Natural Environment Research Council

Scoping a Floods and Droughts Research Infrastructure (FDRI):

Report for the FDRI community

May 2020 to January 2022

Image credit: Nick Everard (UKCEH)

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British Geological Survey

Imperial College London

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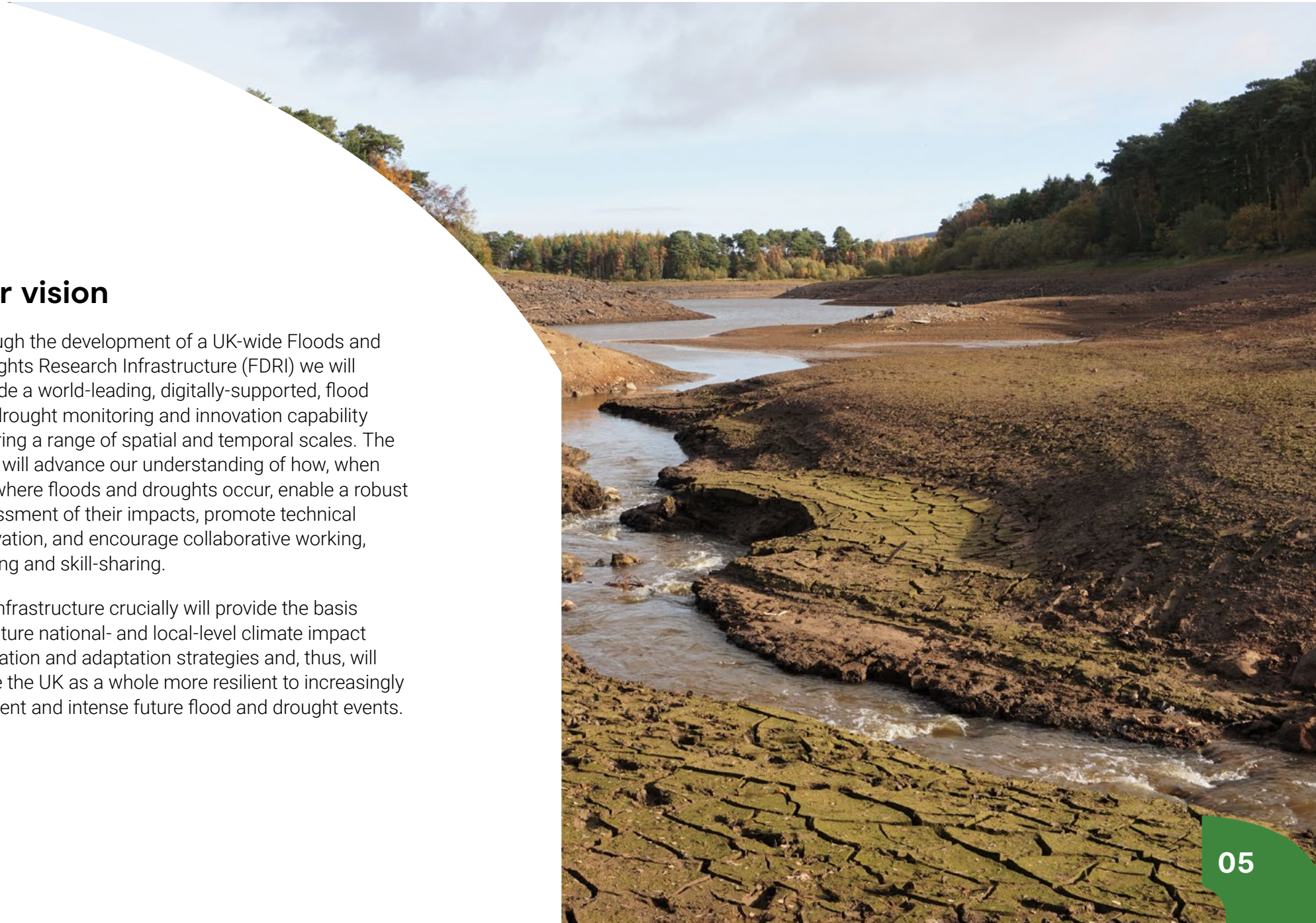
The challenge

Floods and droughts have the potential for immense destruction of homes, wildlife, businesses and infrastructures. They are predicted to increase in intensity, frequency and duration in response to changes in climate and human activity. In 2017, the second UK Climate Change Risk Assessment (CCRA) identified the impacts from flood and drought as two of the most important risks facing the UK in terms of climate change. The need for new science to underpin the UK's preparedness and resilience to these extreme events has never been more pressing.

Obstacles to flood and drought research

Many things have hampered the advancement of flood and drought research in the UK over recent decades. These include, but are not limited to: piecemeal data collection from a wide variety of disparate short-term studies in many different places, problems of sharing, accessing and integrating diverse datasets, inaccurate river flow measurement at the extremes (at times of high- and low-flows), limited support of technical innovation in the field, inadequate monitoring of important catchment processes at relevant scales, and a lack of cohesion and true collaboration across the UK hydrological community. An investment in catchment observing infrastructure would address many of these obstacles.



Our vision

Through the development of a UK-wide Floods and Droughts Research Infrastructure (FDRI) we will provide a world-leading, digitally-supported, flood and drought monitoring and innovation capability covering a range of spatial and temporal scales. The FDRI will advance our understanding of how, when and where floods and droughts occur, enable a robust assessment of their impacts, promote technical innovation, and encourage collaborative working, training and skill-sharing.

The infrastructure crucially will provide the basis for future national- and local-level climate impact mitigation and adaptation strategies and, thus, will make the UK as a whole more resilient to increasingly frequent and intense future flood and drought events.

Executive Summary

The frequency and severity of flood and drought events are increasing across the UK because of accelerating climate change. Improved understanding of these events is required to underpin better prediction, risk management and mitigation. Through providing the underpinning science, the proposed Floods and Droughts Research Infrastructure (FDRI), forms an essential part of the solution.

The need:

In its 2021 report, the Intergovernmental Panel on Climate Change (IPCC, 2021) concluded that there is high confidence that extreme precipitation and related hydrological extremes will increase. Floods and droughts already cause enormous economic, social and environmental impacts, which are projected to escalate in scale without evidence to underpin the UK's increased resilience to them.

According to the UK's own Climate Change Committee, current "progress with adaptation policy and implementation is not keeping up with the rate of increase in climate risk" in the UK (CCRA3, 2021). Urgent action is therefore required to build the UK's resilience to future floods and droughts for us to minimise their potentially catastrophic impacts. Key to building our resilience is developing a far better understanding of how flood and drought events happen so that we can improve the models we use to predict when and where they will happen and how severe they will be.

The solution:

To address this need, UKRI-NERC commissioned a scoping study, to investigate the requirements for a Floods and Droughts Research Infrastructure (FDRI) that would be capable of delivering a step-change in research capability and world-leading science, and which would lead to the UK becoming more adaptable and resilient to floods and droughts.

The FDRI will provide the data that we need to improve our understanding and, ultimately, our model predictions, which will make the UK more resilient to future floods and droughts.

This scoping study was led by the NERC supported research centre: the UK Centre for Ecology & Hydrology (UKCEH), in collaboration with the British Geological Survey (BGS) and two leading UK universities: The University of Bristol and Imperial College London. The study was advised by an independent steering committee formed of experts.

Comprehensive stakeholder consultation involving 749 people from academia, industry, UK environmental regulators and government, has been fundamental to the scoping of FDRI. Stakeholder requirements have informed, and will continue to inform, the design of the infrastructure.

The community-driven FDRI design consists of a UK-wide catchment-scale hydrological monitoring and digital research capability, that combines field-based innovation testbeds with long-term integrated sensor networks, and mobile infrastructure available for UK-wide event response and ground truthing of new Earth Observation (EO) data.

FDRI will underpin enhanced resilience and adaptation to flood and drought events by facilitating collaborative science, transformative innovations in monitoring and data, and by providing a UK-wide capability to observe all parts of hydrological systems during extreme events. The new knowledge and understanding gained will lead to improved planning and management of extreme events through better prediction and mitigation. Although FDRI is primarily a research and innovation infrastructure to advance UK flood and drought research, it will also enable the engagement with other sectors and bring about additional commercial and public sector benefits.

This document outlines the approach of the scoping study, key elements of the resulting FDRI design, and illustrates how the FDRI will form a crucial part of the UK's solution to mitigating future flood and drought risks.

The scoping study concluded in January 2022. The findings and detailed evidence it collected will be used to inform opportunities to boost the UK's hydrological research and innovation capabilities, providing a long-term strategic approach to infrastructure. Further, targeted stakeholder consultation will be important during further infrastructure development and implementation stages.

Call to action

This is an exciting opportunity to shape the future of flood and drought research and improve the UK's resilience to extreme events. Anyone with an interest in hydrological science is encouraged to engage with the FDRI team to ensure the ongoing design and prioritisation of resources is optimised. Please go to the section 'How to get involved'.

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Introduction and context

Flood and drought science

Floods and droughts are complex phenomena driven by transfers of water between the atmosphere, land-surface and sub-surface and these interconnected processes operating over multiple time and space scales are not yet fully understood. The economic, social and environmental impacts of flood and drought events provide us with a diverse stakeholder community, and partnership working is therefore required to understand these events, manage risks and inform policies. However, existing monitoring and data capabilities do not meet the requirements of the UK research and innovation community in addressing these knowledge gaps, and research is often undertaken in a piecemeal way by research groups focused on short-term projects with unique specialisms. FDRI will address these knowledge gaps and challenges by providing new and easily accessible data from a flexible and connected infrastructure.

The FDRI community

We define the FDRI community as including all those with an interest in floods and droughts. It includes academics (from many areas of science e.g. hydrologists, engineers, ecologists, data and social scientists), industrial representatives (from a range of industries e.g. water industry, agriculture, instrument manufacturers), environmental regulators (e.g. Environment Agency (EA), Natural Resources Wales (NRW), Scottish Environment Protection Agency (SEPA), and Northern Ireland Environment Agency), devolved governments, third sector organisations (e.g. Regional Rivers Trusts, Flood Forums) and all citizens facing risks from floods and droughts.

Community consultation

With 749 people having been included in the scoping study, the community's involvement in the design of FDRI is internationally unprecedented. Community enthusiasm, and recognition of the need for the research and innovation that FDRI will enable, has been evident from the start. We recognise that the engagement we have succeeded with to-date is just the start of our co-creation journey. The design, implementation and running of FDRI necessarily will adapt and evolve in response to changing challenges and priorities and to do this we will need to continue to engage with the community.

Here is some feedback from community engagement including workshops and webinars:

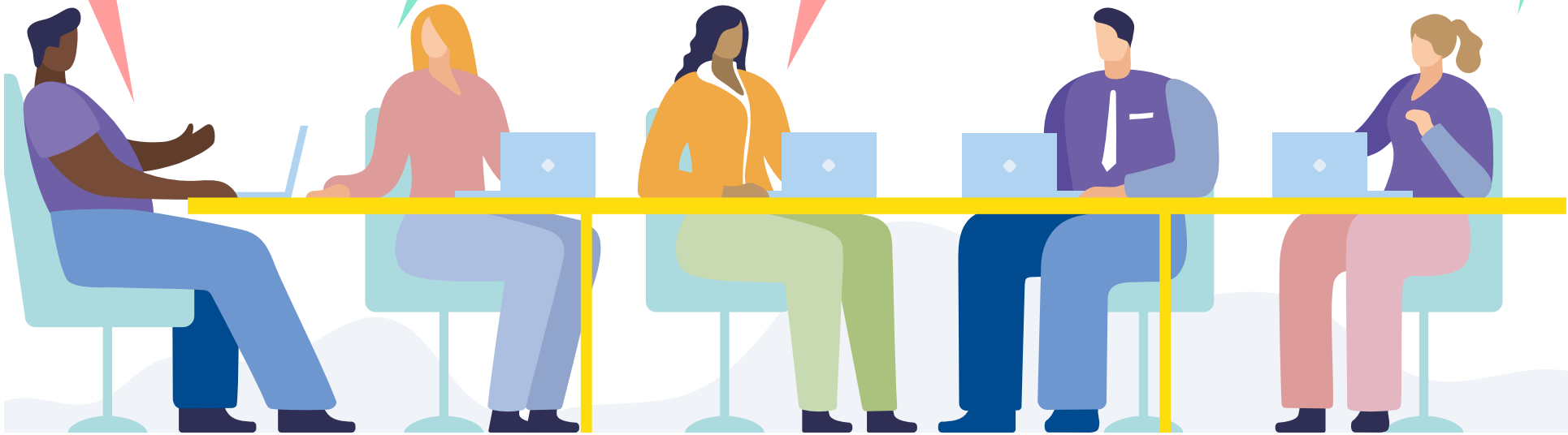
"Was impressed by the work of your team, not an easy task to keep all on board for such a long session."

"Useful discussion, better idea of the FDRI, made useful links with others"

"Many thanks for the most intelligent, analytical, credible & encouraging presentation on approaches to UK flooding I have encountered from agencies or authorities in the 12 months I have been in this role. "

"As company we are very excited to be involved in this."

"The workshop was beautifully orchestrated – encouraging open and friendly discussions – that critically delivered some great thoughts, strong examples and some essential specifics. I would suggest that the workshop (thanks to your preparation and organisation) has not only delivered helpful input to your ongoing bid development – but also strong community engagement by academics/practitioners in readiness for grant calls that would arise if the FDRI programme is funded. Thank you for the opportunity to be part of the process."



In recognition of the opportunity afforded by FDRI, members of the community expressed the following with respect to the initiative:

"There are so many specific research questions (i.e., floods and droughts, and dependent environmental processes) that could capitalise on such infrastructure."

"Currently there are no standard natural catchment test sites which routinely monitor flood and flow relevant metrics. Having these baseline datasets alone, for a range of catchment types would be transformative...Testbed sites could allow us to work more closely with manufacturers to develop bespoke sensing solutions."

A closer look at our proposed FDRI vision

FDRI will be an international exemplar for a community-designed flood and drought monitoring resource including state-of-the-art data capabilities with the overall aim of advancing understanding of these events; especially under rapid changes in climate, land use and water management.

For UK scientists, FDRI will help address critical research questions related to how, where and when floods and droughts occur and what quantities and quality of water are involved. This knowledge is urgently needed for improving flood and drought forecasts and selecting appropriate mitigation options. The new knowledge will allow the effect of uncertainties in hydrological measurements on model predictions and subsequent management decisions to be assessed.

FDRI will create:

- A **UK-wide community designed network of field sites**: digitally supported and intensively monitored. A unique **integration of fixed and mobile instrumentation** will meet scientific evidence needs for near real-time catchment-scale observations of extreme events from across all UK environmental settings and provide testbeds to develop innovative technologies.
- A **digital data capability** to provide a step-change in data discovery, access and integration (including third party data) which, in combination, will enhance the efficiency of scientific practice.
- A **governance structure and capacity building programme** to instil a strong culture of community leadership, multi-disciplinarity, and collaborative working with consideration for skills-sharing and training.
- An **innovation programme** that will be the cornerstone of UK hydrological research and training in support of the UK Government's Innovation Strategy.
- **A sustainable infrastructure** that is designed to meet net zero ambitions and has due consideration for minimising harm to the environment, providing a future for the next generation of hydrological researchers.

With these features, FDRI will contribute to the establishment of a much more integrated and innovative UK hydrological science community, providing major commercial and public sector benefits. Its long-term sustainability will be ensured through its support for innovation and its flexibility in responding to emerging challenges and opportunities for growth. An initial priority for growth will be increasing our understanding of flood and drought impacts. Although FDRI will provide a focus for and facilitate future flood and drought research, it will not obviate the need for short-term science projects in this field. Neither will it replace nor diminish the requirement for the continued, routine river network monitoring of the environmental regulators (EA, SEPA, NRW and DfIR). These practitioners will, however, benefit from the development and field-testing of innovative measurement technologies and digital capabilities.

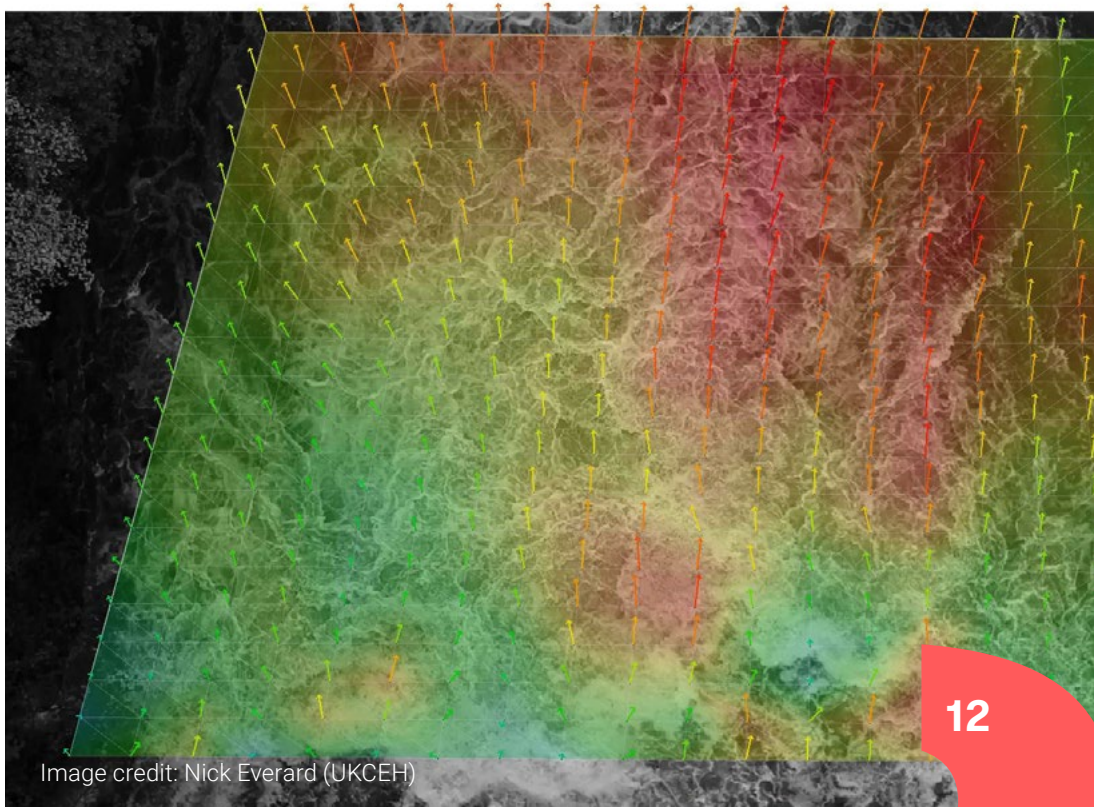


Image credit: Nick Everard (UKCEH)

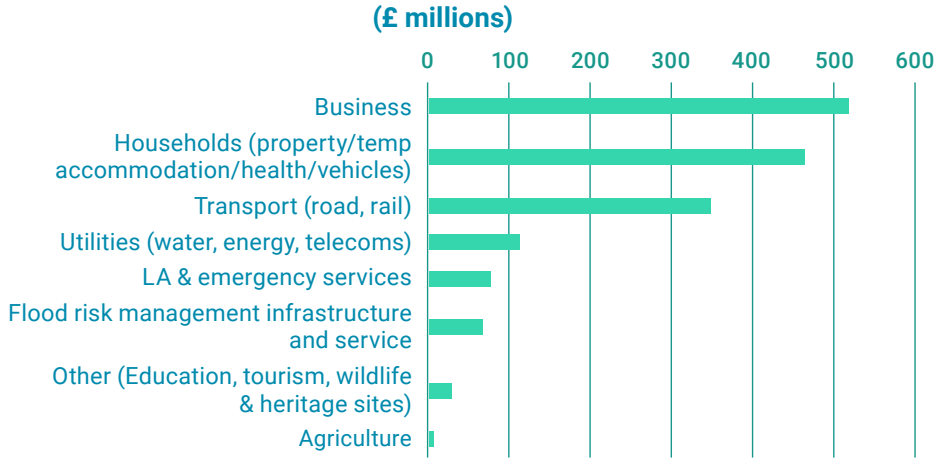
Strategic context

As stated in the second UK Climate Change Risk Assessment (CCRA2, 2017) 'The greatest direct climate change-related threats for the UK are large increases in flood risk and... shortages in water"

Earth's climate is warming, causing the frequency and intensity of flood and drought events to increase (CCRA3, 2021). These events cause significant environmental, social and economic harm. For example, within England, the winter floods of 2015 to 2016 caused £1.6bn in economic damage (Environment Agency, 2018), while drought during 2021 caused a loss in revenue of at least £165m (DEFRA, 2013).

Spiralling damages highlight with clarity that adaptation policies and their implementation in the UK are falling behind the rapidly increasing climate risks that cause higher frequency and intensity flood and drought events (CCRA3, 2021). In the UK, extreme hydrological events are one of the priority risk areas, because they already pose significant risks (including risks to the economy and environmental assets such as soils), which will increase under future climate conditions.

Financial investments in flood and drought mitigation and adaptation strategies are much lower than the potentially avoided damage to the economy, society, and environment; return on investment can be as high as 400:1 (Pappenberger et al., 2015). Such investments require an impartial and robust scientific evidence-base, which is highly dependent on factors such as policy processes and long gestation of engineering solutions. As the major bottleneck to research and innovation in hydrology has been identified as the scarcity of quantitative, high-resolution, and high-precision data, a new transformative, whole-system approach is needed. FDRI will enable novel, pervasive and full-scale catchment monitoring and data processing, components essential for generating the required evidence-base and informing adaptive flood and drought management (Beven et al., 2019; Future of Hydrology, 2020; and Wagener et al., 2021).



Economic costs of the winter 2015 to 2016 floods © Environment Agency 2018. All Rights Reserved.

Policy and government strategy

FDRI will capitalise on advances in digital and monitoring technologies, including advanced connectivity provided by new telecommunications. It will also build on and integrate other recent UKRI investments, such as the Cosmic-ray soil moisture monitoring network (COSMOS-UK) and the UKRI-NERC Digital Environment programmes.

FDRI will support existing policies including, but not limited to:

- **UK Climate Change Risk Assessment and National Adaptation Planning:** Floods and Droughts are identified as serious risks in the UK under climate change, with very high uncertainties. FDRI will provide data at high spatial and temporal resolution, allowing for improved predictive capability and forecasting.

- **Defra 25-year Environment Plan:** FDRI will support the UK government in meeting the need to "reduce risk of harm from environmental hazards such as flooding and drought". New science will inform the design of a new environmental land management scheme taking account of impacts on water in the environment at the catchment scale.

- **UK Governments Policy Statement and the Environment Agency's National (England) Strategy for Flood and Coastal Erosion Risk Management:** FDRI will provide support for the five specified policy areas through developing 'a holistic approach to [flood and drought] risk', through its interdisciplinary and community co-designed approach to working across the UK. In particular, research priorities identified through the UK Flood Hydrology Roadmap will directly benefit from FDRI.

- **Welsh Government:** FDRI will underpin policy and decision-making in Wales, supporting attainment of the goals of the 2015 Well-being of Future Generations (Wales) Act and the 2016 Environment (Wales) Act. A more resilient and a more equal Wales will benefit from a greater understanding of natural hazards such as floods and droughts.

- **Scottish Government:** The Scottish Government is delivering sustainable flood risk management and its Hydro Nation Strategy through developing "improved understanding of the … condition and functioning of Scotland's catchments". FDRI will support this work through its mobile infrastructure which will provide increased capacity to transfer data and knowledge across UK environmental settings.

- **Sustainable Development Goals:** FDRI has been designed with sustainability in mind and will support numerous Sustainable Development Goals including numbers 6: Clean water, 9: Industry, innovation and infrastructure, 11: Sustainable cities and communities, 13: Climate action, and 15: Life on land.

- **National Data Strategy (NDS) and Open Research Data Taskforce (ORDT):** FDRI's innovative approach to data standardisation and utilisation of novel technology will support the delivery of, and access to, high quality research data across domains.

- **UK Innovation Strategy:** Innovation field testbeds available for the community to test and develop technology will support inward investment, contributing to all pillars of the UK Innovation Strategy, and supporting the UK to become a global hub for innovation. This FDRI study was announced as part of the recent UK Innovation Strategy.

- **COP26 Goal 2: Adapt to protect communities and natural habitats:** FDRI will support the building of warning systems and resilient infrastructure through knowledge growth and improved predictive capability and forecasting.

- Digital advances will support UK policy ambitions such as the community-derived **UK Flood Hydrology Roadmap**, and national scientific initiatives such as **the British Hydrological Society (BHS) Working Group on the Future of Hydrological Research**.

Impacts

Research: FDRI will link monitoring with near real-time digital processing tools, and standardisation of regulatory monitoring data. The unprecedented quality of high-resolution hydrological data the FDRI will generate will enable new insights by combining measurements from a wide-range of environmental variables, enhanced scientific workflow efficiency, and agility of future research investments, enabling a step-change in catchment-scale understanding of floods and droughts.

Economy: FDRI will provide an impetus to the UK's economic leadership in flood and drought management, benefiting and facilitating cost savings for numerous sectors including construction, landscape management (e.g. green infrastructure solutions), insurance (e.g. risk assessment) and technology (e.g. environmental sensing). The infrastructure will provide a unique digital infrastructure and fully equipped field-based test sites for business-research collaboration, technical and commercial innovation, and inward investment to enhance prediction and modelling. Economic analysis has shown that similar past initiatives have created very high economic returns, for example digital flood estimation methods and data from NERC delivering benefits of £35M/year (NERC, 2014; Blackmore, 2018). By creating a step change in the availability, integration, accessibility, and analysis of hydrological data, FDRI is expected to multiply economic benefits.

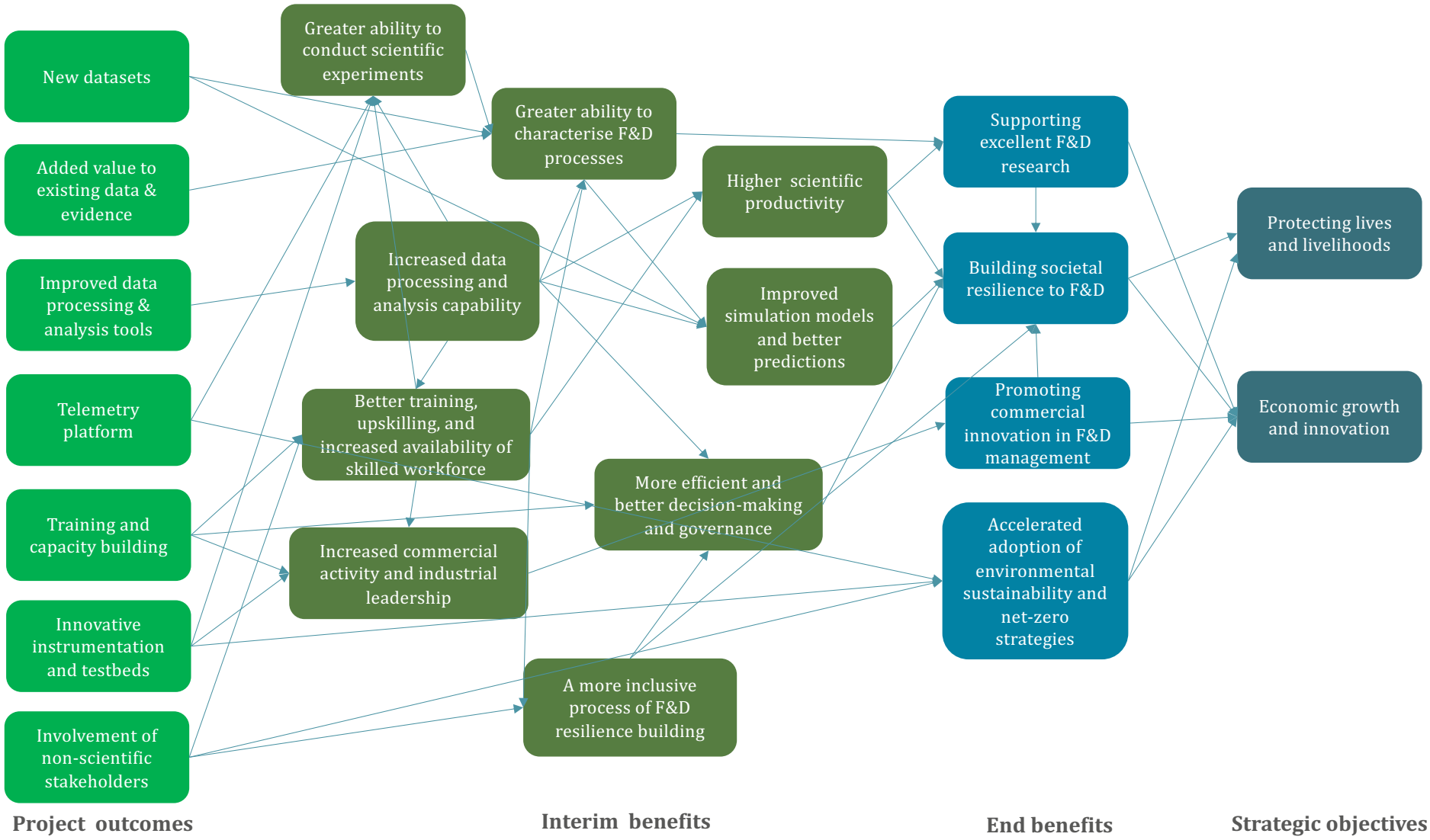
Society: FDRI will deliver benefits to the whole of UK society by reducing impacts of flood and drought events and building resilience. It will generate evidence to develop and benchmark environmental solutions such as resilient infrastructure, improve forecasting, and deliver new technologies for environmental and agricultural management. Social inclusion, knowledge co-creation, and local resilience will be promoted explicitly by engaging citizens in projects, community initiatives, and place-based research actions, enabled through FDRI's distributed catchments, regional connectivity and partnership working.

Environment: FDRI will contribute directly to UK Net-Zero and carbon budget ambitions in several ways, by:

- generating the knowledge-base to implement policy targets for the protection and restoration of freshwater and terrestrial ecosystems
- providing an evidence base to support the adoption of carbon saving flood mitigation options
- providing the capability for researchers to innovate and test new technologies and solutions for energy-efficient hydrological monitoring and analysis
- being built and operated as an exemplar of environmental sustainability, by, for example, investing in low-carbon sensor options and innovations (e.g. photovoltaics), electric vehicles and low-carbon building materials
- working with the NERC Environmental Data Service (EDS) to store/provide data in carbon efficient ways
- utilising existing monitoring infrastructure

In the long-term, FDRI will improve flood and drought prediction and inform climate adaptation strategies. This will have a positive long-term impact on the environment (e.g. reducing biodiversity and habitat losses, improving water quality and reducing public health risks, and impacts to farmland) strengthening the UK's position as an international leader in sustainable hydrological research.

FDRI outputs will lead to many specific benefits



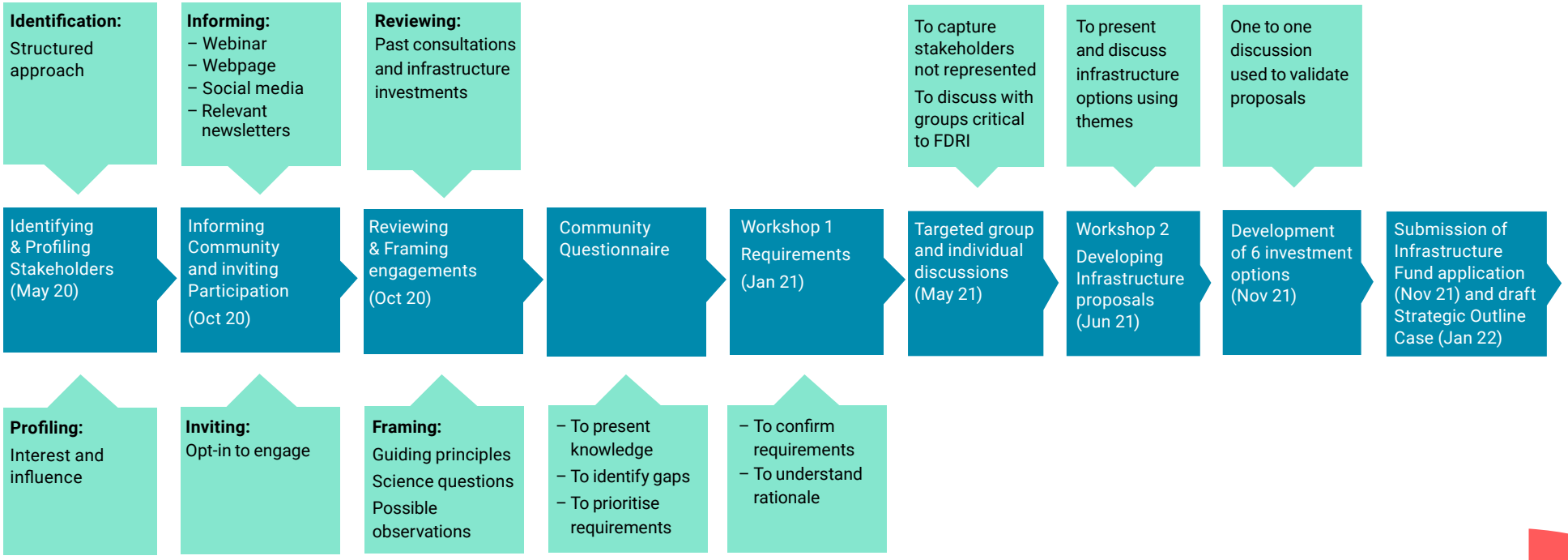
Stakeholder engagement

Wide community engagement was a key part of the FDRI scoping study. We adopted a robust approach, which included an intensive advertising campaign, a structured approach to stakeholder identification and a varied engagement strategy. We worked with key organisations (e.g. government agencies, devolved governments), learned societies (e.g. British Hydrological Society) and current hydrological initiatives (e.g. UK Flood Hydrology Roadmap) to identify stakeholders. Throughout all engagements, we aimed to eliminate discrimination, and promote equity and inclusion. This was achieved through diverse engagement activities, such as updates via email and the FDRI webpage, as well as interactive webinars, workshops and focus groups. Additionally, the project stakeholder engagement list was continuously reviewed to pro-actively identify under-represented groups and increase their representation.

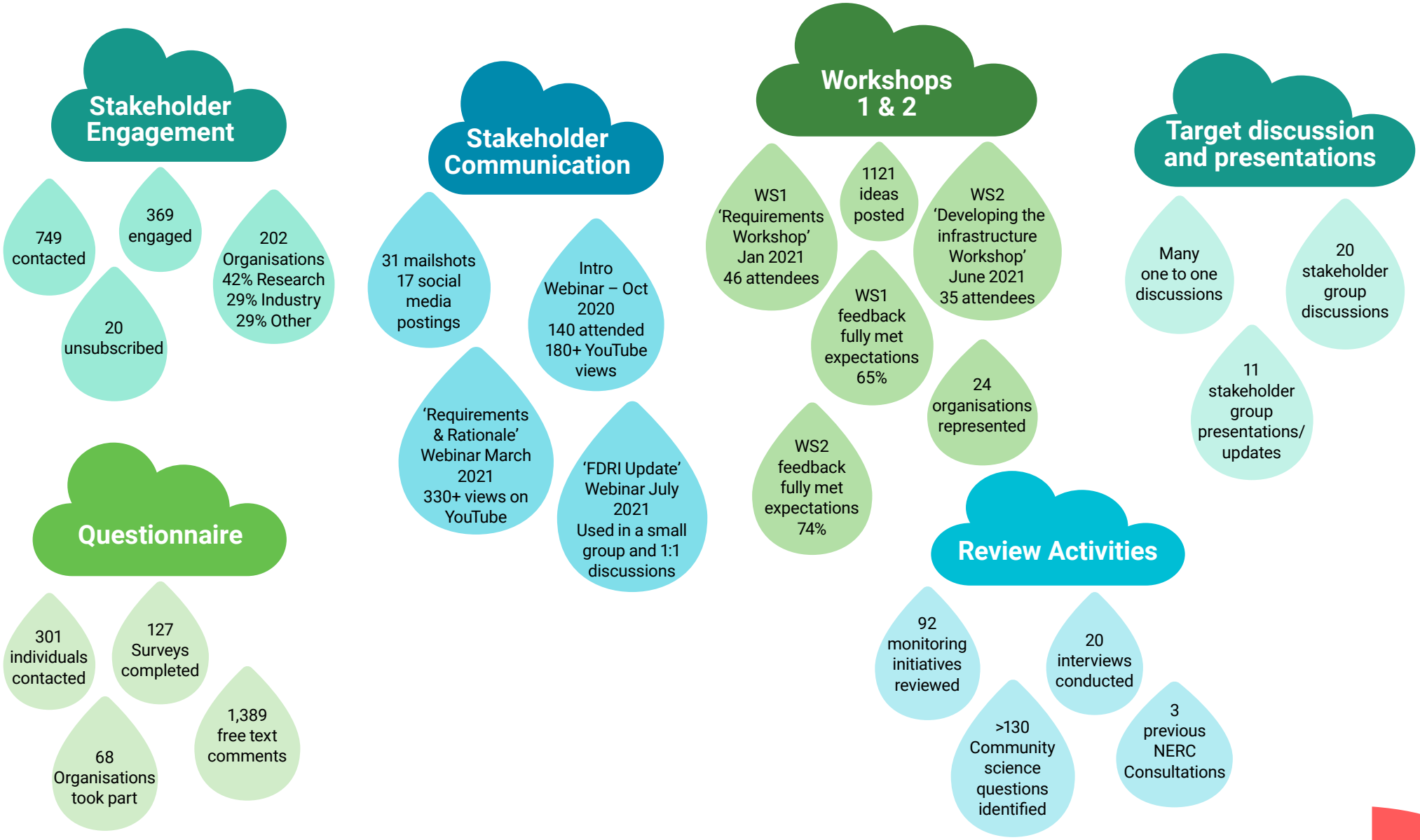
Twitter: **# FDR_NERC**

Email: **FDRI@ceh.ac.uk**

Web: **www.ceh.ac.uk/our-science/projects**



The raindrops in this figure provide metrics on each of our engagement activities:



The community thought the FDRI should:

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Science Case

Science Case

Challenge: Understanding and managing floods and droughts requires an investment in monitoring infrastructure.

Our solution: Next-generation long-term monitoring platform supporting flood and drought research, innovation and data services.

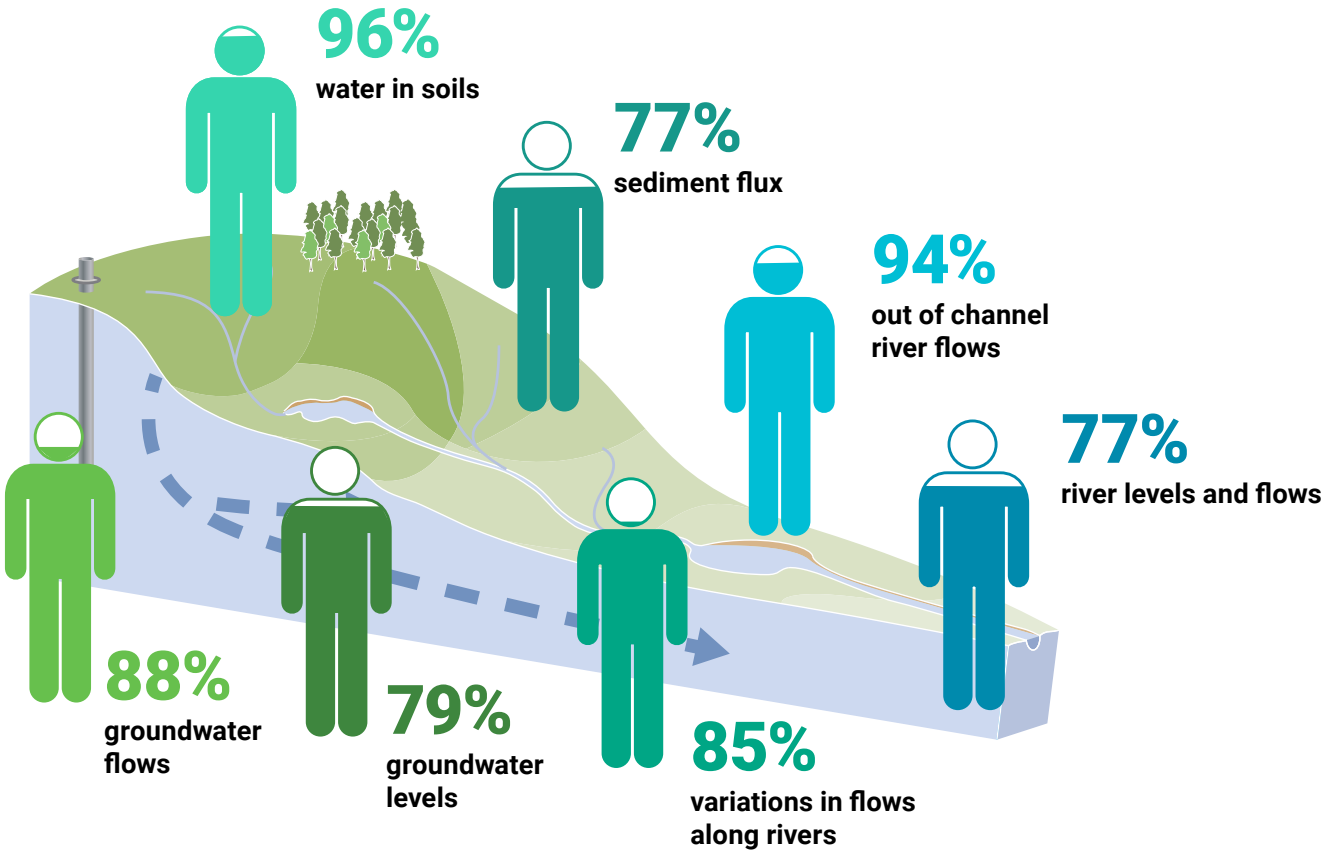
Approach to developing the science case

Building on previous UKRI-NERC consultations, recent community initiatives and lessons from previous monitoring programmes, our science case has been developed and informed by targeted consultations to identify and prioritise requirements. It articulates the importance of the science and identifies specific requirements of the infrastructure. The breadth of the science base that will benefit is considered as well as its contribution to international positioning of UK science. FDRI has been shaped by opportunities for technological innovation, knowledge and technology transfer, and will contribute to Net-Zero+ and sustainability targets. It provides an opportunity to enhance current hydrological monitoring networks and infrastructures, and the data they generate, to provide what is required by scientists to advance flood and drought research and understanding in the UK. Such an advanced, technically capable infrastructure would capture key variations at the extremes of the hydrological regime in the periods of highest (floods) and lowest (drought) flows and would be more capable of determining the effects of different catchment characteristics on flood- and drought-generating processes.

Science & Digital Requirements

The 127 community members who responded to the FDRI questionnaire thought, to better understand flood and drought processes, quantify hydrological extremes, and reduce the uncertainty in our ability to model and predict such extremes, we need more observations of:

- river levels and flows (77% of responders)
- out of channel river flows (94%)
- variations in flows along rivers (85%)
- groundwater flows (88%) and levels (79%)
- water in soils (96%)
- sediment flux (77%)

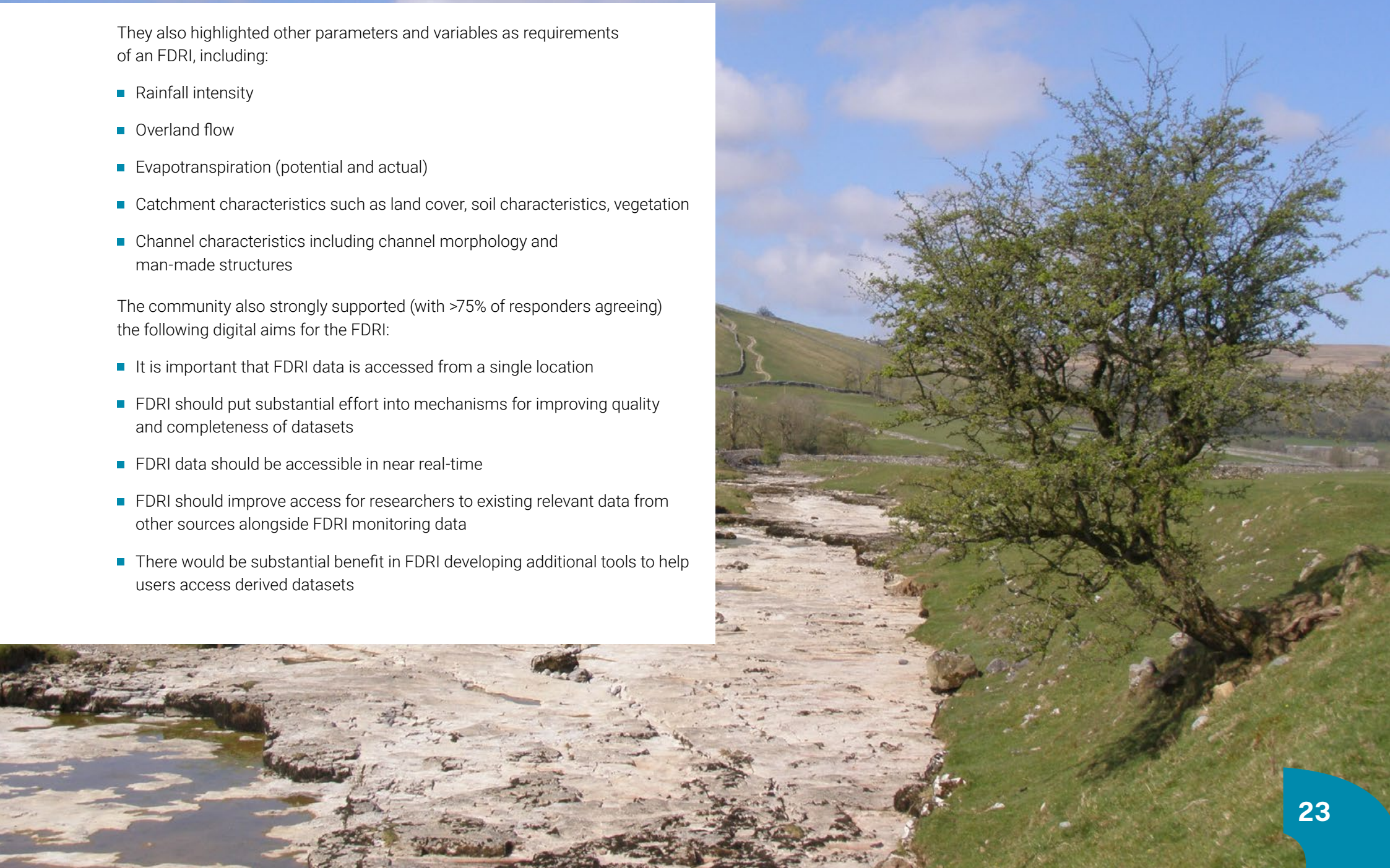


They also highlighted other parameters and variables as requirements of an FDRI, including:

- Rainfall intensity
- Overland flow
- Evapotranspiration (potential and actual)
- Catchment characteristics such as land cover, soil characteristics, vegetation
- Channel characteristics including channel morphology and man-made structures

The community also strongly supported (with >75% of responders agreeing) the following digital aims for the FDRI:

- It is important that FDRI data is accessed from a single location
- FDRI should put substantial effort into mechanisms for improving quality and completeness of datasets
- FDRI data should be accessible in near real-time
- FDRI should improve access for researchers to existing relevant data from other sources alongside FDRI monitoring data
- There would be substantial benefit in FDRI developing additional tools to help users access derived datasets



FDRI aims

Based on stakeholder feedback, the key science questions to be addressed by FDRI, and that are critical to making a step change in our understanding of floods and droughts, are

- What are the key flood and drought generating processes in different catchments?
- Where, and how, does water flow and get stored? How does water quality change during floods and droughts?
- How will floods and droughts change in response to changing climate, land use and water resource management practices?
- How can we improve the accuracy and lead times of flood and drought forecasts?
- How can we provide the data, often in near real-time, to address these questions?
- How can we increase the opportunities for new research using new digital technologies?

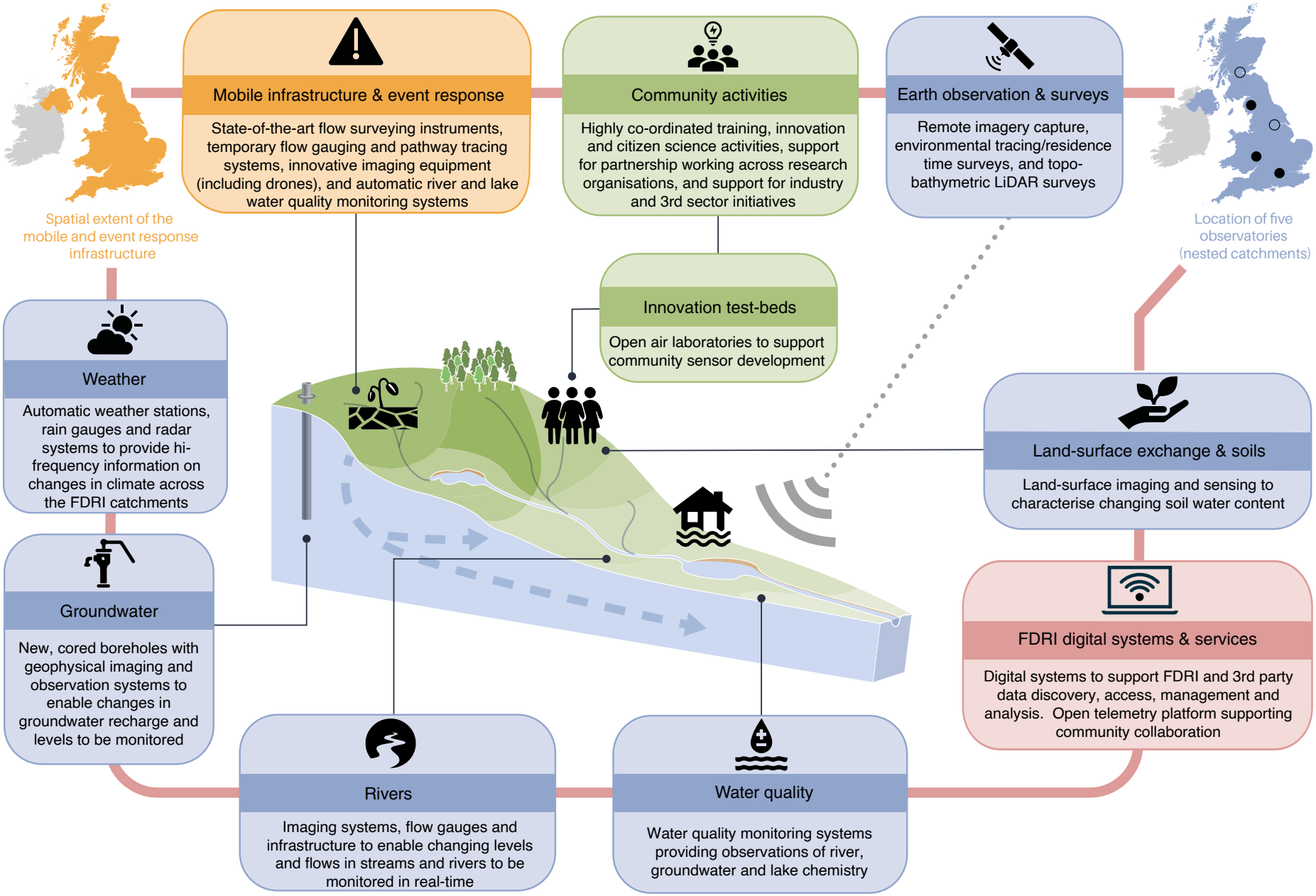
Following extensive community consultation, the FDRI will address these science priorities through its aims to:

- be a **community co-designed** resource meeting the needs of UK innovators and researchers (including, hydrologists, engineers, ecologists, and data and social scientists); involving the development of strong relationships with, for example, industry, regulatory authorities, government, academia and all citizens impacted by floods and droughts.
- provide a **UK-wide river basin scale infrastructure** investment that links hydrological monitoring with state-of-the-art digital capabilities; allowing transferability of knowledge across different UK settings to be assessed.
- **observe extreme flood and drought events** and respond to new challenges through implementing long-term co-located observations with the flexibility to accommodate new measurements.
- provide **campaign and extreme event observations across the UK** using rapidly deployable mobile instruments to respond and provide data in near real-time.
- provide knowledge with reduced uncertainty of entire hydrological systems (including atmospheric inputs, groundwater, and surface water) at scales previously not possible (i.e. river basins and beyond); enabling the development of decision support tools needed to **underpin evidence-based policies** made by environmental regulators **and decisions** made by industry.
- provide a **step-change in data access and the efficiency of scientific work** by supporting data integration and standardisation of third party and FDRI data, allowing for both high volume and quality data to be analysed across different scales, and at near real-time.
- provide unique, fully equipped and integrated **field-based testbeds** to support innovation in monitoring and digital capabilities; from lab-based concepts to research, development, deployment and adoption.
- facilitate **new approaches to collaborative working across disciplines including training and skills-sharing.**
- be scalable and capable of growing as funding becomes available and new requirements or technologies emerge.
- provide an **international exemplar** of the design and implementation of an integrated monitoring and digital facility in accordance with the **UK's carbon net zero strategy.**

The proposed FDRI will therefore augment existing monitoring and data infrastructures; providing a step-change in the study of catchment processes through:

- **Supporting** high quality hydrological monitoring across a diverse community of catchment-based interest groups to deliver further data to enhance evidence for flood and drought mitigation measures and enable greater research. It is planned that additional funding will enable programmes of work to support citizen scientists in contributing to local understanding and observations of extreme events.
- **Enhancing** the UK network of ~2,700 rain gauges to better capture spatial variations in rainfall in upland areas where 60% of river flow is generated and across catchments during extreme events to enhance understanding of flood dynamics.
- **Complementing** the UK's dense but operationally-focussed river flow observation network (>1500 stream gauges) to capture research-quality data across a range of catchment scales, and better integrate monitoring of the whole water cycle including evaporation, soil moisture and groundwater, to deliver increased understanding of hydrological processes.
- **Augmenting** the very limited extent of groundwater level observations in the UK which generally focus on deeper aquifers used for water resource management, to provide new information on linked groundwater – surface water systems, susceptible to hydrological extremes.
- **Capitalising** on advances in hydrological monitoring techniques and technologies including surface velocimetry, tracer applications, cosmic-ray and quantum soil moisture measurement techniques, UAV, USV and satellite mounted sensors to deliver new high temporal and spatial resolution measurements across the hydrological cycle.
- **Engaging** proactively with existing citizen science flood and drought initiatives and supporting and enabling new partnerships.
- **Revolutionising** the way hydrological data-driven research is undertaken by leveraging advances in computing infrastructure, comprehensive streams of real-time data, and data science developments.
- **Joining-up** capabilities across NERC data centres to support the creation and provision of interoperable, web-accessible data, in particular for hydrological sensor and monitoring data, to drive the digital transformation in hydrological research.
- **Integrating** comprehensive streams of high-resolution monitoring data from 3rd parties, including rainfall and flow data from UK measuring agencies, alongside new FDRI monitoring.
- **Innovating** through fully integrated field-based innovation testbeds for the development of new sensor systems, taking development from laboratory to field-scale to enable rapid increases in Technology Readiness Levels; enabling the novel study of catchment processes and data curation and / or analysis.
- **Delivering** long-term monitoring with a community-driven and adaptable configuration to meet evolving research needs and support the development of new monitoring techniques.

This figure illustrates the indicative FDRI infrastructure for one observatory hosting fixed infrastructure (listed in the rounded boxes), and is not an exhaustive list of all the infrastructure that will be included. The top right UK map illustrates proposed regions for FDRI observatories; three hosting fixed (solid circles) and two subject to targeted mobile (open circles) infrastructure. The top left map illustrates the UK-wide coverage of the FDRI mobile and event response infrastructure.

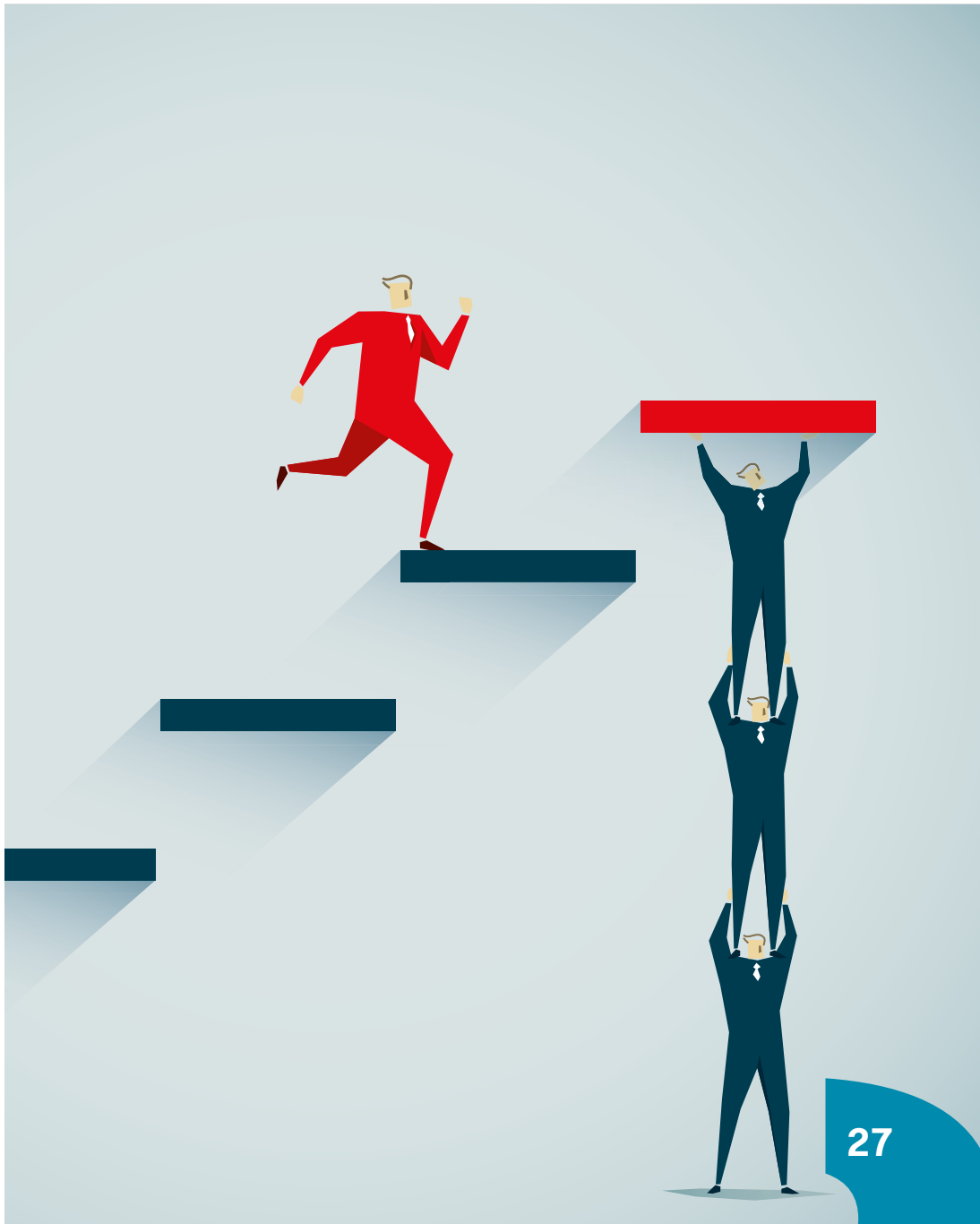


The new flood and drought science and monitoring capabilities provided by the FDRI will enable a step-change in UK research capacity. Rather than continuing to pursue piecemeal research into hydrological extremes across the UK or between sometimes poorly-connected disciplines and observational research teams, the FDRI will resolve this fragmented approach by providing an open, national research infrastructure; enabling community initiatives.

Beneficiaries and collaborative working

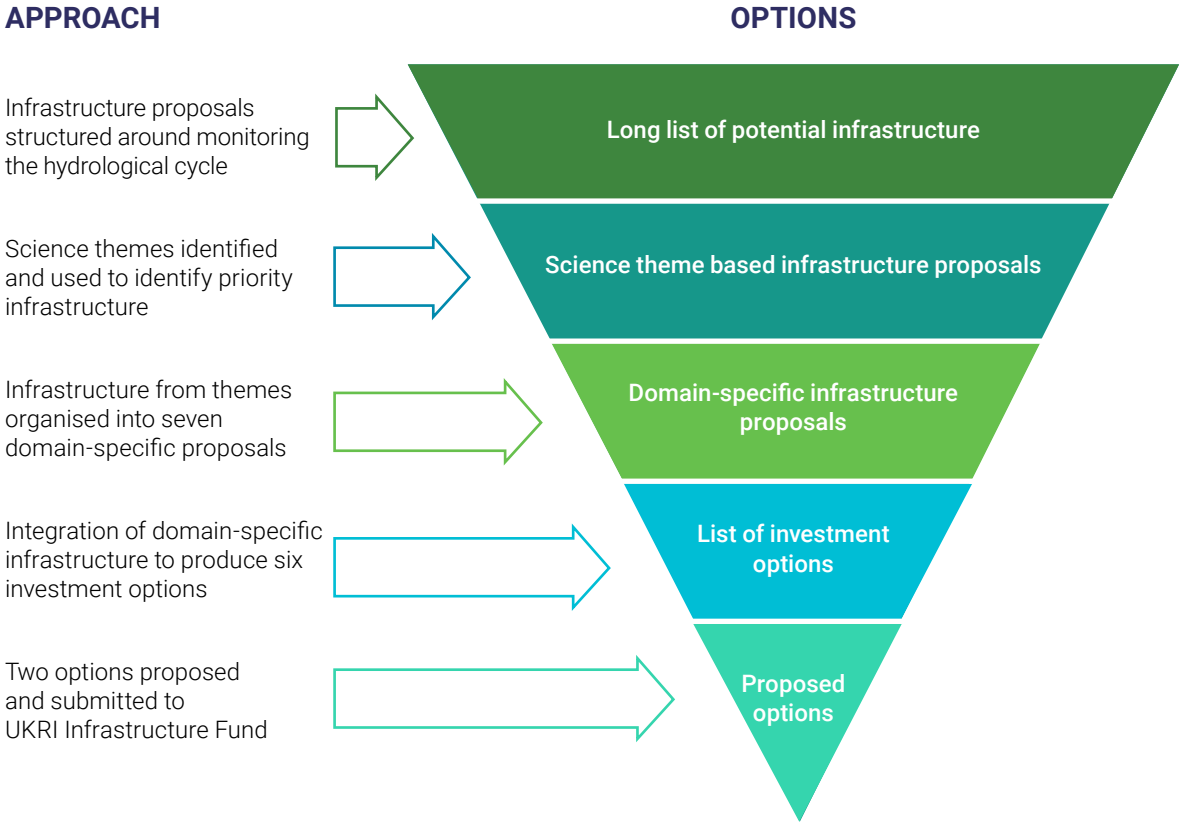
The UK plays a leading international role in many priority research fields, central to the management and mitigation of environmental hazards, including, for example, hydrology, and environmental technologies. All need robust data and process understanding from field-based observations. Through community working across multiple disciplines, from regional to the UK scale, important advances will be made in the science needed to address the FDRI research questions. Areas of science that focus on the impacts of flood and drought hazards will also benefit through further collaboration (e.g. sociology, economics, environmental science, and epidemiology). FDRI will have a global impact. It's exhaustive data (including standardised third party data) will be available globally in near real-time through NERC's Environmental Data Service; newly developed software routines, protocols and monitoring designs will also be made available in the public domain.

FDRI has drawn on lessons-learnt from similar-scale international initiatives such as Terrestrial Environmental Observatories (TERENO) and Modular Observation Systems for Earth Systems (MOSES) in Germany, and is actively engaging with similar overseas initiatives such as the Critical Zone Observatories (CZO) in the US to benefit from the mutual exchange of data, technologies, and experiences. By delivering the first nationally-coordinated integrated system of monitoring infrastructure dedicated to hydrological extremes, the FDRI will ensure that the UK is at the forefront of research infrastructure dedicated to addressing floods and droughts and the lessons learnt from this approach will be shared globally.



Infrastructure investment options

To ensure the FDRI investment represents a community co-designed initiative, infrastructure proposals (i.e. instruments, installations and digital functions) were developed from science questions provided by stakeholders and subsequently considered during community consultation activities; these aided the identification and refinement of our proposed infrastructure investment options.



Key questions used in screening infrastructure investment options:

- Will new scientific understanding with reduced uncertainty be provided to increase our resilience to floods and droughts?
- Will it be a nationally distributed investment, supporting collaborative working, with an event response capability?
- Will it support innovation and training?
- Will it provide results from diverse places with wide applicability?
- Will digital infrastructure facilitate hydrological workflows (data transmission, integration, processing and access)?
- Will community science be supported?

The project team balanced the community requirements with other budgetary and practical considerations to propose optimal investment options for the FDRI. Several options were developed to allow a flexible and scalable infrastructure.

Selecting infrastructure options

Following extensive community consultation on what the FDRI should comprise and aim to achieve, six possible options for its implementation were identified. The FDRI option designs have been driven by the community requirements identified through the 21-month consultation which included two stakeholder workshops, a questionnaire, targeted group discussions and many one-to-one conversations. The delivery team ensured the investment options provided a range of capabilities whilst meeting budgetary constraints, including a consideration of ongoing running costs critical to the financial sustainability of the investment. We have called the six identified options: Do Nothing, Do Minimum, Bronze, Silver, Silver Plus and Gold. The options that we feel most closely meet community requirements are the Gold and Silver Plus options. In both the Gold and Silver Plus options, five catchment-observatories (fixed instruments in three and mobile in others) are necessary to transform flood and drought research and innovation capacity; the capability of FDRI to deliver research and innovation scales with investment options.

What's included in the Gold option?

Observations:

- UK-wide, high quality, digitally supported, hydrological observations; observing all parts of hydrological systems (including novel measurements), and integrating fixed and mobile instruments. Enabling holistic understanding, change detection, assessment of uncertainty and transferability, and facilitating extensions to the core infrastructure.

Digital capability:

- Provision of web access for researchers to obtain, analyse and integrate near real-time data with uncertainty from FDRI and third parties. New tools will facilitate the adoption of innovations in monitoring and the use of new data streams.
- Enhanced functionality for NERC Data Centres; supporting data management, access and use.
- Plug and play telemetry and an open data management platform to support research and community monitoring initiatives and increase the quality, accessibility and long-term preservation of their data.

Innovation:

- Community engaged in innovation, links to external activities developed and an innovation pipeline established. State-of-the-art, fully integrated innovation field testbeds set up in three observatories.
- Selected high priority innovations implemented to accelerate increases in their Technology Readiness Levels (TRLs) (including novel applications of remote sensed imagery for soil moisture and river flows, use of rainfall radar and technologies for subsurface water flow monitoring).

Training and outreach:

- Training in UK regions with extensive web resources will enhance the monitoring and data skills in the community.
- Outreach and engagement activities will ensure the community is engaged.

3

Achievements and next steps

Achievements and next steps

This document has outlined our vision, approach to consultation and the science case for the proposed Floods and Droughts Research Infrastructure: an innovative and transformational research capability, designed to improve understanding, reduce risk of, and increase resilience to, flood and drought events across the UK.

While we recognise this is just the beginning of a path towards achieving the overall ambition of FDRI, the FDRI scoping study has widely consulted and initiated strong engagement across the community.

It has already delivered successful outputs including presentations, a publication in preparation, and an international publication in a peer reviewed journal:

Knowledge gaps in our perceptual model of Great Britain's hydrology (2021)
Thorsten Wagener, Simon J. Dadson, David M. Hannah, Gemma Coxon, Keith Beven, John P. Bloomfield, Wouter Buytaert, Hannah Cloke, Paul Bates, Joseph Holden, Louise Parry, Rob Lamb, Nick A. Chappell, Matthew Fry, Gareth Old
Hydrological Processes, e14288, https://doi.org/10.1002/hyp.14288

How to get involved...

This is just one step toward an exciting future of long-term flood and drought observations, supported by digital and innovation services for the next generation of hydrological researchers and innovators.

Do you want to be part of it?

We have discussed the project with a range of stakeholders on the need and requirements for change, agreed the options to take forward for quantitative assessment, and explored options for funding and delivery. Moving forward, we want to continue to work collaboratively with the community to develop this exciting project; this is important as there will be emerging needs of the sector and society and FDRI needs to be agile with capacity to grow and develop over time. Future work will be focused on, for example, the development of the Business Case, governance, procurement, monitoring and evaluation, and the determination of locations of observatories for the proposed infrastructure. These areas may be progressed using focus group discussions so please advise if you would like to be included. Your support is critical to the future success of FDRI.

If you wish to get involved or find out more about the project, please contact:

FDRI scoping study delivery group: fdri@ceh.ac.uk

NERC Capital team: capitalrequirements@nerc.ukri.org

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