Flood and Water Management

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Casting back through 2022 we might remember Hurricane Ian, the calamitous flooding in Pakistan, South Africa and Australia to name a few. If not the floods, one might recall the droughts of the last year. In the American southwest, the Horn of Africa or China where low flows limited hydro power causing the lights in Shanghai to dim and made rivers in Europe and the United States unnavigable.

From a flood and drought perspective was 2022 an exceptional year with an unusually large number of rare events? Or in the face of the obvious evidence of climate change, have we become sensitised to natural disasters. Whether from the perspective of the scale of human suffering, or in insurance and capital markets, it is important to understand this to respond in an appropriate manner.

Either way a growing proportion of the world's population are at risk of flooding[1] and other severe weather events like wildfire or drought. Therefore, the need to develop tools that help improve the understanding of risk is obvious. We will continue to work with our partners at Newcastle University to improve and develop novel uses for the CityCAT model. This type of tool is useful to deal with simple cause and effect, for instance where heavy rainfall causes flooding.

[1] Tellman, B., Sullivan, J.A., Kuhn, C. et al. Satellite imaging reveals increased proportion of population exposed to floods. Nature 596, 80–86 (2021). https://doi.org/10.1038/s41586-021-03695-w

However, global systems are becoming more complex and interrelated, this makes it hard to understand overlapping vulnerabilities. There were several notable occasions in 2022 where one event could be linked to the another, or where the harm of subsequent events was amplified. An example of this occurred east of Los Angeles. In 2020 a fire scorched the hillsides leaving them bare and weakening the soil[2]. This was followed in 2022 by rainfall on the burn scar which caused severe landslides putting lives at risk and damaging property.

The field of "compound" events, covering hazards as well as interacting risk, is receiving a lot of attention in academic and practitioner communities. This is not a new topic; it is covered in a 2005 Department for Environment Food and Rural Affairs report 'Dependence Mapping and Best Practice[3]'. It has though gained prominence due to high impact events involving multiple drivers such as those described above. We will work toward a better understanding of the nature and dependences of these sequences to develop improved tools for analysis, simulation and estimation for risk management and insurance purposes.

While we will retain a global focus with Newcastle University, we will also zoom into South East Asia with our partners at the National University of Singapore. In this case we will also look at a range of CMIP6 (Coupled Model Intercomparison Project Phase 6) scenarios using regional climate models to show how the risk landscape is evolving. These will be used to unpack climate impacts on various sectors in the region.

This brings us back to water management in a changing climate. Traditional methods of reducing risk are effective but, owing to the carbon footprint arising from construction and operation of assets, the potential to use them may be limited. There are two ways around this which we intend to explore in more detail. Either, when our systems fail, we should ensure they do so gracefully and recover quickly; Or, we should find novel ways to reduce the risk of drought or flooding; Natural and Nature Based Solutions have the potential to fill a part of this gap and may also offer enticing co-benefits, however quantification of these benefits needs further development.

Neil Gunn
Head of Flood and Water Management

[2] After the Fires: Hydrophobic Soils. Dr Randy Brooks. University of Idaho Extension Forestry Information Series

[3] Joint Probability: Dependence Mapping and Best Practice: Technical report on dependence mapping R&D Technical Report FD2308/TR1 March 2005

Climate gentrification

Physical climate hazards such as flooding, and wildfires present a major threat to mortgage lenders, insurers, and the broader financial system. It is becoming clearer that such hazards are increasing in frequency and severity, coinciding with increasing exposure of populations to such threats.

Physical climate hazards are not a new phenomenon – real estate markets have endured and been responsive to extreme weather events throughout history. However, as trends in extreme events emerge, there is growing evidence that these hazards are already having a direct monetary effect on property prices. Changes in property prices pose a major financial risk to homeowners, mortgage and insurance industries, bank portfolios, and wider financial systems.

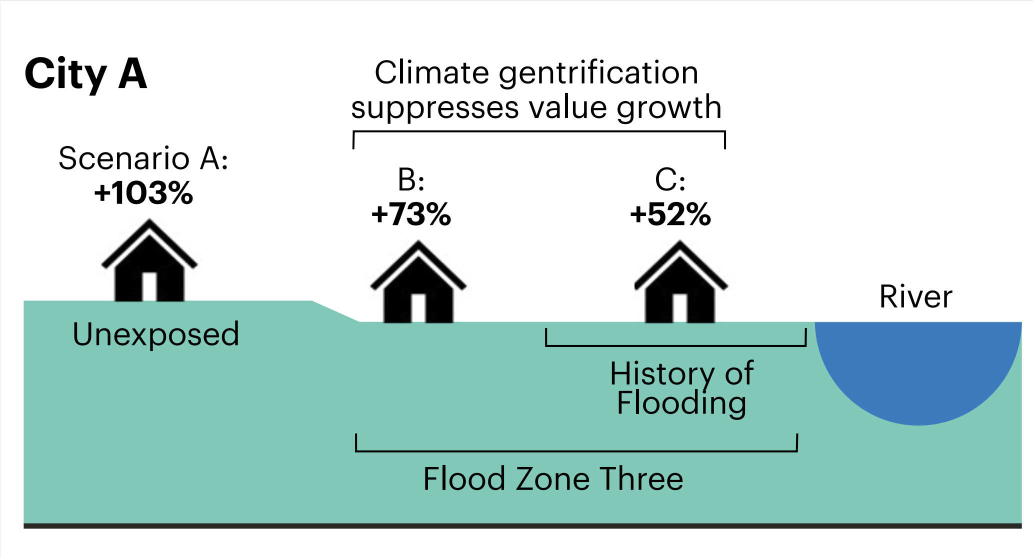
This is leading to a process of urban area selection where there is greater demand for properties possessing climate resilient traits (e.g. located at higher elevations). This is already driving up property prices possessing such traits, compared to properties more exposed and/or less protected against physical climate hazards that may experience discounted valuations. Climate gentrification describes this process of area selection and the collective effects of individual and collective investment responses to physical climate hazards (e.g. flooding and wildfires) in residential and commercial housing markets.

To demonstrate climate gentrification in action, we conducted a case study on a flood prone UK city. By using publicly available data a simple repeat-sale hedonic price model was developed to explore the effect of flood zoning and flood history on changes in property prices at the postcode level. Three scenarios were used to analyse changes in property prices (see Figure 1). We show that just by being located within Flood Zone 3 (defined by the Environment Agency as land with a 1 in 100 or greater annual probability of river flooding) on average, results in a price difference of 30%, relative to properties that are unexposed. This price difference is further exacerbated under scenario C, for properties that are located within Flood Zone 3, and have had a history of flooding.

Scenario A considers the change in price for properties unexposed to fluvial flood risk. Scenario B considers the change in price for properties located within Flood Zone 3 (defined by the Environment Agency as being land with a 1 in 100 or greater annual probability of river flooding).

Meanwhile, scenario C considers the change in property price for a property located within Flood Zone 3 and which has been flooded twice.

Fig. 1: **Climate gentrification in action within a flood-prone UK city. Results of the hedonic modelling show percentage changes in property prices in City A between 1995 and 2021 depending on location relative to fluvial flood risk.**



Source: Josh Thompson, Loughborough University

We aim to develop a forward looking analysis framework to understand how the effects of inland flooding (pluvial and fluvial) and coastal flooding, have on property prices, and how this may change under projected storylines of climate change. In addition, we aim to investigate ethical considerations that should be considered in parallel to the due diligence on evaluating climate risk exposure.

Loughborough University

Loughborough University and Josh Thompson

The Department Geography and Environment, in the School of Social Sciences and Humanities at Loughborough University conducts cutting-edge research, working internationally with other researchers, industry and government to increase understanding of our rapidly changing planet. It is recognized for excellence and leadership across six interdisciplinary research themes: Cities; Children, Youth and Families; Climate-Water-Energy; Hydroclimate, Risk and Resilience; Migration and Nation; Understanding and Managing Environmental Change. PhD researcher Josh Thompson is conducting this research under the supervision of Professor Rob Wilby, and aims to develop statistical methods to analyze climate gentrification and develop a forward-looking analysis to understand how the effects of flooding on property prices may change under projected storylines of climate change.

Transport resilience and recovery strategies

Climate change is leading to an increasing frequency and severity of extreme weather events. This requires new techniques to be developed to ensure that both existing and new transport networks are resilient to changing conditions.

Recent research has been focusing on predicting climate hazards and analysing vulnerability of infrastructure systems using numerical models while overlooking the benefit of real-time operation and rapid recovery plans.

Moreover, as trends in extreme events emerge, there is growing evidence that these hazards are already having a direct monetary effect on people's lives, travel, and even property prices. This leads the to consider travel convenience and urban area selection. How to achieve the resilience of transport networks in the face of potential climate hazards is an urgent and important issue for managing insurance risk and resilience.

When facing the pressure of natural hazards, what is the first step toward creation of a resilient road network? What analytics might we need to develop advice to enable corporate, finance and public sector institutions to embrace the climate decade ahead.

This project will include solutions to reduce risks and arrange insurance and alternative risk transfer programmes across public, private and mutual sector companies.

This will help to direct sustainable and resilient investment thereby integrating climate risks into mainstream investment decision making, including portfolio allocation and asset valuation

For this research project, we will seek to understand to what extent it is realistic, with innovative approaches, to determine the resilience evaluation of road networks. Furthermore, it will help us to decide what further research will be needed for developing this solution, first as proof of concept, and then in subsequent commercial and public sector applications.

The project will work toward development of a topology-based evaluation approach of resilience on urban road networks against floods. As a result, the aims of this project can be summarized as follows.

- To conduct an in-depth assessment of resilience on urban road networks against floods;
- To perform comparative studies between the static and dynamic recovery strategies and quantitatively reveal the effectiveness and shortcomings in terms of the performance restoration.

This research project is made with a combination of literature review/interview and approach/demo development. The outputs of this project will include conducting a simulation-based comparative investigation to understand the effects of floods and the recovery processes on urban road networks. This will be followed by the development of a topology-based evaluation approach of resilience on urban road networks against floods. Additionally, we will comparatively analyse the performance of urban road networks under two recovery strategies, namely the "First-Close-First-Reopen" recovery strategy and the dynamic recovery strategy. Finally, we will develop an illustrative case study based on London area. We will consider the system-of-systems level to cover related traffic alternatives, e.g., roads, rail, cycles, airplanes etc.

UCL

Qiuchen LU, MPhil Ph.D. MCIOB A.M.ASCE. Associate Professor in Digital Built Asset and Facility Management The Bartlett School of Sustainable Construction, University College London, UK. Director, Construction and Real Estate Division, UCL Centre for Blockchain Technologies

Dr. Qiuchen Lu is an Associate Professor at The Bartlett School of Sustainable Construction (BSSC), University College London. Her research team facilitates the transformation of built environment towards the '3S (Smart, Sustainable, reSilient)' future through digital technologies such as twins and AI. Towards 3S future of built environment, she has established a completed story of Digital Twins in the Built Environment, including creating the geometrical digital twins, exploring research and implementation of digital twins and building new values of digital twins from building to city levels. As the lead and first author, her work was published as the very first book related to digital twins in the built environment: Digital Twins for the Built Environment: Fundaments, Principles and Practice. Before joining UCL, she was a research associate at the Institute for Manufacturing, affiliated to the Centre for Smart Infrastructure and Construction and Centre of Digital Built Britain (CDBB), at University of Cambridge.

Her research team secured research grants as PI/Co-PI through the EPSRC and ICE to build smart and resilient city building and infrastructure systems, including 'evaluation of resilience on urban road networks against epidemic spread', 'investigating the impact of adding new airline routes on air transportation resilience'. Her international reputation has been built on effective collaboration with an extensive network of academics and industrial practitioners. She was elected to be the Committee Chair of 30th European Group for Intelligent Computing in Engineering (EG-ICE2023) International Workshop, and will host the EG-ICE2023 at UCL with Cardiff University. She also sits on the European Committee of Young Experts in China Highway & Transportation Society, and is a Committee Member of ASCE Global Centre for Excellence in Computing and ASCE Data Sensing and Analysis Committee.

Tailings Storage Facilities

Recently published standards are a step in the right direction but there is more to do.

Tailings Storage Facilities (TSFs) rank among the largest engineered structures on earth and are required to store mining waste after ores are extracted. They are usually embankment dams made from locally won materials and thereafter the tailings are used in construction. Mine tailings are pumped or deposited into the sites as a slurry and are composed of fine silts and sands which can be toxic or radioactive.

The World Bank[1] acknowledges that the need for electrification of sectors and clean energy generation means a more mineral intense future than would be the case in a fossil fuel economy. More marginal ores are being exploited, generating more tailings in relation to the amount of ore won. After accounting for recycling, it is anticipated that the volume of tailings will increase by 26% over the next 5 years[1].

Failures of TSF can be catastrophic, leading to serious loss of life and extensive pollution, killing rivers and blighting landscapes to a point where remediation is prohibitively costly. Together with regulatory penalties and litigation, this has adverse effects on public perceptions of mining and investor confidence.

The life of a TSF starts in the operational phase where, after initial design and enabling works, the retaining embankment is progressively raised to store increasing volumes of waste. At the end of operational phase, the asset should be made safe for the remainder of its life. According to the International Commission on Large Dams (ICOLD), the post closure phase should be considered to last in perpetuity, during which the asset should function as an inert landscape feature.

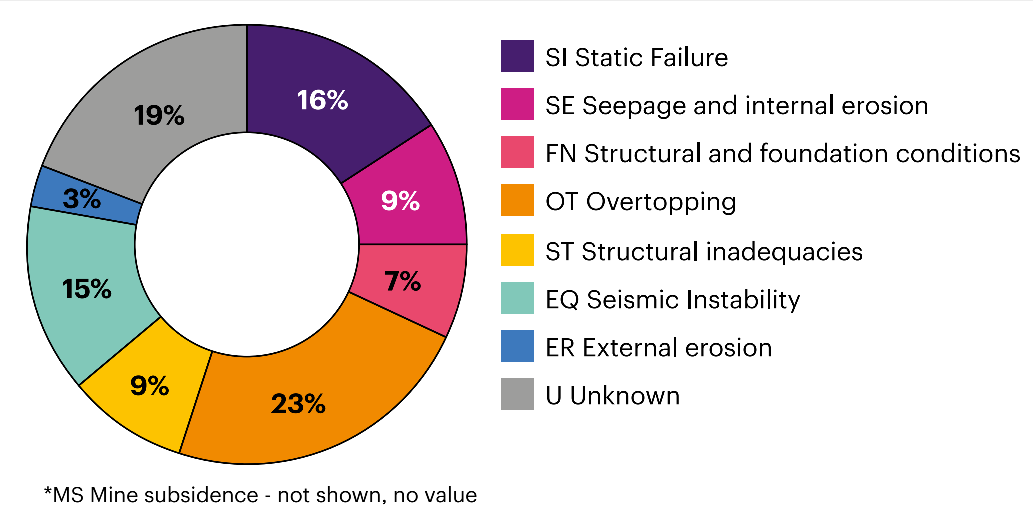
Records of the number and type of TSF are known to be incomplete, as are statistics on the causes of failure. Attempts have been made over the years to catalogue active and post have contributed to the understanding of the number and location of TSF But the picture is still hazy. In terms of describing the mode of construction or changes in asset condition.

There have been several other notable failures in the last decade. As a result, investors have encouraged operators to update standards and working practices. The outcome of this process is the 2020 Global Tailings Review. It has resulted in the publication of the Global Industry Standard on Tailings Management[3] (GISTM). A recent publication in Nature[2] of the data compiled during the production of the GISTM notes that 10% of all tailings facilities have reported a stability issue.

[1] Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition. 2020 International Bank for Reconstruction and Development / The World Bank

[2] Global Industry Standard on Tailings Management 2020. https://globaltailingsreview.org/global-industry-standard/

Fig. 1: **Leading Failure Modes of TSF**



Source: Global Industry Standard on Tailings Management 2020.

We all learn from our mistakes and, in dam engineering, this is especially true. A recent paper[4] analyses the statistics of TSF failure (Figure 1). Among the paradigms of a high risk TSF is of an operational facility using upstream construction. Given the dynamic nature of the operational phase, it is unsurprising that 90% of failures occur during this period. The causes of failure can be split into several categories but broadly the top three are driven by water-related issues, structural inadequacies or seismicity. As a side note the proportion of 'unknown' causes is a telling reflection of the historical quality of record keeping. Whatever the cause of failure, commentators universally identify that poorly developed ways of working with inadequate engagement and supervision at a senior level amplify risks and allow the indicators of failure to go unaddressed.

ICOLD Bulletin 139 "Improving Tailings Dam Safety" (ICOLD, 2011) is under review and is likely to strengthen recommendations around accountability, responsibility and competency. It should also be noted that the standards the GISTM suggests are often exceeded by standards set within national jurisdictions. These local standards are set according to each society's tolerance of damage or loss of life. Standards in GISTM are more tolerant of risk and puzzlingly refer to lower standard during construction when failure is most likely.

[3] Tailings facility disclosures reveal stability risks, Daniel M Franks, Scientific Reports, Nature Portfolio 2021. https://doi.org/10.1038/s41598-021-84897-0

[4] A new look at the statistics of tailings dam failures; Luca Piciullo; Engineering Geology 303. https://doi.org/10.1016/j.enggeo.2022.106657

We are already experiencing the impacts of climate change. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6)[5] states that there is high confidence that recent heavy rainfall events that lead to catastrophic flooding have been made more likely by climate change.

Though there is uncertainty, extreme rainfall events which might cause a TSF to overtop are becoming more likely. In the UK, there have been 20 instances since the year 2000 where the design precipitation for reservoirs has been exceeded. This puts a designer in an uncomfortable position where there is significant uncertainty for an asset that has a long lifespan.

The WTW Research Network is providing advice to clients through our academic linkages and in-house expertise. We will work through fault tree analysis to understand failure modes and breach sizes before we develop a CityCAT module tool to simulate how run out of viscous tailings might propagate. and visual wavebands is maturing.

As an underlying theme to technical drivers, the academic and technical literature agrees that risks are reduced where three steps are put in place:

1. Improved monitoring helps to identify crises soon enough to take remedial action. The offerings of in-situ and remote monitoring systems that can detect changes in position and moisture content remotely using Synthetic Aperture Radar and visual wavebands is maturing.

2. A well developed and exercised emergency plan might avert failure and /or mitigate impacts.

3. Neither though are of much use without strong organisational capabilities and corporate accountability to strengthen assurance.

[5] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32, doi:10.1017/9781009157896.001

https://medium.com/illumination/new-international-esg-regulatory-proposals-in-a-nutshell-744f212dc34d

https://www.churchofengland.org/about/leadership-and-governance/church-england-pensions-board/pensions-board-investments/investor

https://www.churchofengland.org/news-and-media/investors-commit-further-action-mining-2nd-anniversary-brumadinho-tailings-dam

https://www.bhp.com/-/media/documents/environment/2019/190607_coe.pdf

Underwriters, investors and operators would do well to ask a few more searching questions as to how portfolios of these assets are designed and managed.

While the GISTM was an important step toward international tailings dam regulation, some questions remain unanswered.

- Why are standards lower during the riskier construction/operational phase?
- Why is it that the GISTM standards are lower than those used for reservoirs in general. This is especially pertinent as the failure rate of TSFs is already about 100 times higher than for water supply reservoirs and because of pollution risks relative harm is magnified.
- GISTM standards are often lower than those in national jurisdictions. This could place a corporation in a tight spot if a liability arose in one country and was brought to trial in the jurisdiction where the company was listed.

These questions come at a time when governments[6] and regulators[7] are looking to ensure that ESG (Environmental, Social & Governance) labelling has real meaning.

[6] https://www.gov.uk/government/speeches/finance-resilience-net-zero-and-nature
[7] https://medium.com/illumination/new-international-esg-regulatory-proposals-in-a-nutshell-744f212dc34d

Benefits and costs of Nature Based Solutions

Humanity is developing at an astonishing rate, with the population of the globe recently assessed as having passed 8 billion in November 2022[1]. The trend toward living in urban environments is also accelerating with over 65% of people projected to be living in cities after 2050[2]. For most this means striking improvements in prosperity, but there are significant downsides.

Our urban environments are imperfect; 58% of cities are prone to at least one kind of natural disaster[2]. They may overheat or flood and, with the effects of climate change, the burden of drought and disease are putting the provision of food and health services under stress.

The built environment itself often amplifies natural hazards. Hard surfaces contribute to urban heat islands, accelerate run off during rainstorms and contribute to reduced water quality. The construction materials we use also hasten climate change and the amounts of materials we are using is accelerating. Globally cement comprises 8% of global emissions[4]. Between 2011 and 2013, China poured more cement than the US in the entire 20th century[3].

We are exceeding the capacity of the natural environment to carry us and have to modify our behaviours so as to close the loop on our impacts. We need to remember that there is no economy without the ecosystems which give us life support. The pressing need to find sustainable solutions is being played out in recent deliberations like the talks at COP15 and COP27.

Nature Based Solutions (NBS) have the potential to answer some of these questions and mitigate many of the pitfalls of traditional engineering. There are a wealth of different takes and names for what comprise NBS. Essentially, they all seek to provide services using natural and sustainable habitats. These challenges might include but are not limited to flood management, clean water, disaster risk management or food, sometimes all at once.

[1] Population United Nations Department of Economic and Social Affairs, Population Division (2022). World Population Prospects 2022: Summary of Results. UN DESA/POP/2022/TR/NO. 3.

[2] Urbanisation 2,3 Gu, Danan (2019). Exposure and vulnerability to natural disasters for world's cities. United Nations, Department of Economics and Social Affairs, Population Division, Technical Paper No. 4.

[3] USGS Cement Statistics 1900- 2012; USGS, Mineral Industry of China 1990 – 2013.

[4] Ellis, L. D., Badel, A. F., Chiang, M. L., Park, R. J.-Y. & Chiang, Y.-M.Proc. Natl Acad. Sci. USA 117, 12584–12591 (2020).

For example, under the guidance of the University of Arizona, the city of Tucson is buying up flood prone lots and converting them into combined play areas and flood ponds, incidentally enhancing recharge in an arid region. Across Australia urban authorities are collaborating to form the Australasian Green Infrastructure Network. One of their aims is to establish city planning practices encouraging the adoption of green walls, roofs and facades to mitigate extreme heat and flooding.

Alongside city scale interventions governments are changing their approach and developing standards and guidelines. In the UK CIRIA C802 2022[5] sets guidelines for fluvial flood managers. A number of jurisdictions (especially UK, Netherlands, US and Canada) have cooperated in the production of the USACE Natural and Nature based solutions Guidelines 2021[6] and the University of Waterloo in Ontario has published guidance which is due to be adopted in Canada.

Some interventions like the use of willow spilling to manage riverine erosion are ancient and nearly lost crafts. Many measures are effective and frequently used. But we live in an age where the quantification and the measurement of benefits for business case development are paramount to the selection of preferred options and the understanding of risk.

[5] https://www.ciria.org/CIRIA/Navigation/Events/Event_Display.aspx?EventKey=E22710

[6] https://ewn.erdc.dren.mil/?page_id=4351

Nature based solutions are enticing but often struggle in the face of quantitative cost-benefit analysis. Not because they are ineffective but because it is complex with natural systems than engineered solutions where cost-benefit appraisals are more easily applied. This can act as a barrier to proposing and implementing NBS.

Sometimes though the benefits are well described, within the USACE guidelines the use of reefs to mitigate the affects of storm surges is illustrated as follows: Across 3,100 km of the U.S. coastline, the topmost 1 m of coral reefs prevents the 100-year flood from growing by 23%, avoiding flooding effects for 53,800 people (62% of the population in this 3,100 km of coastline), avoiding USD$2.7 billion in damages to buildings along this coastline, and avoiding USD$2.6 billion in indirect economic effects[7].

This kind of precision is very helpful to proponents of NBS and is more common with coastal flood management projects. Though there are exceptions the potential for fluvial flood management or water quality management are less clearly elucidated. Even with well understood topics the assessment of whole life costs and benefits and post implementation monitoring are acknowledged to need more research[7].

In fluvial contexts benefits are often harder to find, meeting societal expectations of flood risk reduction with NBS alone is often beyond reach of catchment based approaches. Land earmarked for use for flood management may be required for a range of other uses such as energy generation, food production or housing. Inland therefore NBS may be a component of overall land and water management activities.

Almost all NBS projects have extensive co-benefits perhaps to tourism, fisheries, water quality or in carbon sequestration. Like the intended benefits they are tricky to assess and require post construction monitoring to be assured of benefits realisation. There is a tendency for proponents of NBS to view proposed solutions through the lens of their discipline, seeking benefits from within their silo. This is often as a result of the behaviours of those who commission the primary purpose of projects. There are good examples of where this has been addressed at inception stage but there are barriers to best practice.

With more traditional NBS we should seek to improve ways of assessing projects. With more novel techniques there may be many more questions to answer.

[7] U.S. Geological Survey, 2021, Mineral commodity summaries 2021: U.S. Geological Survey, 200 p., https://doi.org/10.3133/mcs2021

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