment for different types of nature-based solutions, allowing the design team to compare options and shape the design to deliver the benefits where they are most needed. On completion, the scheme will free up capacity in sewers by capturing up to 58,000 m^3 of surface water and benefit a local community of around 90,000 people. It will bring more greenery to the public spaces, creating more aesthetically pleasing places and cleaner local environment. Sustainable flood resilience schemes like Mansfield demonstrate the potential for nature-based solutions to make towns and cities more resilient to climate change while improving quality of life for residents and boosting biodiversity. The diagram below shows how a more comprehensive Total Value economic model can be applied to help prioritise NbS interventions across Natural, Social, Financial, Manufactured, Human and Intellectual Capitals.

Application of a multi-capitals total value approach to green infrastructure in Mansfield.

Recommendations and opportunities

Recommendations to address practical barriers to water resilience and NbS

Thinking through the challenges that have arisen during my experience working on water resilience and NbS, I have compiled the following recommendations to be able to address these barriers in a more practical and pragmatic way:

Governance and scale

1. There is generally poor understanding of roles and responsibilities for all parties across the water cycle, that is, governance. This can be significantly improved by mapping organisational roles and responsibilities across it.
2. The scale to adopt, for management of water-related issues, should be catchment or sub-catchment, not site scale, to reflect

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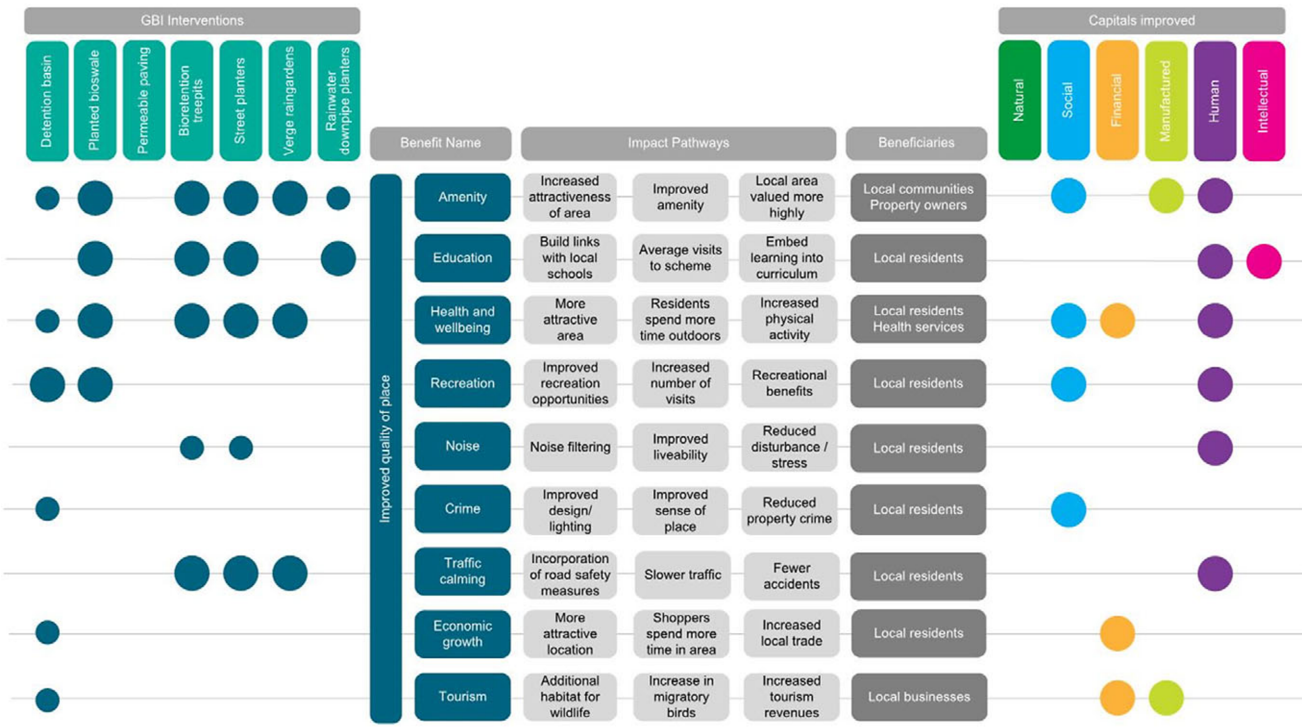

greater understanding of the dynamics of the natural processes and the scale at which they operate.

3. There are political difficulties in managing incremental stresses, for example, sea-level rise, because political tenure and policies are generally short-term. This can be overcome through drawing on globally structured research, for example, Inter-governmental Panel on Climate Change (IPCC).
4. There is a tendency to adopt a reactive approach to dealing with short-duration water-related shocks, for example, storms. There is also a tendency to manage and fund the management of water-related shocks and stresses separately and in isolation; A more integrated and holistic approach that considers both the shocks and stresses that can occur, and how to improve overall resilience, is more effective, for example, CWRA (Resilience Rising & Arup, n.d.).

Systems thinking

5. Current legislative requirements are focused on point discharge rather than catchment or sub-catchment compliance. Considering the whole system holistically would be more practical.
6. There is a predominance of silo mentality applied without recognising that interventions affect a water system, and that system has dependencies and interdependencies with other systems.

Total value, procurement and funding

7. There is a lack of widespread application of a total value economic framework to assess multiple contributions and beneficiaries to interventions from multiple parties. This leads to ineffective citizen involvement in decision-making. Adopting a Total Value approach can potentially unlock multiple and co-beneficiaries – public-, private- and third-sector contributing to multiple outcomes.
8. Lowest cost, output-based procurement with no consideration of relevant experience, specialist expertise and local knowledge will lead to higher project outturns. Adopting an outcome-based, quality-cost approach will deliver significantly greater value and more positive outcomes.
9. Where there are competing priorities and where there is a need for specific funding there can be difficulties aggregating/pooling different funding streams. A Total Value approach can help to unlock that situation.

Nature based solutions (NbS)

10. There is a limited knowledge base for the application of NbS but this is growing. Sharing good practice and lessons learned transparently and openly will help accelerate the adoption of them.
11. There are challenges monitoring the effectiveness of NbS given the spatial benefit of their application rather than point-source. Advances in data acquisition with low-cost data monitors are helping to address this.
12. There have been difficulties in upscaling NbS as it requires multi-stakeholder collaboration and puts pressure on governance structures that have not been developed specifically to accommodate NbS. This is particularly acute around maintenance issues. This could be improved with more widespread use of NbS and the shift to delivery of NbS through specialist landscape firms and more third-sector community involvement.
13. There is a general failure to take into account local context when transferring good practice from other places. This is essential and local knowledge can be invaluable in this regard through third-sector organisations, for example, River Trusts.

Opportunities for further research

The recommendations are aimed at pragmatic ways in which barriers and challenges can be overcome. Some key areas for further practical research include the following:

Governance

1. Re-visiting governance across the water cycle at catchment and sub-catchment scale from first principles to clarify roles and responsibilities of all parties to accelerate the delivery of restorative and regenerative solutions. This has not been done since water treatment and wastewater treatment was first introduced and currently our more dynamic climate extremes are testing the existing arrangements to the limit.

Systems thinking

2. Greater understanding of system dependencies and inter-dependencies from actual examples of water-related shocks and stresses and how it has transformed the solutions.
3. Understanding future pressures on our water systems due to climate change (bringing together mitigation and adaptation) – possibly through scenario-based thinking.

Total value, procurement, funding and nature based solutions

4. Identification of the benefits (and co-benefits) of water resilience and NbS.
5. More practical application of total value economic models with sharing of lessons learned to accelerate adoption.
6. More enlightened procurement that is outcome-based with a total value approach embracing biodiversity and low/no carbon solutions;
7. The role that data science/digital/citizen science could play as a key enabler and a way of achieving greater local stakeholder buy-in to a more practical, common-purpose, outcome-based approach.
8. Unlocking the land-water-food-energy nexus in a practical way that relates to real-life challenges and issues rather than just concepts.

Other

9. Consider how to include perspectives from other sectors or disciplines, for example, artists in your approach to explore the catalytic potential of a fresh outlook on the same issues to refresh your thinking and understanding.

Conclusions

Through my education and career, I have learned that water and climate change are inextricably linked. The water cycle provides a simple framework of understanding – a system – to flex due to climate change impacts such as shocks – short-duration events, for example, storms; and longer-duration incrementally changing stressses, for example, sea-level rise. The United Nations Framework Convention on Climate Change estimates that over 90% of the impacts of climate change are felt across the water cycle. This framework operates within a relatively fragile band of gas, our atmosphere. Nature has evolved mechanisms to naturally mitigate the causes of climate change in soil and vegetation, for example, trees, plants, wetlands, algae and seaweed. The water cycle is a natural system. When we try to harness and manage that system including how we change land-use, abstract water and transport, treat and re-use it, we can artificially exacerbate natural extremes and even create new ones.

There are a number of key developments in the area of natural capital accounting (UK Natural Capital Accounts, 2014; British Standards BS8632:2021, 2021) that help to provide a more informed evaluation of the services provided by NbS and may therefore help in more widespread adoption in the future. There has also been significant progress through the Biodiversity COP15 process (CBD, 2022) and in the UK on the biodiversity net-gain approach (Natural England, 2023). These both contribute to a more representative Total Value approach to assessing catchment interventions that has the potential to more readily engage a more diverse range of stakeholders. We must strive to consider each other's respective perspectives and hopefully this can lead to greater common purpose.

There is still work to do to embrace systems-thinking to help manage climate change by mitigating the causes, adapting to the

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impacts and building resilience to people, places and our environment. If we embrace sustainable development, restore our streams, rivers and land-use and regenerate to increase biodiversity then we will be working more in tune with nature for generations to come.

Epilogue: The industrial revolution and climate change – 'A fragile band of gas'

As an aside to my reflections in the light of all the above experience, I thought I would share a quite unique and personal exploration into climate change, the biggest threat humanity has faced. I have thought long and hard about how we embraced the Industrial Revolution as a force for good, accelerating the understanding and application of science, technology and engineering and harnessing the forces of nature. In order to try and gain some fresh insight I was keen to explore this through the eyes of somebody who would have a wholly different perspective to me, an artist. I shared my thoughts with an Arup colleague, Graham Dodd, who is also an Arup Fellow (Arup, n.d.) specialising in materials. We agreed to jointly commission an artist, Peter Coates, to explore this further. This was called 'Starting Point' (Peter Coates, 2017).

We visited Ironbridge in Shropshire, the birthplace of the Industrial Revolution (Historic UK, n.d.), and stood upon the iron bridge crossing the River Severn. While Graham and I were thinking about the materials that the bridge was constructed from; Peter was looking at the reflection the arch of the bridge made in the water creating an earth-like global image when viewed at a distance. During his post-visit reflections in his studio in North Yorkshire, he was listening to Radio 4 and heard the British astronaut Tim Peake describing the earth from space as 'being surrounded by a fragile band of gas' (Tim Peake, Astronaut, 2017) and this struck a chord for him in terms of how we are influencing the very 'fragile band of gas' that enables life to exist. This was the different perspective we had hoped to explore. This is now being progressed as an innovative creative collaboration between the artist and Arup to form the basis for a major public art installation to highlight these issues.

Climate change is being experienced across the water cycle I learned at school and as it flexes, we must do all that we can to mitigate the causes, adapt to the impacts and build resilience to people, places and nature.

'We saw a bridge, Peter saw the earth through the reflection in blue and green' (Ironbridge Gorge, Shropshire, n.d.).

Open peer review. To view the open peer review materials for this article, please visit http://doi.org/10.1017/wat.2023.11.

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