CREW CENTRE OF EXPERTISE FOR WATERS

Centre of Expertise for Waters

PROGRAMME REPORT 2016–22

CREW CENTRE OF EXPERTISE FOR WATERS

Centre of Expertise for Waters

PROGRAMME REPORT 2016–22

Nikki Dodd, Rachel Helliwell, Bob Ferrier

Hydro Nation International Centre

The James Hutton Institute

Scottish Government
Riaghaltas na h-Alba
gov.scot

CREW CENTRE OF EXPERTISE FOR WATERS

Published by CREW – Scotland's Centre of Expertise for Waters. CREW connects research and policy, delivering objective and robust research and expert opinion to support the development and implementation of water policy in Scotland. CREW is a partnership between the James Hutton Institute and all Scottish Higher Education Institutes. The Centre is funded by the Scottish Government.

This document was produced by: Nikki Dodd, Rachel Helliwell, Bob Ferrier
Centre of Expertise for Waters
Hydro Nation International Centre
James Hutton Institute
Craigiebuckler
Aberdeen, AB115 8QH.

Please reference this report as follows: Dodd, N., Helliwell, R., Ferrier, B. (2022). Centre of Expertise for Waters Programme Report 2016–2022. Available online at: crew.ac.uk/publications

Dissemination status: Unrestricted

Acknowledgements: CREW would like to thank Scottish Government RESAS and all CREW Partners and wider stakeholders, Project Steering Groups, Research Teams and CREW team members 2016–2022 for their contributions to the content included in the Programme report.

Cover photographs courtesy of:
Left: James Hutton Institute
Centre: James Hutton Institute
Right: Digestors by Richard Webb, CC BY-SA 2.0,
https://commons.wikimedia.org/w/index.php?curid=9153664

Contents

1.0 **Directors Introduction** 1

2.0 **Executive Summary** 2

3.0 **External Context** 3

4.0 **Internal Context** 3

5.0 **Outputs and Outcomes** 4

5.1 **Supporting Policy and Practice** 4

5.1.1 **Stakeholder Engagement** 4

World Water Day events (2018–2022) 4

CREW COP26 activities 5

Water Wall in Motion: Uniting Communities Through Film 5

International Dissolved Organic Carbon workshop 5

International governance and management of small rural private water supplies 5

DEFRA Catchment Management Modelling Platform and launch event 6

Scottish One Health Antimicrobial Resistance Register (SOHAR) 6

Natural Flood Management Network and website 6

CREW stakeholder feedback, Impact Review, and theories of change 6

5.1.2 **Policy relevant outputs** 7

IUCN CREW River restoration and biodiversity report 7

Developing Scotland's Shellfish Water monitoring programme 9

Private Water Supplies and Climate Change 9

Private Water Supplies and the local economic impacts in Scotland 9

Assessing climate change impacts on the water quality of Scottish standing waters 10

Antimicrobial Resistance & Technologies for Monitoring & Treatment in Water 10

Influence of beaver activity on natural functioning & water resource management 10

COVID-19 surveillance: wastewater epidemiology 11

5.1.3 **Impact on policy** 13

Scotland's National Coastal Change Assessment: Dynamic Coast 13

Long-term impacts of flooding 13

Pharmaceuticals in the water environment and the One Health agenda 16

Radon in groundwater drinking water supplies in Scotland 17

5.1.4 **Benefits to other stakeholders** 17

Valuing your Soils 17

Rural Sustainable Drainage Systems design and build guide 19

Climate change and risk to water resources in Scotland 20

North Glasgow Integrated Water Management System 20

Surface water flood forecasting for urban communities 21

Handbook of Catchment Management 21

5.2 **Collaboration and Multidisciplinary Working** 21
Centres of Expertise and Sefari Gateway 23
Yorkshire Integrated Catchment Solutions Programme (iCASP) 23
Scottish Universities Partnership for Environmental Research (SUPER) 23
Scottish Alliance for Geoscience, Environment and Society (SAGES) 23
Scottish Freshwater Group (SFG) 24
The UK Water Partnership 24
UK Water Innovation Strategy 24
Chartered Institute of Water and Environmental Management (CIWEM) and VIBES Scottish Environmental Business Awards 24
Hydro Nation International Centre 24
Hydro Nation Scholars Programme 24
Hydro Nation Water Innovation Service and links to industry 25
Hydro Nation Chair Research and Innovation Programme 25

1.0 Directors Introduction

I am very pleased to introduce this Programme Report (2016–2022) for the Centre of Expertise for Waters (CREW).

The Centre is an established and trusted knowledge broker, informing policy, agency and other stakeholders of current understanding and future expected changes across the water sector. All activities are supported by academic excellence and expertise from Scotland's Universities and Research Institutes. The Centre's "here-and-now" delivery is built on keeping pace with developing policy challenges and drawing on experts within the water community to deliver timely outcomes.

Globally, water resources are under extreme and increasing pressure from human activity, including climate change, increased urbanisation, over-abstraction, pollution, wider degradation, biodiversity depletion and loss of natural capital. These are globally shared challenges but expressed in different ways in different locations.

Water is at the heart of Scottish life- socially, environmentally, and in economic terms as a sector in its own right, and as a critical resource in Scotland's manufacturing, agriculture, food and drink, tourism and energy sectors. Scotland's "Hydro Nation" agenda supports the Government's vision as a world leader in the sustainable management of water. To deliver that vision we must ensure that the respected knowledge generated by research underpins our future. This ambition is central to CREW's values, which provides an important pillar to the agenda. Our underlying ethos has, and will continue to be, to deliver the right information to the right people at the right time, and in the right way.

Over the last six years, and as highlighted in this Programme Report, CREW has delivered more than 105 projects in the process of meeting its objectives of supporting policy and practice, and in delivering relevant outputs. We aim to achieve this through our core principles of; co-construction, communicability, trustworthiness, timeliness, supporting an inter-disciplinary vision, and focusing on impact, outcome and "value".

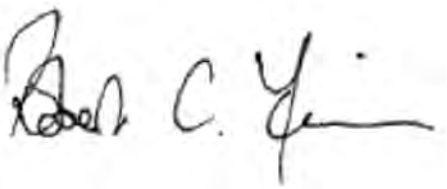
Latterly in this programme, we faced a global pandemic which underlined the need for rapid scientific advice and knowledge flow to policy, practice, and the public. Drawing on networks and partnerships CREW was requested to coordinate research in support of the "National surveillance programme for Covid-19 RNA in wastewater", acting as a focus for Scottish and UK partners to share updates on wastewater-based epidemiology (WBE) as the pandemic evolved. The value of this seamless delivery at such a critical time, exemplified CREW as a robust, resilient, and responsive Centre.

But we also continue to learn and improve. Reviewing and streamlining our quality management processes to meet sometimes rapidly changing user needs and improving and broadening our engagement with research providers. Our annual funding cycle does place practical difficulties in meeting the demands on new projects and this has required an extremely flexible approach to commissioning and delivery, supported by our diligent and highly motivated CREW Facilitation Team.

The professionalism and dedication of the Team must be acknowledged as critical to the success of the Centre. Working across numerous projects they balance the need for responsiveness to changing circumstances, whilst avoiding "mission drift" as knowledge and understanding evolves. These specialist skills must be both nurtured and developed.

There are many interesting examples of CREW's work throughout this report, and the team and all research partners are proud to highlight what has been achieved, and we hope you find it of interest.

Now more than ever, our most pressing challenge is to drive through a green agenda with water at its heart, and where sustainable development, a circular low-carbon economy, with increased public awareness and engagement, are the drivers for a more equitable society. Going forward, we look to the future challenges in support of the water sector and environment and our role in a Hydro Nation vision that encourages a Scotland that is green, just and sustainable.



Bob Ferrier

CREW Director

Hydro Nation International Centre

James Hutton Institute

2.0 Executive Summary

The Centre of Expertise for Waters (CREW) supports the Scottish Government, and delivery partners, to inform and steer water policy, by delivering objective and robust research and expert opinion. The Centre contributes to a range of Scottish/UK/EU policy development and implementation strategies, including the United Nations' Sustainable Development Goals, in particular Goal 6, for the provision of clean water and sanitation for all by 2030, and continues to serve Scotland's legislative Hydro Nation agenda.

In 2016–2022, CREW's broad thematic areas, linked to key policy areas in Scotland's water sector were: Flooding and Coastal Erosion; Sustainable Communities; Catchment Management; and Water Quality. CREW developed and managed 105 projects including high-impact projects on river restoration and biodiversity, National Coastal Change Assessment (Dynamic Coast) and long-term impacts of flooding on communities. CREW's dual funding stream (capacity building and call down projects) and the Centre's interdisciplinary reach have allowed the Centre to remain agile in responding to both emerging and developing policy areas, and urgent policy, regulatory or industry research needs. Notably, CREW capacity building projects have explored climate change impacts on the water quality of Scottish standing waters and resilience of Private Water Supplies, and through its call down service, CREW has coordinated crucial research in support of the National surveillance programme for Covid-19 RNA in wastewater.

CREW's approach to science-policy research involves multi- or interdisciplinary teams co-constructing projects and events in a trans-disciplinary way, together with the stakeholder community. CREW's community of stakeholder organisations and Steering Group membership was expanded in 2018 to encompass interests from the food and drink and circular economy sectors. Scottish Canals, Zero Waste Scotland, and Food Standards Scotland were welcomed as new CREW partner organisations. Latterly CREW has engaged with Consumer Scotland, representing the interests of the public. Key collaboration and multidisciplinary working activities in support of policy and practice during this Programme have included: science: policy liaison via CREW's theme groups; engagement with CREW's research community (Higher Education Institutes (HEI) and Research Institutes); closer working with the Strategic Research Programme (SRP); joint working and sharing best practice with the other Centres of Expertise (CoEs) and Sefari Gateway. Activities in support of the Hydro Nation agenda have included: liaison with the Hydro Nation Scholars (and Fellows) Programme in opportunity awareness and knowledge exchange activities; involvement in the development of the Hydro Nation International Programme which led to the establishment of the Hydro Nation International Centre (HNIC) at the James Hutton Institute in Aberdeen; contribution to HNIC World Water Day events, and; supporting the Hydro Nation Chair to establish new partnerships and collaborations.

Throughout the Programme, the Centre has been proactive in reviewing, improving, and future-proofing its processes. The CREW Director and CREW Steering Group have provided both essential strategic oversight and advice and an important audit function. In 2018, CREW formalised its quality management processes in a quality manual and team members have pursued Continued Professional Development in quality and risk management. The Centre was praised for its quality manual in the Centres of Expertise Mid-Programme Review and has actively engaged in sharing best practice with the sister Centres of Expertise and Sefari Gateway. CREW has also invested in its Communications through commissioning an external review of its strategy and channels of communications. Early actions on the recommendations of the review aided the Centre's ability to adapt to changing communication preferences and working patterns both in general and in relation to the COVID-19 pandemic. CREW adopted and steadily increased its use of social media to share project findings and event information, with continued use of the CREW website as a publicly accessible repository for CREW outputs. CREW has continued to grow its connections with a wide range of relevant organisations and networks. The team have collaborated on and contributed to a range of increasingly virtual and hybrid conferences, CREW workshops and other water-related activities, such as Scottish Alliance for Geoscience, Environment and Society, and Scottish Freshwater Group events, and the Scottish Universities Partnership for Environmental Research doctoral training programme.

With growing numbers of requests being received for capacity building projects as the Programme progressed, CREW developed and implemented a revised project request and prioritisation process in 2019. Submission of an initial idea, discussion and feedback from stakeholders and review by a panel of scientific experts, prior to co-construction of a full project specification, has been adopted to use stakeholder time effectively and improve the transparency and rigour of the project selection process. Additionally, CREW established a new CREW

Policy Fellowship Programme in 2021 in response to research community requests for CREW to facilitate a mechanism to highlight critical water-focused science challenges facing policy developments.

To enable the Centre to build on the learning of two Programmes of CREW (2011–2016, 2016–2021) in its future activities, CREW commissioned an independent Strategic Impact Review in 2021–2022, which engaged with CREW's stakeholder community. The review gave clear evidence of CREW's impact on policy and benefits of CREW projects to wider stakeholders and society. Impact activities, enabling factors, intermediate outcomes, and actual benefits at different stages within the CREW project lifecycle were identified and summarised in high-level theories of change diagrams. Recommendations from the review will inform further improvements to the Centre's operations and formalise pathways to impact in the next Programme.

3.0 External Context

CREW is governed according to key policy areas in Scotland's water sector including flooding, coastal erosion, catchment management, rural sustainability, and water quality management. Cross-cutting activities focus on managing impact and adapting to climate change, land use and urbanisation, promoting the circular economy, a post-COVID green recovery, the move to net zero and a just transition for communities. The Centre has supported EU and national policy development and implementation strategies and Scotland's ambition to deliver the United Nations' Sustainable Development Goals both nationally and internationally. Examples below highlight CREW's central principles that knowledge generated should improve understanding and communication between science and policy, promote improved networking and win-win solutions, and deliver tangible impact and longer-term outcomes for the water environment and society. CREW supports Scottish Government, SEPA, Scottish Water, NatureScot, DWQR, Scottish Canals, ZWS, WICS, in their work to develop and implement water related policy in Scotland. As policy needs evolve, CREW remains agile to meet emerging demands.

- CREW has led workshops, contributed to consultations and evidence for the second (2016–2021) and third (2021–27) round of **River Basin Management Planning** for the Scotland and Solway Tweed River Basin Districts with ambitious plans for mitigating diffuse and point source pollution to improve water quality, resources, and physical condition of rivers. Such activities have fed into support the reviews of the EU Water Framework (2019) and Bathing Waters Directives (2020). Universally, there is growing interest in delivering a circular economy as evidenced by the "Roadmap to a Resource Efficient Europe" and the "Circular Economy Action Plan," with several relevant CREW projects in consideration for the next Programme.
- Coastal erosion was a policy priority with the successful delivery of Phase 2 of **Scotland's Coastal Change Assessment** (NCCA2) which revolutionised the evidence base of coastal change; leading to mitigation, adaptation and resilience plans at key sites; increased adaptation awareness and assessed social vulnerability to coastal erosion. NCCA2 supported the delivery of the Adaptation Sub-Committee of the Climate Change Committee report and Scotland's obligations under multiple aspects of the Climate Change Adaptation Programme, Flood Risk Management Act, Community Resilience Strategy, Scottish Planning Policy, National Marine Plan, Historic Environment Scotland's Climate Change Action Plan, Land Use Strategy and Scottish Biodiversity Strategy.
- **Private water supplies** and rural water management remain a policy priority, supported by CREW's Sustainable Rural Communities theme, with strong links to Scottish Government's policy group in this area including the Recast of the EU Drinking Water Directive resulting in a new risk assessment process and the redraft of the Private Water Supplies (Scotland) Regulations 2006.
- CREW is a central pillar of the **Hydro Nation International Centre**, a one-stop shop for activities around talent development, innovation, research, and impact for the water sector.
- Drawing on networks and partnerships established in 2020–21 CREW coordinated research in support of the **National surveillance programme for Covid-19 RNA in wastewater**, acting as a focus for Scottish and UK partners to share updates on wastewater-based epidemiology (WBE) as the pandemic evolved.

4.0 Internal Context

In 2016–2022, CREW's performance was actively monitored, improvements were sought, and risks actively monitored and managed:

- **Governance and Risk**: The CREW Steering Group (CSG) provided an important audit function and acted as a valuable source of strategic guidance, particularly

through linkages and connections with research in the UK, European and international arenas. Standing items at Steering Group meetings included reviewing CREW's risk register and programme of work and scrutinising a procedure of the Group's choice. In 2016–17 a new invigorated Steering Group was formed to help guide the future direction and relevance of CREW work. In 2018–19, there was a further refresh reflecting upon interest from other sectors such as food and drink and circular economy. The Steering Group comprised the following organisations: Scottish Government, SEPA, Scottish Water, Drinking Water Quality Directorate, Water Industry Commission, Food Standards Scotland, Zero Waste Scotland, Scottish Canals, and Senior Advisors representing British Geological Survey, UKCEH, Universities of Dundee, Leeds, Cranfield, and MASTS. The guiding principles developed with the CSG to reduce and manage risk will be adopted with the new CSG in the coming programme.

- **Management**: The CREW Director, Bob Ferrier, provided essential strategic oversight throughout the Programme. The Facilitation Team, responsible for the day-to-day management of the Centre saw several staff changes but retained the model of one Centre Manager and two Project Managers. In 2019, CREW welcomed a Finance and Database Manager and the current Centre Manager, Rachel Helliwell. In 2021–22, additional Project Managers were employed to assist with completion of a high volume of projects and events before the end of the Programme.
- **Procurement**: A new service agreement with MASTS University of St Andrews in 2016–17 addressed previous concerns held by the HEIs on IP ownership.
- **Quality management**: In 2018, CREW produced a Quality Manual detailing all processes and procedures, which was praised in the Mid-Programme Review. In 2019, a new project prioritisation and scoring procedure was implemented in response to high volumes of capacity building project requests. In 2020, CREW applied an ISBN number to published outputs to standardise archiving and attribution.
- **Communications**: In 2018, CREW commissioned an external review of its Communications strategy and channels, launched a Twitter account and refreshed its branding. CREW has increasingly contributed to online and hybrid events.
- **Research services**: CREW delivered 34 call down and 68 capacity building projects, plus 3 CREW policy fellowships in 2021–22 as part of a programme to provide an opportunity for Scotland's water research community to voice what they perceive to be the most critical water-focused science challenges facing policy developments.
- **Strategic impact review**: In 2021, CREW commissioned an independent review to investigate, showcase and explain how CREW projects develop impact and make evidence-based recommendations to enhance CREW's future impact.
- **Thematic areas**: In recognition of changing and emerging science-policy needs, CREW's 'Protecting Drinking Water' theme was renamed 'Water Quality' to additionally cover wastewater. 'River Basin Management Planning' was renamed 'Catchment Management,' with increased focus on circular economy. 'Sustainable Rural Communities' became 'Sustainable Communities' to include urban water issues. Further changes in theme names are planned in the new Programme.

5.0 Outputs and outcomes

5.1 Supporting Policy and Practice

5.1.1 Stakeholder Engagement

CREW has delivered a wide range of stakeholder engagement opportunities during this Programme: from World Water Day events and a Hydro Nation Virtual Pavilion at COP26, to a Water Wall in Motion initiative; from international workshops on Dissolved Organic Carbon (DOC) and regulation of rural private water supplies to the development of a Defra funded Catchment Management Modelling Platform and launch event, a register of activities relating to anti-microbial resistance (AMR) research associated with Scotland and a Natural Flood Management Network website. CREW has also provided opportunities for its stakeholder community to critique its processes and highlight the impact of CREW's projects and approaches via online surveys (2019 onwards) and an independent review of CREW's strategic impact in 2022.

World Water Day events (2018–2022)

HNIC and CREW have championed the importance of World Water Day on the 22nd of March as an opportunity to discuss the emerging water-related opportunities and challenges in Scotland and internationally. The CREW team partnered the delivery of stakeholder events in 2018, 2019, 2021 and 2022 with the wider HNIC family. (The event planned for 2020 was postponed due to COVID-19 restrictions). The annual events have been hosted by the HNIC, with financial support and strategic direction from

the Scottish Government's Water Industry Team and delivered in partnership with CREW's research community and wider stakeholder groups.

The premise of World Water Day is to engage a range of speakers, co-ordinate resources for online and hybrid events, chair sessions and capture discussions and experiences of key stakeholder representatives, government officials, academics, researchers, and engage scientists from the Hydro Nation Scholars Programme, as part of their CPD, in the production of reports and online resources for wide circulation and adoption as follows:

2018 Scotland's contribution to international water policy and research

2019 Resilience to Drought and Low Flow Conditions in Scotland

2021 Valuing Water

2022 Realising the benefits of Scotland's Waters, followed by CREW Lecture

101 people attended the March 22nd, 2022, World Water Day Event in person. The online resources webpage with interactive livestream (including Vevox question submission app) and virtual tours attracted 118 registered attendees and many more page views/people on the day (415 unique page views/people). One of the top pages visited was the Sharing Knowledge Virtual Tour (related to CREW activities). CREW launched its first Annual lecture following the World Water Day Event, which attracted 53 registered in-person attendees and 26 registered online attendees.

CREW COP26 activities

CREW was a significant contributor to the Scotland's Hydro-Nation Virtual Water Pavilion, an immersive virtual experience around water for COP26 – delivered by HNIC with contributions from the whole water sector – which shows how Scotland's Hydro-Nation agenda is supporting the water sector's response to the climate emergency. The pavilion offered the opportunity to create a bespoke experience reflecting individuals own interests. The virtual web tours provided information showcasing Scotland's innovation and knowledge, the vision for blue-green cities, the journey to net-zero and international activities. The CREW Director was invited to be on the Water Security Panel and the CREW Manager was invited to provide some personal thoughts on Climate Change COP26 in Face the Facts in September 2021. The CREW team contributed a chapter titled Supporting Evidence-Based Water and Climate Change Policy in Scotland Through Innovation and Expert Knowledge: The Centre of Expertise for Waters (CREW) to book Water Security Under Climate Change Edited by Biswas, A.K. and Tortajada, C which was launched at COP26.

Water Wall in Motion: Uniting Communities Through Film

In March 2020 when the pandemic succeeded to 'lock Scotland down', CREW, in partnership with SEFARI Gateway, SAGES and HEIs, opened a video competition to virtually engage Scotland's water community and share contemporary views of the importance of water in research, management, innovation and recreation. Videos were submitted to one of seven thematic areas and were captured online for future use as a teaching resource and to promote wider engagement of Scotland's water community. A film of the winning entries was shown at World Water Day 22nd March 2022.

International Dissolved Organic Carbon workshop

An international workshop was held as part of the CREW project, 'Reviewing best practice in the delivery of good drinking water quality using a prevention-led approach', delivered by the James Hutton Institute. The overall aim of the project was to collate evidence related to prevention-led approaches from catchments with similar characteristics to those in Scotland and identify the benefits they could bring to safeguard drinking water supplies. The project sought views, nationally and from other EU (and international) countries, on how or what they have learnt from implementing a prevention-led approach. The workshop focused on advancing knowledge of evidence for protecting drinking water supplies in Scotland from DOC and colour. The workshop included representatives from international case-studies selected by the project steering group, as well as the steering group members and the project team. The outputs of the project have helped to inform policy makers on best practice in implementing a prevention-led approach to improve drinking water quality including the benefits it could bring to drinking water management.

International governance and management of small rural private water supplies

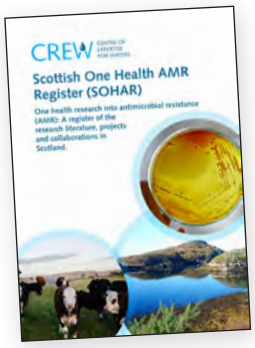
A workshop was held as part of a comparative EU and non-EU CREW project on regulation of rural private water supplies (a collaboration between The James Hutton Institute and the University of Dundee), which included delegates from the UK, Iceland, Germany, Netherlands, and Ireland to gather views on their own governance

and management models and seek potential solutions to the problems faced in delivering water services to rural communities. The findings from the workshop were incorporated into the overall conclusions and enhanced the overall recommendations made in the project outputs. This study and other related work on private water supplies will underpin new research proposed in the next programme.

DEFRA Catchment Management Modelling Platform and launch event

CREW, as part of a multi-agency delivery consortium, developed a Catchment Management Modelling Platform for a DEFRA funded project. This web-based platform provides a one stop shop for models used in environmental policy related research. As well as the catchment models, the web platform has a directory of data that is open access, providing a useful database for researchers in the field. A key role for CREW was working with stakeholders to identify the questions they wanted the modelling platform to answer. Over one hundred potential questions were identified and subsequently prioritised through workshops. The project culminated in a dissemination workshop organised by CREW in London in 2017. There were over sixty delegates, which included representation from government, academia, and industry. The day comprised of several talks on the functionality of the site followed by interactive sessions.

Scottish One Health Antimicrobial Resistance Register (SOHAR)



A CREW project in 2021, delivered by Scotland's Rural College, Moredun Institute, The James Hutton Institute, Rowett Institute and University of Edinburgh, aimed to determine activities relating to AMR research associated with Scotland in the past five years, and to relate them to the UK National Action Plan (NAP) (2019–2024).

The project generated a register of activities, which has become a focal point for stakeholder engagement allowing organisations to access contemporary research and identify gaps in research to potentially steer new projects in the next CREW programme.

Natural Flood Management Network and website

Scotland is seen as leading the way in the implementation of the Floods Directive, particularly with respect to natural flood management (NFM). A CREW project in 2018, undertaken by the James Hutton Institute, developed a unique platform to share NFM knowledge and best practice in Scotland and to aid coordination. Initiation of the Network was in the first instance, an interactive website for NFM practitioners, biannual e-bulletin, and periodic NFM workshops to share best practice. The Natural Flood Management Network and website was launched by the Scottish Government at an event jointly organised by SEPA, the Environment Agency and CIWEM, as a platform for policymakers, researchers, scientists, and anyone interested in the use of landscape features to reduce flooding to share approaches, raise awareness and encourage collaboration. This resource is creating an invaluable tool for those tasked with delivering a sustainable approach to flood risk management in Scotland, and the ongoing maintenance and development has been supported by the RESAS Strategic Research Programme. At the launch, Environment Secretary Roseanna Cunningham said: *"The Scottish Government is committing £42 million annually to protect homes in many of our most flood-prone areas. To fully capitalise on this, it is essential that we share our excellent practical and scientific skills, and this new network will help ensure that natural flood management actions are successfully delivered across Scotland."* SEPA Chief Executive, Terry A'Hearn, added: *"SEPA works every day to help Scotland be better prepared for future increased flooding. A vital part of that is working with our partners to identify how we can better manage flood risk, and the new NFM Network Scotland portal will be of great benefit to our staff in their roles."*

CREW stakeholder feedback, Impact Review, and theories of change

One of CREW's strategic priorities is to meet and exceed the needs of its stakeholders. CREW engages with its project requestors, researchers, and project steering group members to gather feedback on CREW projects e.g., through annual online surveys (2019–2021). In 2022, CREW commissioned an independent impact review (Jensen et al., 2022) to investigate, showcase and explain how CREW projects develop impact and make evidence-based recommendations to enhance CREW's future impact. The review involved mixed-methods research, with an emphasis on creating 'theories of change' that by visually encapsulate the CREW impact process. This

included scoping analysis of relevant documents such as Annual Reports, as well as web and social media analytics. The focus of data collection for the research was CREW's external stakeholders and CREW staff. A multi-stage research approach was used, starting with interviews with key CREW staff to orient the study, then extending out to external stakeholders and CREW researchers. Finally, participatory workshops conducted with both external stakeholders and CREW researchers were used to refine and elaborate preliminary findings.

A selection of survey responses are presented in Figures 1–3. Figure 4, a high-level theory of change diagram, describes impact activities (red), enabling factors (yellow) and outcomes that have been linked to impact development from CREW projects. Impactful processes, practices and cultures have been developed since CREW's inception as a Centre of Expertise to enable CREW to have the capacity to facilitate impact at every stage of a project's lifecycle (see legend) e.g., through co-construction of project requests with stakeholders and integration of specialised scientific expertise. Enabling factors are characteristics that explain why an activity

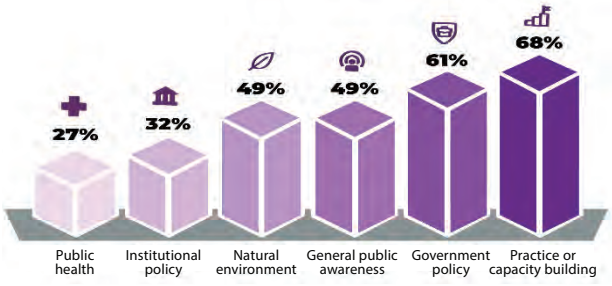


Figure 1. Top survey responses to 'What types of impact has this CREW project helped to develop?'

Figure 2. Top survey responses to 'Did the following factors contribute to the project's impacts for beneficiary organisations?'

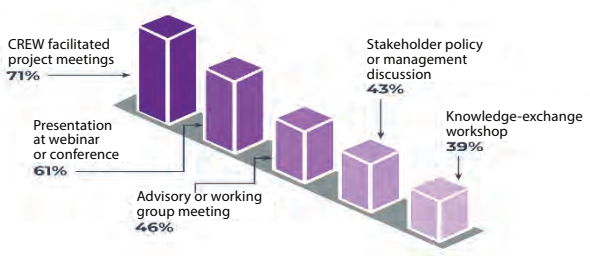


Figure 3. Top survey responses to 'What types of CREW project outputs or activities helped to develop this project's impacts for beneficiary organisations?'

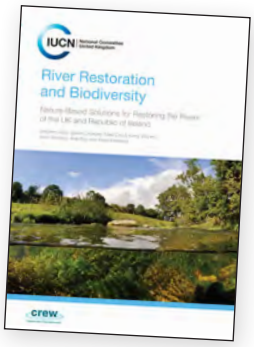
Figure 1-3. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

helped to achieve impact, for example through provision of dedicated project managers and sufficient resources for early and effective communication and impact development. Two levels of impact developed from CREW projects are identified. Intermediate outcomes (shown in blue) are demonstrable or perceptible new outcomes with individuals, groups, organisations, and society linked to the project. For example, a CREW output may validate or clarify a specific concern within a stakeholder organisation, the policy impact of which may be that stakeholders have relevant, robust, practically applicable evidence to advocate for policy change. Actual benefits (green) are the demonstrable or perceptible benefits of particular new outcomes or changes linked to the project and are included in theories of change for selected high impact case studies presented in 5.1.2, 5.1.3 and 5.1.4.

5.1.2 Policy relevant outputs

CREW projects stem from water policy needs and outputs are delivered in a format best suited to the requesting policy makers and implementers. Within this Programme, examples of policy relevant outputs CREW has delivered include: a joint IUCN-CREW publication on river restoration and biodiversity; recommendations for the development of Scotland's shellfish water monitoring programme; reports on private water supplies focused on climate change impacts and local economic impacts respectively; an assessment of the impact of climate change on the water quality of Scottish standing waters; policy briefs on antimicrobial resistance and the potential influence of beaver activity on the natural functioning of rivers and streams in Scotland, and; a suite of analysis/ reports on "early warning" potential of wastewater-based epidemiology in the context of COVID-19 surveillance.

IUCN CREW River restoration and biodiversity report



The CREW report, 'River restoration and biodiversity: nature-based solutions for restoring the rivers of the UK and Republic of Ireland', produced by the James Hutton Institute, was published jointly by the IUCN and CREW, and launched at the Freshwater Biological Association in Windermere, UK in 2017. The event was attended by forty-five attendees representing a wide range of conservation and environment bodies around the UK and Ireland. Presentations were made by Scottish Natural Heritage (now NatureScot), Scottish Wildlife Trust and IUCN followed by a question and

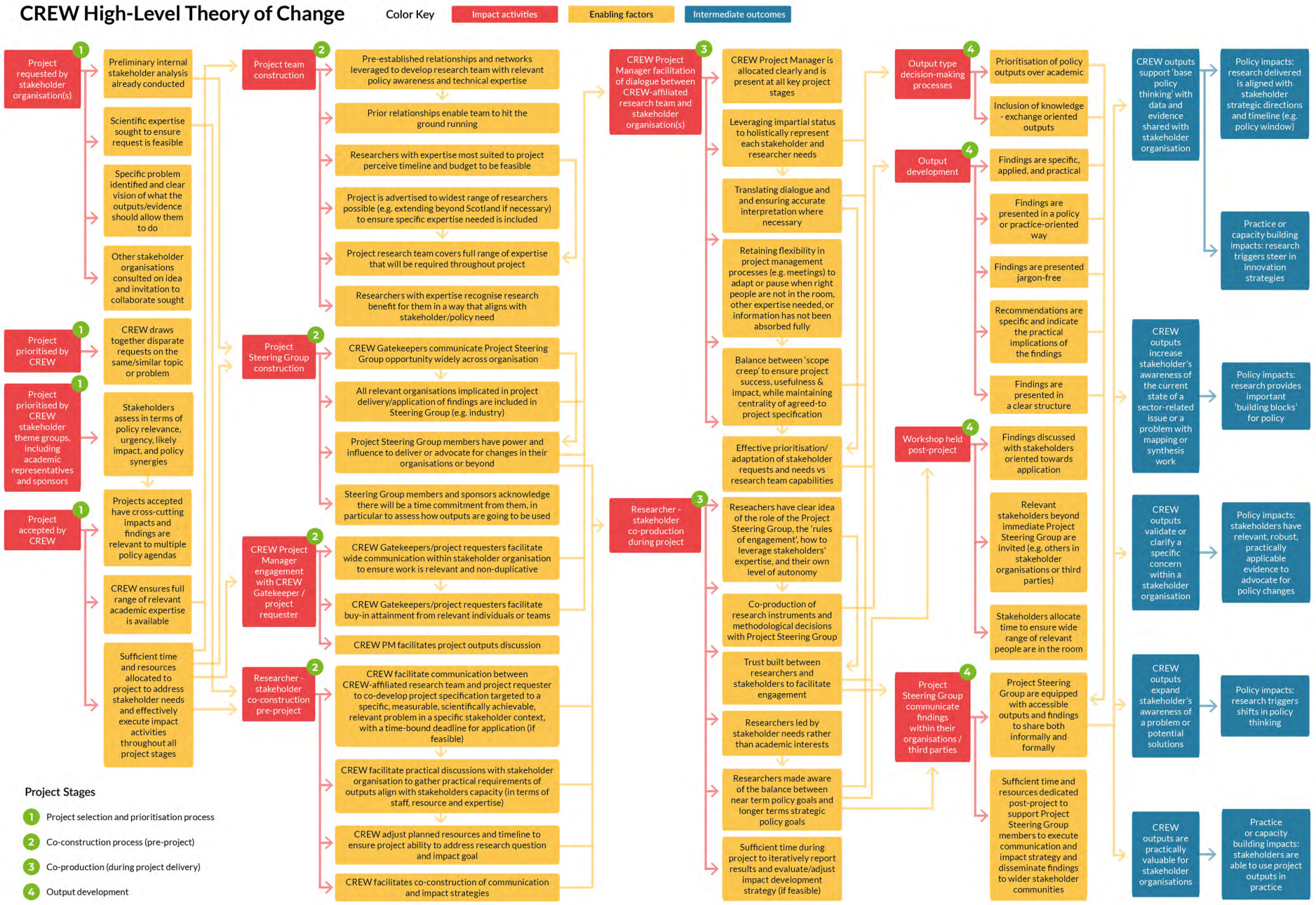


Figure 4. CREW High-Level Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

answer and discussion session. The report bridges the gap between scientific understanding of rivers and river processes, and its practical application in restoring river habitats. In the report Foreword, Simon Stuart (Chair, IUCN Species Survival) and Piet Wit (Chair, IUCN Ecosystem Management) wrote *"we encourage both the British and Irish governments to take its recommendations very seriously and to set an ambitious agenda for river restoration which can become an example for other countries to follow."* The report is currently being translated into Chinese by the Ministry of Water Resources as a restoration handbook for all staff.

Lead policy contact: **Angus Tree**, NatureScot

Developing Scotland's Shellfish Water monitoring programme

The Developing Scotland's Shellfish Water monitoring programme project, carried out by the James Hutton Institute and Biomathematics and Statistics Scotland (BioSS), set out to develop recommendations for the delivery of a scientifically robust, efficient and cost-effective sanitary survey programme and environmental monitoring programme to better inform FSS and SEPA shellfish water programmes. In consultation with FSS and SEPA, the report, published 2018, identified the strengths of current approaches and opportunities for improvements to inform future discussions with Scotland's shellfish industry. Opportunities for integration of FSS and SEPA programmes and recommendations for Standard Operating Procedures (SOP) for sanitary surveys were also provided. Review of international shellfish research and the results of national-scale data analysis of shellfish E. coli provided the evidence-base for the recommendations to help inform policy development for the Water Environment (Shellfish Water Protected Area: Environmental Objectives) (Scotland) Regulations 2013 to ensure they provide proportionate and adequate protection for the Shellfish Water Protected Areas.

Lead Policy contact:
Joyce Carr, Scottish Government

Private Water Supplies and Climate Change

In 2020, CREW published a report on "The likely impacts of climate change (amount, frequency, and distribution of precipitation) and the resilience of Private Water Supplies", delivered by the James Hutton Institute. CREW engaged DWQR, SEPA, Citizen Advice Scotland, Scottish Water, and Scottish Government's Water Industry Team in the project's Steering Group to ensure that policy questions on rural water supply vulnerability to climate change were effectively addressed. The report was launched through a CREW blog and a press release by the James Hutton Institute followed by further media engagement, including an article in the Scotsman and local papers. Environment and Climate Change Secretary, Roseanna Cunningham told The Scotsman: *"This important research provides more evidence that climate change is having a growing impact on our natural environment and resources."*

Lead policy contact:
Jon Rathjen, Scottish Government Water Industry Team

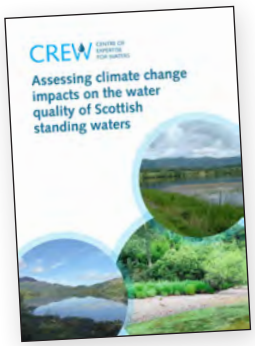
Private Water Supplies and the local economic impacts in Scotland

The importance of private water supply (PWS) resilience in Scotland was highlighted in a CREW study led by Glasgow Caledonian University. The report, published in 2020, showed that many micro- and small businesses in remote areas of rural Scotland rely on PWS, making rural communities potentially less resilient, economically, and otherwise. CREW supported the project team's engagement with a wide range of stakeholders, including residential and business private water supply owners and users, local communities, and local authorities. The report was launched through a press release by the James Hutton Institute. The project team argued that *"whilst tourism is widely regarded as a welcome economic opportunity in rural areas, the sudden rise in water demand, such as along the heavily promoted North Coast 500 tourist route, was recognised as an issue requiring urgent attention. Better regulatory oversight and support and enhanced communication between relevant agencies*

both locally and nationally is essential so rural businesses and communities can continue to grow." This and the previous PWS project, lay the foundation for future work in the next programme on the wider impacts of water scarcity.

Lead policy contact:
Sue Petch, Drinking Water Quality Regulator

Assessing climate change impacts on the water quality of Scottish standing waters

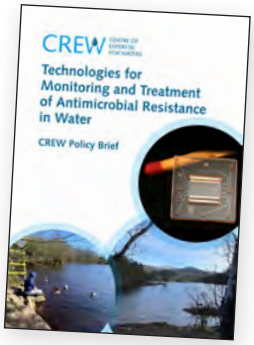


Scotland, like the rest of the world, is facing an unprecedented climate change crisis. Amongst other impacts, this is affecting the quality of its standing waters such a lochs and reservoirs. This CREW project complied and assessed the key evidence available to improve our understanding of climate change impacts on the water quality of Scottish standing waters at national, regional, and local scales. The project focused on the interactions between climate change, the drivers of eutrophication problems and their impacts. The team synthesised information from the literature, expert opinion, and monitoring data, and used statistical analyses and visualisation combined with climate change scenario modelling to address six strategic water research questions.

Key findings outlined in the report published in 2021, include that climate change is affecting the water quality of Scottish standing waters, specifically in relation to algal blooms, at multiple scales, mostly through increases in air temperatures and changes in rainfall patterns. Climate change will increase the risk of algal blooms developing in Scottish lochs and reservoirs. Increases in algal blooms are often associated with a higher risk of potentially harmful toxins from cyanobacteria being released into the water. Recommendations were made on changes needed to adapt water policy and existing monitoring networks as part of Scotland's strategic and coordinated response to the climate crisis. Media attention received on publication of the report included the BBC, The Independent, The Times and France24.

Lead Policy contact:
Karen Mitchell, NatureScot

Antimicrobial Resistance & Technologies for Monitoring and Treatment in Water

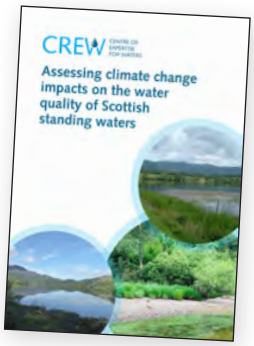


Over 700,000 deaths each year are due to diseases caused by drug resistant pathogens and failure to curtail antimicrobial resistance (AMR) could cause ten million deaths per year globally by 2050. The UK 5-year NAP for Antimicrobial Resistance highlights the important role of the environment, including water, and taking a "One-Health" approach to tackling AMR. Additionally, implementing AMR surveillance is critical to understand the role of water in proliferation and transmission of AMR, the risks to human health and the environment, and to inform selection, and application, of mitigation methods and treatment options.

In 2021, CREW policy fellows undertook a comprehensive literature review and engaged with a range national and international experts from policy, academia, and industry through a workshop (>20 participants), interviews and questionnaires (>30 respondents) to deliver a set of tailored recommendations on AMR in Scotland. The policy note delivers an overview of the AMR issue in Scotland's waters while the policy brief focuses on the available technologies for AMR surveillance. These two interlinked CREW Policy outputs will help improve the understanding of the knowledge gaps and next steps to be taken in Scotland's policy on antimicrobial resistance in waters. Going forward CREW will continue to work with the OHBP to further this important area of work.

Lead Policy Contact:
Barry Greig, Scottish Government Water Industry Team

Influence of beaver activity on natural functioning and water resource management



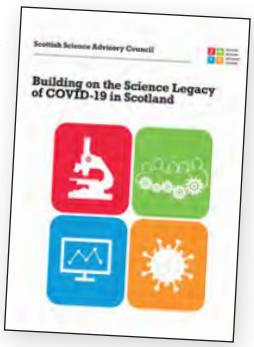
This CREW project provided an evidence review of the role of beavers in modifying physical processes, and the potential benefits they may bring for Scottish rivers, streams, and water resources. Most of the evidence of beaver activity effects on streams and rivers points to positive contributions to local ecosystem services, including water supply and purification, wetland creation and river restoration. Enabling these and other positive contributions may also involve compromises

and care must be taken to manage any disbenefits, such as local loss of land. Recommendations include that the potential for beaver activity to contribute to ecosystem services should be considered in relevant riparian management appraisals. However, discussion with landowners and wider
societal groups is required to inform such appraisals and mitigate local adverse effects of beaver activity. The publication of the report led to an invitation of the team and CREW project manager to the National Beaver strategy workshops in March 2022 aimed at designing a nationwide strategy for management, mitigation, research and development and on beavers in Scotland for the next 10 years. The report published in 2022, and associated press release also captured the media's attention (e.g. here).

Lead Policy Contact:
Martin Gaywood, Nature Scot

COVID-19 surveillance: wastewater epidemiology

CREW has been at the forefront of Scotland's response to the COVID-19 pandemic since 2020 and played a key role in coordinating research and establishing partnerships behind the National surveillance programme to inform public health policies in Scotland. The pandemic has been driven by the repeated emergence and spread of viral variants. The development of a new laboratory testing programme was required for Scotland to derive this additional benefit from the existing investment in sampling and extracting viral material from Scottish wastewater. CREW engaged the University of Edinburgh in the development of methods to detect SARS-CoV-2 variants in wastewater and worked closely with Scottish Water, SEPA and the government in the development of a Scotland-wide Wastewater Based Epidemiology (WBE) approach to COVID-19 variant surveillance. A key finding is that Next Generation Sequencing of wastewater provides significantly more information on variants than PCR-based methods and the method developed in the CREW project has potential for analysing multiple pathogens simultaneously providing valuable data for public health purposes. The project is carefully curating and sharing technical products from the SARS-CoV-2 WBE programme, such as laboratory protocols, data analysis programmes and data compilations to create long-term impact.



The project delivered a workable, testing process for variants. CREW received additional support from Scottish Government to deliver this work. Both the national programme and the present CREW project involve clusters of different expertise spanning multiple institutions. A key feature is that data produced by Scottish Water/SEPA/University of Edinburgh are re-used in organisations such as BioSS with different focus and expertise. Valuable lessons learned on the working methods, structures and interactions that contributed to the SARS-CoV-2 WBE programme in Scotland have been analysed to infer suggestions on how these may contribute to future, urgent programmes (e.g., monkeypox). CREW engaged the Scottish Government's CSA ENRA and RESAS, wider Government representatives, Public Health Scotland, SEPA, Scottish Water, DHSS/JBC on the project steering group to ensure that policy needs on current and emergent WBE applications are met and recommendations are shared. The CREW Manager attended a Scottish Science Advisory Council (SSAC) meeting and the CREW COVID-19 work was reported in the SSAC Report – Building on the Science Legacy of Covid-19 in Scotland. Figure 5 by Jensen et al. (2022) summarises the type (see legend) and nature (see individual coloured boxes) of impact activities (in red), enabling factors (in yellow) and intermediate outcomes (in blue) from the CREW work. Actual benefits (in green) included that wastewater plant staff were provided with full personal protective equipment (PPE) long-term and capacity was built to detect new variants before they are a cause for public concern resulting in lower public health risks.

Lead Policy Contact:
Prof. Andrew Millar, SG CSAENRA

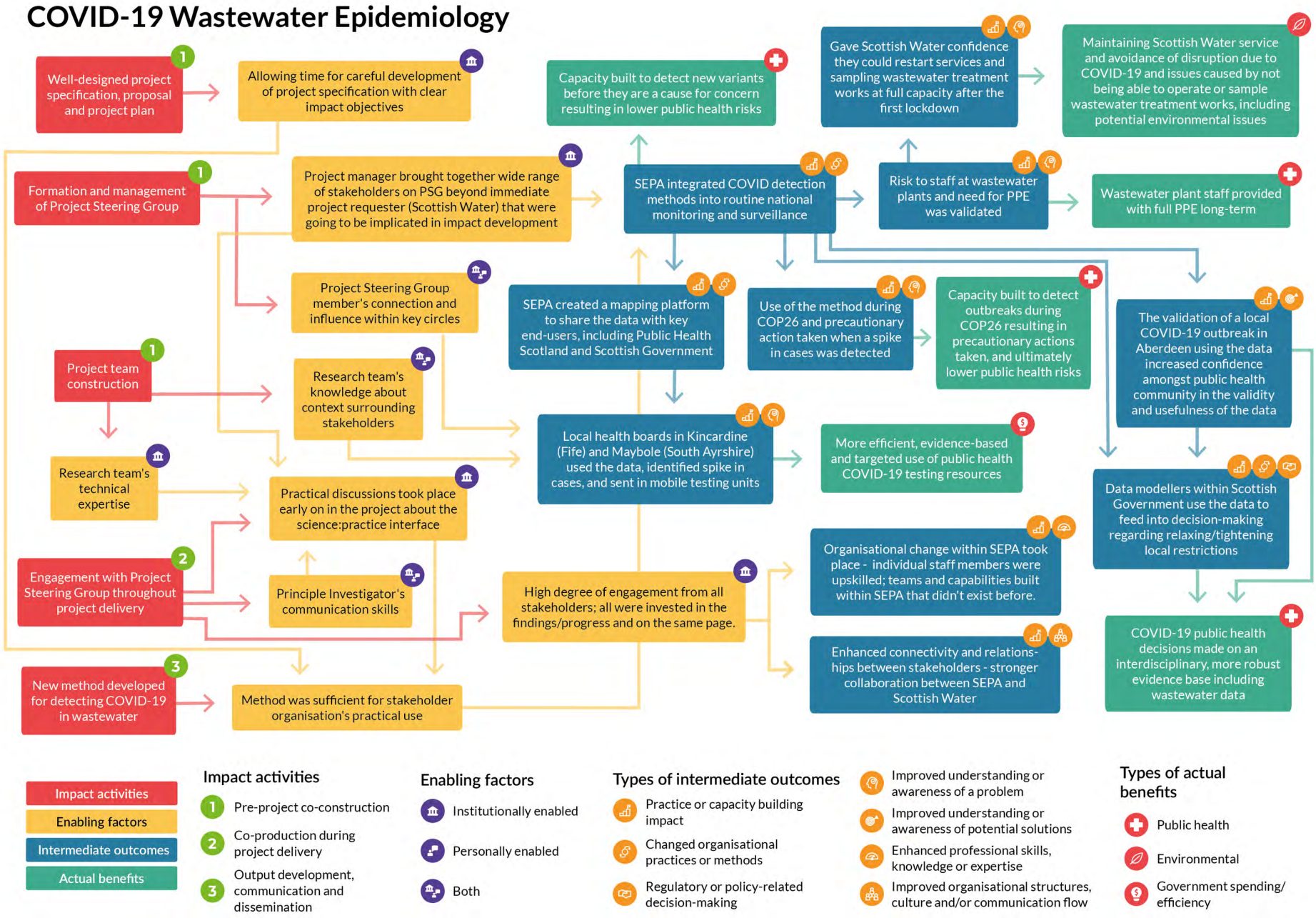
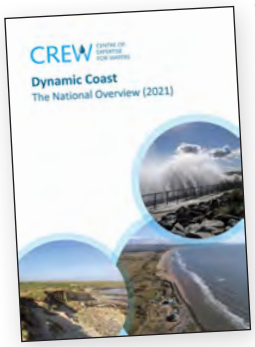


Figure 5. COVID-19 Wastewater Epidemiology Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

5.1.3 Impact on policy

Examples of CREW projects which have impacted policy include Scotland's National Coastal Change Assessment, a study of long-term impacts of flooding on communities, work on pharmaceuticals in the water environment supporting the One Health agenda, and a methodology for monitoring of radon in groundwater public water supplies.

Scotland's National Coastal Change Assessment: Dynamic Coast



The CREW project Scotland's National Coastal Change Assessment (NCCA) (Phase 1 2015–2017, Phase 2 2017–2022) was delivered by the University of Glasgow and the Scottish Government in partnership with NatureScot, SEPA and Historic Environment Scotland, with the aim of creating a shared evidence base to support more sustainable coastal and terrestrial planning decisions in the light of a changing climate. Dynamic Coast is an open access web-based tool, which offers easy-to-use-interpret reports and maps of the entire 21,000 km of Scottish coastline, allowing swift identification of potential areas of erosion and vulnerable assets such as roads, rails, or houses. The web resource achieved 13,000 hits from 8,000 users globally by March 2019 and the project won the Spotlight Prize at the 4th Scottish Knowledge Exchange Awards 2019. Phase 2 revolutionised the evidence base of coastal change; produced mitigation, adaptation, and resilience plans at key sites; increased adaptation awareness and assessed social vulnerability to coastal erosion. Dynamic Coast continues to support the UK Climate Change Risk Assessment and multiple strands within the Climate Change Adaptation Plan (SCCAP1 & 2), Terrestrial Planning Policies (NPF3 & 4) and Marine Planning Policies (National and Regional Marine Plans). Important evidence from Dynamic Coast was presented for public sector duties under the Flood Risks Management (Scotland) Act 2009 in January 2021 (via SEPA and local authorities) and supported Scottish Government's Marine Licensing Team, in their licensing for harbour dredging. The work also supports aspects of the Community Resilience Strategy, Scottish Planning Policy, Historic Environment Scotland's Climate Change Action Plan, Land Use Strategy and Scottish Biodiversity Strategy. The project contributed to a portfolio of evidence that led to a £12 million boost for coastal change adaptation that was announced in the Programme for Government (Sept 2020). Outputs from Phase 2 will be used to prioritise actions on the ground during its implementation c.2023-. Figure 6 summarises the type (see legend) and nature (see individual-coloured boxes) of impact activities (in red), enabling factors (in yellow) and intermediate outcomes (in blue) from the two phases. Actual benefits (in green) included that both communities and assets at risk from coastal erosion were better prepared for risks and due to identification of risk areas, costly reversal of development decisions were averted.

Lead Policy Contact:
Debi Garft, Scottish Government.

Long-term impacts of flooding

This CREW study highlighted the profound and long-lasting impacts of flooding on individuals, businesses, and communities in North-East Scotland following the winter 2015–2016 flooding. Over three years, researchers from the James Hutton Institute and the University of Aberdeen found that the impacts of the flooding surpassed the immediate financial and physical damage experienced in the aftermath of the floods. Many impacts of flood events are long-lasting, including stress, financial hardship, and ill-health (and mental health). Researchers and participants worked together to develop advice to others at risk of being flooded in the future. The summary report, launched through an article in the Guardian and a press release, with further media engagements including an interview for BBC Landward, includes advice on having a household emergency plan that clearly sets out what actions should be taken in the event of serious flooding, considering options for making property more flood-resistant and resilient, ensuring adequate insurance cover is in place, and registering with SEPA's Floodline service. The report recommends that flood alerts and warnings should use accessible language to help ensure that appropriate action is taken by the public. It also highlights the importance of using a variety of methods to communicate information, including traditional (print and broadcast) media, social media, and other online channels.

Figure 7 summarises the key impacts (red), enabling factors (yellow), intermediate outcomes (blue) and actual benefits (green) from this project. Benefits include a diverse stakeholder group comprising of

Figure 6. Dynamic Coasts Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report. (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

Figure 7. Impacts of Flooding Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

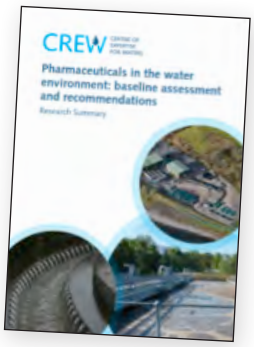
insurance agencies, surveyors, construction and building standards agencies engaging more directly with flood-affected communities. For example, through community engagement events co-organised with the Scottish Flood Forum and Flood Re, a joint initiative between the Government and insurers which aims to make the flood cover part of household insurance policies more affordable.

Dr Pascal Lardet, SEPA Flood Warning & Informing Unit Manager and member of the project steering group, stated: *"Every day the Scottish Environment Protection Agency helps Scotland prepare more powerfully for future increased flooding and the impacts of climate change. These impacts can be devastating, and this research offers unique insights into the experience of people and communities in Scotland following the major floods of winter 2015/16…SEPA has a key role to play to help people be better prepared and able to take action when flooding is expected. We are already learning and adapting our own services thanks to this research project, for example by improvements to our flood early warning and real-time water level information. We are keen to better design our services around customer needs, and this research output will help us do that."*

Cabinet Secretary for the Environment, Climate Change and Land Reform, Roseanna Cunningham cited the report at the SNIFFER Flood Risk Management Conference 2020 as part of her keynote speech: *"I have seen for myself the immediate impact flooding has but this study helps us better understand how devastating flooding is for businesses, families and communities alike…This is why the Scottish Government has supported the Scottish Flood Forum since 2008. This year, we have made £190,000 available to the Forum to help communities prepare for and recover from flooding…I am grateful to the residents of Ballater and Garioch who gave their time to speak to the researchers about their personal experiences and look forward to the findings from this study to help build on our resilience and minimise the impact of flooding across the country."* The research was also cited when the Flood Risks Management (Scotland) Act 2009 was laid before the Scottish Parliament by the Scottish Ministers under Section 52 in January 2021.

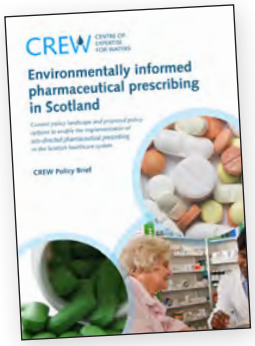
Lead Policy Contact:
Debi Garft, Scottish Government

Pharmaceuticals in the water environment and the One Health agenda



Since 2018, CREW has been instrumental in creating effective networks and opportunities for co-constructing and facilitating research around a) reduction of pharmaceuticals in the water environment, and b) environmentally informed or eco-directed prescribing. Benefitting from additional funding from Highlands and Islands Enterprise, CREW organised a workshop in Stockholm with partners from SEPA/Scottish Water/NHS Highland to learn and bring intelligence back to Scotland about the WISE List philosophy. That trip forged the OHBP. Further funding was secured for a SEFARI Gateway (SPARK) project on the transport, fate and impact of pharmaceuticals in the environment in Scotland here.

The initial CREW project, carried out by researchers at Glasgow Caledonian University, the James Hutton Institute and the University of the Highlands and Islands delivered the first national assessment of pharmaceutical pollution in Scotland's water environment (Summary report, Full report). To enhance access to the pharmaceutical database, and realise the impact from this important research, CREW worked with the OHBP and the research team to develop an interactive data Visualisation Tool that was ultimately funded and hosted by SEPA (completed in 2022). The data (and gaps identified) have informed a review of SEPA's Chemicals of Emerging Concern monitoring and Scottish Water's monitoring of septic tanks. The data are also being used as part of SEPA/Scottish Waters 'One Planet Choices' project/trial in the Eden catchment. Within NHS Highland, there has been ongoing development of a 'green formulary' based on environmental impact and ecotoxicological risk, plus antibiotic and local prescribing changes. An innovative Scottish partnership, One Health Breakthrough Partnership (OHBP) has been using the results to promote practical actions to reduce this globally recognised public health and environmental issue and is now a partner in Hydro Nation, with the One Health Hydro Nation project (2020–present) receiving funding from the Scottish Government to further promote the important work instigated by CREW via effective multi-agency collaboration.



In 2021–2022, a CREW Policy Fellowship acted to further enhance understanding and awareness of Environmentally informed pharmaceutical prescribing in Scotland. A joint analysis of policies on pharmaceutical prescribing and environmental monitoring of pharmaceutical substances in water environments was conducted to investigate whether the current policy landscape supports the adoption of eco-directed prescribing in the Scottish context. A three-pronged policy framework was proposed to effectively integrate eco-directed prescribing as a joint programme of health and environmental sectors in the country. The framework includes: 1) the organisation of a coordinative mechanism between key stakeholders; 2) systematic integration of environmental criteria in formulary development supported by expert evaluation of environmental risks of pharmaceuticals; and 3) improving knowledge of healthcare workers and the public on the environmental impact of medicines.

Lead Policy Contact:
Barry Greig, SG Water Industry Team

Radon in groundwater drinking water supplies in Scotland

As part of a review of the implications of Council Directive 2013/51/Euratom on radon regulations in drinking water, CREW and the James Hutton Institute recommended a map of areas of likely medium- and high-risk of exposure to radon in drinking water using data from British Geological Survey, Health Protection Agency and SEPA.

The Phase 2 report Radon in groundwater drinking water supplies in Scotland (2017) presented comprehensive evidence on radon concentrations in public and private groundwater supplies in Scotland, and provided recommendations for the monitoring and mitigation of radon in all groundwater public water supplies at the treatment plants and for private water supplies in the high-risk area. Figure 8 provides an overview of the impact activities (red), enabling factors (yellow), intermediate outcomes (blue) and actual benefits (green) from the CREW work. A key enabling factor was effective mediation and dialogue facilitation. Intermediate outcomes include that methodology developed by the project enabled DWQR to transpose the Council Directive 2013/51/Euratom via the Private and Public Water Supplies (Miscellaneous Amendments) (Scotland) Regulations 2015. Scottish Water also now tests for radon in drinking water in specific locations using the targeted sampling approach and ultimately saves money for both Scottish Water and households with private water supplies.

Lead Policy Contact:
Sue Petch, Drinking Water Quality Regulator

5.1.4 Benefits to other stakeholders

CREW's science-policy priorities include engaging with a wide range of information users and communities to maximise the benefits of the research to society. Examples of outputs and activities with benefits beyond the policy community include the Valuing Your Soils projects and Rural Sustainable Drainage Systems practical design and build guide for Scotland's farmers and landowners; a review of climate change and risk to water resources for Scotland's water industries; a role in facilitating discussions in the development of the North Glasgow Integrated Water Management System; ongoing benefits from a CREW surface water flood forecasting project, and; sharing knowledge through a Handbook of Catchment Management.

Valuing your Soils

It can take 500 years to replace 25 mm (1 inch) of topsoil, yet in the UK it is estimated that 2.9 million tonnes of soil are eroded each year, and soil quality is diminished by poor practices. CREW commissioned the "Valuing Your Soils" brochure and additional materials, videos, podcast, training course and farmer events to help Scottish farmers, crofters, and land managers protect and improve their most valuable resources.

The brochure, funded by CREW and produced by SRUC in partnership with stakeholders, includes useful information about Scotland's agricultural soils and practical advice outlining the upfront financial savings and business benefits of better soil management and the efficient use of resources. Action and problem-specific 'field-sheets' were designed 'with farmers for farmers,' with the

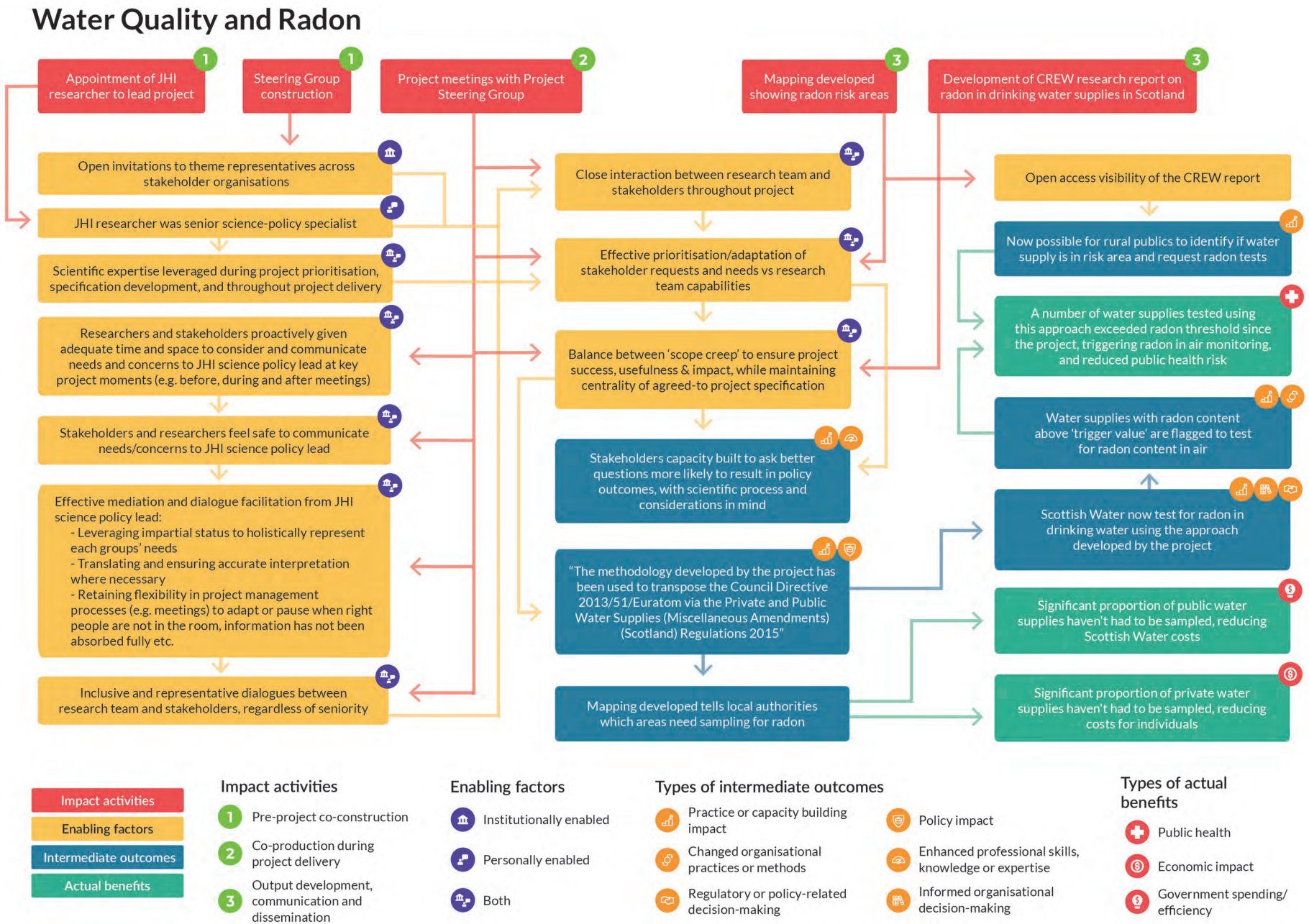


Figure 8. Water Quality and Radon Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

appendix containing more detailed technical information and research case studies highlighting evidence from current investigations of Scottish farm soils.

Five regional engagement events for farmers were held at the case study farms used within the 'Valuing Your Soils' guidance. The events aimed to make a real impact to the farming community and increase farmer uptake of the guidance specified in the booklet through training, demonstrations and opportunities for knowledge exchange and open discussions between farmers, advisors, and researchers. Video and podcast resources were produced as an additional means of sharing findings with the farming community. These included 'Protecting Soils using Controlled Traffic Systems with Robert Ramsay at West Mains of Kinblethmont' and 'Chisel Ploughing to Open Dairy Farm Soil Structure with Hugh McClymont at Crichton Royal Farm.'

Further events and outputs from this project and related CREW projects within this Programme include a two-day stakeholder training course on 'Risks to Soil Health, Structure and Drainage' in 2016 which explored findings of the Valuing Your Soils project plus two other CREW projects through workshops and in-field training on soil examination and management in relation to water quality and flood risks. In 2022, two guidance documents were produced, one titled 'General Diffuse pollution prevention solutions' which outlined practical ideas to protect soils and reduce diffuse pollution risks, and although there is no 'one-size-fits-all' approach, a second guide titled 'Soil Erosion and Diffuse Water Pollution Mitigation' which examined how much some of these measures cost and how easy they are to put into practice. A technical report, "A state of knowledge overview of identified pathways of diffuse pollutants to the water environment,' (2022) highlights the main routes soils and nutrients are lost to the water environment. Key findings indicate that standard agricultural practices are the main source of nitrogen and phosphorus pollution rather than poor nutrient management practices in Scotland. Spatial modelling showed that surface runoff and erosion are the main source of phosphorus loss in arable soils while phosphorus loss through drains is also a key pathway, particularly in improved grasslands on soils with artificial drainage. Good soil nutrient management such as the use of a fertiliser plan linked to soil sampling for nutrient status and soil pH is a simple and cost-effective measure for minimising pollutant losses.

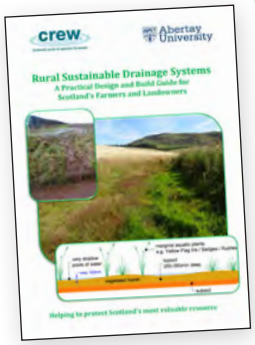
Rural Sustainable Drainage Systems design and build guide

Soil cultivation, manure/fertiliser applications and chemical spraying can all contribute to diffuse pollution from agricultural land. Rainfall-runoff from farm roads, tracks, yards, and dusty roofs are also potential sources of diffuse pollution. As highlighted in the example above, this not only has cost implications for a farmer but these incidents across a catchment have a significant impact on the water environment.

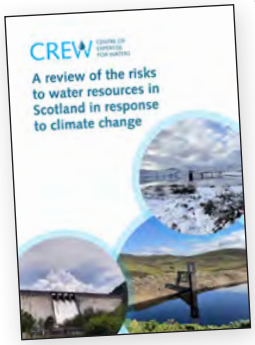
CREW commissioned a Design and Build guide that can be used by farmers and land managers to reduce diffuse pollution through use of Rural Sustainable Drainage Systems (Rural SuDS). Rural SuDS reduce agricultural diffuse pollution impacts as they are physical barriers that treat rainfall-runoff. They are low cost, aboveground drainage structures that capture soil particles, organic matter, nutrients, and pesticides before they enter the water environment. Rural SuDS for steadings prevent blockages in drains and ditches. They contribute to good environmental practice and farm assurance schemes. In fields they can be used for returning fertile soil back to farmland and will help a business become more resilient to the impacts of climate change. Trapping soils, organic matter and nutrients means that valuable assets can be reclaimed – recent studies indicate savings of £88 per hectare per year.

Published in 2016, the guide, produced by Abertay University, provides information for users to help select, design, and build the most suitable rural sustainable drainage systems for farms and explains how to look after the systems. It can also be used by farmers etc. who wish to apply for an Agri-Environmental Climate Scheme (AECS) grant. The guide also promotes the wider benefits of rural sustainable drainage systems such as coping with extreme weather related to climate change, localised flood prevention and enhancing biodiversity. Case studies included in the guide illustrate how these practices have been successfully applied around Scotland.

Climate change and risk to water resources in Scotland



There is "irrefutable evidence" that the global climate is changing due to human activities. Even in 'water rich' countries like Scotland, these changes will have implications for the future of water resources. In Scotland, changes in rainfall patterns (spatially, temporally, and seasonally), together with the frequency and magnitude of extreme weather events including flood and drought, would result in significant challenges for Scotland's key industries including the water sector. Such changes will impact drinking water supply, energy, agriculture, economic activity, and supply chains. Although there are inherent uncertainties surrounding the climate change projections for precipitation at the global scale, and what they mean regionally for Scotland, especially in the short-term (e.g., the next 30 years), water companies in Scotland increasingly need to compare and balance the evidence relating to changes to Scotland's climate with their medium to long term planning decisions about the way water is stored, managed, and used.



This CREW report published in 2022, provides a review of studies that have assessed historical and future river flow and water availability changes in Scotland, as well as evidence on how climatic, hydrological, and other catchment-based processes may influence water resource availability in the future. Some of the key findings of the review include that river flows (outflows) have increased significantly over the 1961–2010 period in Scotland. While UK total annual outflows may not change significantly, future seasonal projections in the UK generally show seasonal reductions in spring and summer flows, a mixed pattern in autumn flows, and small increases in winter flows.

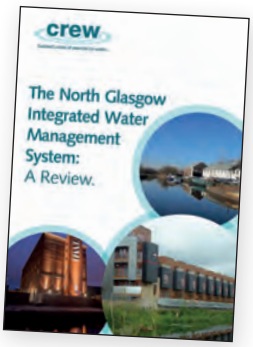
The review highlights that there is uncertainty regarding future frequency, duration and magnitude of both droughts and floods, including their timing and spatial extent, due to the different methodologies, indices and thresholds used and different types of hazards analysed in the studies reviewed. However, there is a consensus relating to an increase across all metrics (frequency, magnitude, and duration) Scotland-wide in a warming climate. In terms of droughts, in Scotland, compound hydro-hotspots (droughts and floods) are projected to occur across eastern Scotland and the Highlands and Islands, including the Loch Ness and River Tay catchments in the far future. In the 2050s, irrigation demand, especially in summer, may rise due to an increase in temperatures alongside an increase in potential evapotranspiration.

Water scarcity in Scotland – especially for private water supplies and water-dependent industries (e.g., whisky or agriculture) – may become an issue in the near-future, particularly where these industries are groundwater-dependent. The report outlines recommendations for future lines of research on effects of climate change on Scotland's water resources. Evidence from this project has supported resilience planning in the Scottish water industry.

North Glasgow Integrated Water Management System

The Metropolitan Glasgow Strategic Drainage Partnership (MGSDP) is a non-statutory partnership between public bodies involved in managing surface water, water quality, flood risk, investment planning and economic delivery, with a vision to 'Sustainably Drain Glasgow.' Since its inception the partnership, which consists of Scottish Water, Glasgow City Council, Scottish Canals, South Lanarkshire Council, Clyde Gateway, Scottish Enterprise, Renfrewshire Council, East Dunbartonshire Council and SEPA has sought innovative ways to manage urban water systems that are ultimately sustainable, support the continued growth of Glasgow and meet the objectives of the Hydro Nation Agenda.

The MGSDP began following severe flooding in July 2002 in the East End of Glasgow. It was recognised that an integrated strategy to master planning was required to meet the needs of all stakeholders as responsibilities for stormwater management in Scotland are divided between several parties, with conflicting statutory duties and unaligned funding streams making collaboration difficult.



When the resulting North Glasgow Integrated Water Management System (NGIWMS) was at a study phase, CREW was asked to act as a neutral organisation and validate the plans together with hosting stakeholder workshops to support the implementation of the MGSDP vision for NGIWMS. At two CREW-facilitated workshops, the MGSDP partners engaged and discussed the operation, charging mechanisms, investment requirements and delivery plan

to translate their vision into a sustainable reality for Greater Glasgow as Glasgow City Council embarked on delivering their regeneration plan for North Glasgow. A review was published by CREW in 2016 with recommendations on system governance, leadership, and funding considerations.

A second CREW project was commissioned by the partnership in 2019 as the MGSDP entered its next phase, and the partnership wished to take stock of the gains made, study its impact, and fully understand how the knowledge gained can be used to address challenges other cities in Scotland face. In the coming decade, the scientific, political, and public aspirations to mitigate climate change impacts will result in increased demand for investment in adaptive approaches and collaborative working. To support the MGSDP and inform policy developments, the research team reviewed how it has operated to identify the lessons learnt. Lessons learnt were considered in the context of both the MGSDP's future and the development of new partnerships.

The integrated approach to water management will provide a range of benefits that include long-term regional growth; jobs in the local area; ecological recreational spaces; green infrastructure; sustainable urban drainage; internationally recognised case study in best practice water management; and improvements to air quality.

Surface water flood forecasting for urban communities

Ongoing and far-reaching benefits to stakeholders, summarised in Figure 9, have been realised from a CREW project in 2014–2015 by CEH and the James Hutton Institute in collaboration with the Met Office and SEPA. The project developed a modelling methodology for surface water flood forecasting that could be operated in real-time. Enabling factors linked to stakeholder engagement are highlighted in yellow (Figure 9). The Commonwealth Games in Glasgow 2014 was the first intended opportunity to test the methodology in a real situation where the risk of flooding was considered a major concern to strategic operations. Intermediate outcomes (blue, Figure 9) include that the system is still being used by SEPA in Glasgow and was later adopted in England and Wales. With further external funding, the system was also piloted in Kerala, India and Sahel, Africa. The forecasting system has been beneficial for issuing transport warnings and informing the emergency services community (green, Figure 9). The team published the research in the Journal of Flood Risk Management in 2016 and won the Royal Meteorological Society Innovation Award 2018.

Handbook of Catchment Management

In 2021, the CREW Director, Bob Ferrier, and Prof. Alan Jenkins, UKCEH published the Handbook of Catchment Management, Second Edition. The first edition (2010) provided a benchmark on how understanding and actions in catchment water management had evolved in recent decades. Eleven years on, the catchment management concept is entering a new phase of development aligned to contemporary and future challenges. These include climate change uncertainty, the drive for a low-carbon, energy efficient and circular society, the emergence of new pollutants of concern, the integration of water across the Sustainable Development Goals (SDG) and the link between water, energy, and food. These developments are framed within an increasingly data rich world where new analytics, sensor technology and processing power are informing increasingly real-time decision making. The challenge is also to increase cross-compliance and policy integration to meet multiple stakeholder objectives, and to link actions to achieve cost-effective outcomes.

5.2 Collaboration and Multidisciplinary Working

CREW's central principles include promoting improved networking and win-win solutions as part of delivering tangible impact and longer-term outcomes for the water environment and society. Whilst CREW's projects inherently involve collaboration and multidisciplinary working, CREW's engagement goes far beyond its project work. Examples are given below of collaborative working with/contribution to: the Centres of Expertise and Sefari Gateway, iCASP, the Scottish Universities Partnership for Environmental Research, the Scottish Alliance for Geoscience, Environment and Society, Scottish Freshwater Group, UK Water Partnership, UK 2050 Water Innovation Strategy, Chartered Institute of Water and Environmental Management, VIBES Scottish Environmental Business Awards and wider Hydro Nation initiatives, including the Hydro Nation Scholars Programme, the Hydro Nation Water Innovation Service, and the Hydro Nation Chair Research and Innovation Programme. Collaborations and examples of multidisciplinary working described in this section will continue into the next programme and exciting new partnerships will evolve that will help CREW address contemporary challenges in the water sector.

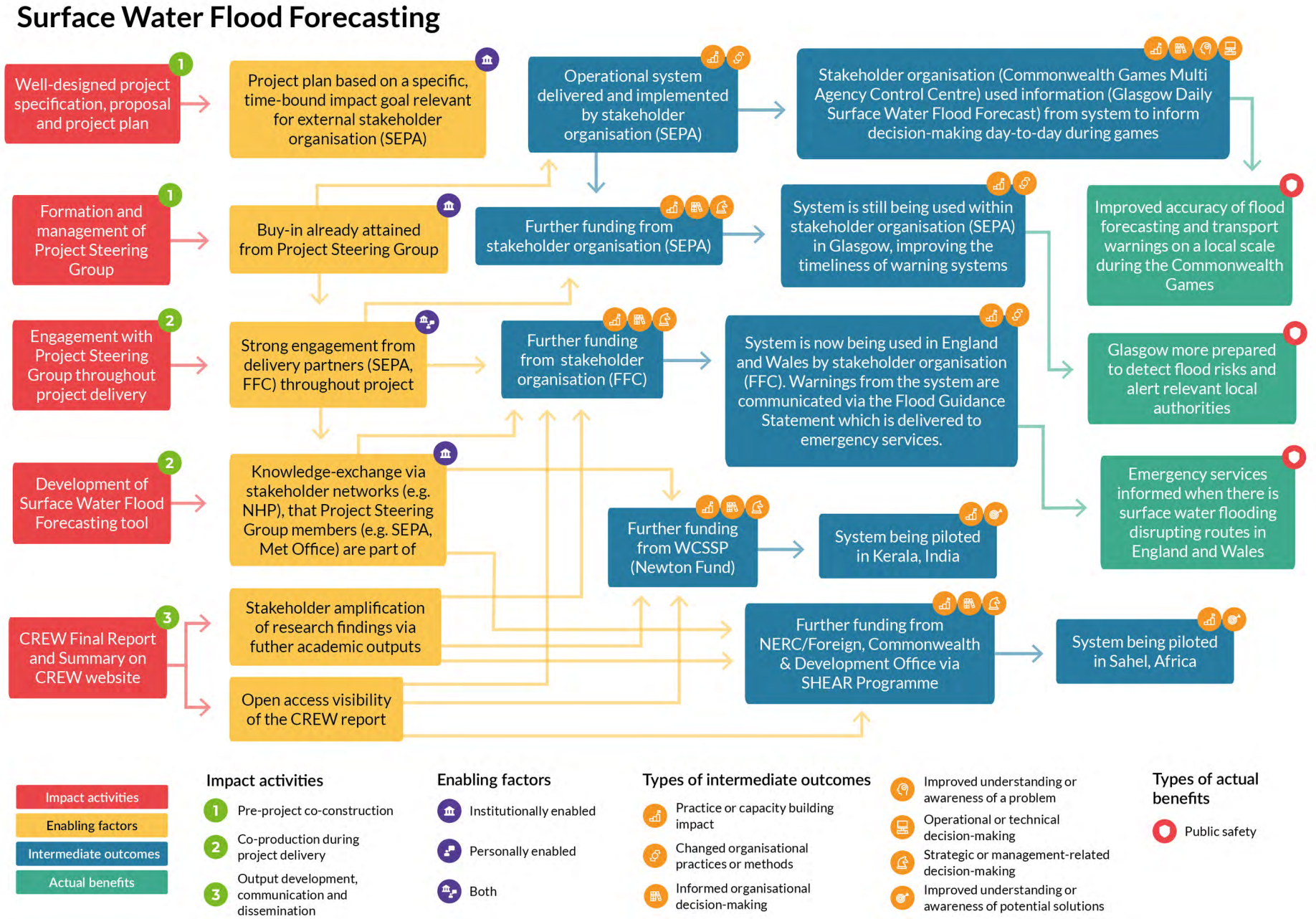


Figure 9. Surface Water Flood Forecasting Theory of Change. From Jensen, E., Reed, M., Noles, S. (2022) CREW Strategic Impact Report (Internal report) by the Institute for Methods and Innovation and Fast Track Impact.

Centres of Expertise and Sefari Gateway

CREW has collaborated with sister Centres of Expertise (CoE) exploring the various Centre operational models; learning from shared experiences on delivery options; seeking opportunities for synergy and added value on the projects we lead; delivering joining training; planning for COP26 and wider events. An example of the collective value of all Centres working together to deliver the wider policy needs was the joint analysis of the potential role of forestry to contribute towards Scotland's net zero carbon emissions target, from the perspective of catchment management, social science, water quality/quantity, climate change, tree health and disease. Concurrently, CREW has been working with SEFARI Gateway to coordinate efforts and identify opportunities to raise the profile of water and the research being undertaken across the RESAS portfolio.

The Centres of Expertise Mid-Programme (2018) review panel encouraged CREW to share its operational processes and Quality Manual as a template for other Centres. CREW and CXC have worked closely together to identify synergies in project requests related to flooding and peatland management and have developed a formal communication plan. The Centres shared a stand at the Sniffer Flood Risk Management Conference in 2019.

Yorkshire Integrated Catchment Solutions Programme (iCASP)

The CREW team constantly strives to improve our delivery model and how we operate. Prof. Julia Martin-Ortega, a member of the CREW Steering Group, introduced the CREW team to the Yorkshire Integrated Catchment Solutions Programme (iCASP) team who are working to generate benefits for Yorkshire by applying environmental science to catchment challenges. The Centres shared knowledge on operational and financial models, procurement processes and the catchment challenges we face, but most importantly, solutions and approaches to overcome issues.

Scottish Universities Partnership for Environmental Research (SUPER)

The Scottish Universities Partnership for Environmental Research (SUPER) Doctoral Training Programme (DTP) is built around a well-established collaborative group of universities delivering world-leading research in natural environmental science. CREW works closely with the SUPER DTP providing training courses and expert advice as part of the PhD project selection process.

Each SUPER partner is a member of the Marine Alliance for Science and Technology for Scotland (MASTS) whose research and training collaborations address innovative scientific challenges across the NERC remit in topics (environmental physics and chemistry, biodiversity, global change and mathematical modelling of populations and ecosystems). More recently the SUPER DTP extended its remit to themes of direct relevant to CREW covering the "catchment to coast" paradigm that supports the holistic study of the ecological dynamics of systems from headland rivers and catchments through lowland regions and riparian systems to transitional waters and shallow marine ecosystems.

Collaboration with the SUPER DTP informs CREW of the broader water-related research activities in Scotland and creates a further avenue – beyond the CREW HEI Champions – for CREW engagement with the research community. This special relationship allows CREW to maintain a contemporary handle of relevant academic research to support future CREW projects. Engagement with the programme permits an efficient and effective exchange of information on a practical level to
a) avoid duplication of research themes/projects across, for example, the Hydro Nation Scholars Programme;
b) allows CREW to share experience with students as part of their Continuous Professional Development e.g., 'Writing for a policy audience';
c) through this route CREW is actively training the next generation of academics to potentially deliver future CREW projects.

Scottish Alliance for Geoscience, Environment and Society (SAGES)

The CREW Manager developed strong links with the Scottish Alliance for Geoscience, Environment and Society (SAGES), is a representative on the organising committee and acts as co-leader of the Integrated Water Cycle Management forum with Dr Irena Connon, University of Dundee. The research interests of the Integrated Water Cycle Management forum broadly align to CREW's Thematic areas and therefore provide an excellent network to facilitate the dissemination of high impact, multidisciplinary research demanded by a Centre such as CREW. Topics covered by the fora include a) water resource management to help reduce the risks posed by

climate change; b) the routes in which Scotland is leading the transition to net zero carbon emissions through innovative solutions; and c) how to ensure that water resource management and transitions to net zero are socially and environmentally just.

The CREW Manager collaborated with the SAGES committee to coordinate Annual Science Meetings (ASM), forums, workshops and has contributed to working groups to produce integrated proposals in response to funding calls etc. In 2022 as part of the COP26 campaign, CREW directly engaged in 'SAGES stories: Scottish science for a climate-ready future' and SAGES financially supported the prize giving for the Water Wall in Motion initiative at World Water Day.

Scottish Freshwater Group (SFG)

CREW has worked closely with the Scottish Freshwater Group (SFG) which promotes expertise and collaboration on a wide range of issues related to the freshwater environment. Bi-annual event agendas focus on a common theme of interest or open topic discussion and comprise a blend of talks, bite-size presentations, and lunchtime poster session. The CREW Director opened the 105th Scottish Freshwater Group Meeting (2021) which was led by the Hydro Nation Scholars. Scottish Freshwater Group's Action Team help SFG members to collaborate on fundamental issues and drive the ambition for Scotland's freshwaters. The CREW Manager is co-leader of the Climate Action Team (Scottish Freshwater Group), chairing Action Team meetings and sessions at SFG events.

The UK Water Partnership

The CREW Manager is part of The UK Water Partnership. Established in 2015, the UK Water Partnership aims to provide a strategic vision for the development and growth of the UK water industry. It brings together a diverse water sector and related organisations in a single alliance, promoting mutual understanding, cooperation, and coordination. The CREW Manager attends UK Water Partnership meetings, collaborative events, and delivery group meetings and shares useful information as and when relevant, with relevant stakeholders and the research community in Scotland.

UK Water Innovation Strategy

Drawing in the extensive networks and multidisciplinary working developed over the programme, CREW actively coordinated responses on behalf of the Scottish consortia to consultations for the first UK 2050 Water Innovation Strategy (published in 2020). The Strategy sets out a vision for transformational change across the water sector up to 2050 and ensures that Ofwat's £200 million Innovation Fund is targeted at projects to deliver the most benefit for the sector.

CREW was approached in 2021 to join a consortium to develop a proposal to manage the Innovation Fund and, specifically, to draw on CREW's networks to provide water sector/industry insight, combined with advice and guidance on the set-up and design of the programme (e.g., peer review of application forms etcetera). Whilst the bid was unsuccessful, it did highlight the wider reputation of CREW beyond Scotland for successes in effective partnership working and collaboration.

Chartered Institute of Water and Environmental Management (CIWEM) and VIBES Scottish Environmental Business Awards

CREW established links with CIWEM/VIBES and jointly planned/sponsored an event in March 2020 to engage early career scientists from HEIs to explore the effects of climate change on water and to understand how Scotland is adapting to such changes or improving water efficiency. The event was postponed to due to Covid19 and will be rescheduled early in the next programme. The VIBES Scottish Environment Business Awards are a partnership between Scottish Environment Protection Agency (SEPA), The Scottish Government, Energy Saving Trust, Highland & Islands Enterprise, Scottish Enterprise, South of Scotland Enterprise, Scottish Water, Zero Waste Scotland and NatureScot.

Hydro Nation International Centre

CREW is a central pillar of the Hydro Nation International Centre (HNIC), a one-stop shop for activities around talent development, innovation, research, and impact for the water sector, established in 2019. Linking industry, policy, research, and agencies to support economic development and good stewardship of water resources and to share best practices around the world, CREW personnel were intimately involved in the development of the HNIC and have contributed to Hydro Nation international projects and activities within this reporting period.

Hydro Nation Scholars Programme

The Hydro Nation Scholars Programme, managed through the Hydro Nation International Centre, supports PhD student research on innovative water challenges and aims to develop the water leaders of the future. Hydro Nation Scholars Programme PhD projects are highly relevant to the 12th objective of the Hydro Nation policy agenda – to develop the economic, environmental, and social value of Scotland's water resources. The PhD projects span industrial application, socioeconomics and value, governance, climate change, resilience, rural economies and environmental, physical, ecological, and hydrological mechanisms and impacts and innovation across the water sector, and as such there is often complementarity with CREW projects and occasions where scholars or alumni have contributed to CREW outputs. CREW liaises with scholars and their academic supervisors within the Hydro Nation Scholars Programme and Fellows Programme in opportunity awareness and knowledge exchange activities, including HNIC hosted events such as World Water Day, and CREW personnel have been intimately involved in the development of bespoke training and engagement programmes for the scholars.

Hydro Nation Water Innovation Service and links to industry

During the 6-year programme, CREW worked closely with Scottish Enterprise, Highlands and Islands Enterprise, and Scottish Government to stay abreast of developments in water technology innovation, specifically for drinking water and wastewater treatment. This is a core goal of the Innovation/National Theme of the Hydro Nation Strategy and embedded in CREW's Water Quality theme. One of the goals of the Hydro Nation Strategy is to support innovation for the water sector so new products and processes can be bought to market more quickly for the benefit of the water industry, thereby reducing costs for consumers, reducing carbon emissions, and contributing to the blue/green/circular economy and net zero agenda. CREW was tasked with a project to review the current funding/support landscape to better design the next iteration of Hydro Nation Water Innovation Service (HNWIS).

The CREW report entitled 'The Scottish Water Innovation Landscape: Challenges and Opportunities for the Hydro Nation Water Innovation Service,' informed the revision of HNWIS which ultimately led to the establishment of a new 'water' pillar in the development of the Hydro Nation Water Innovation programme through a water stream within the Energy Technology Partnership (ETP). Going forwards, new collaborations will be forged with the ETP.

Hydro Nation Chair Research and Innovation Programme

Prior to the appointment of Prof Andrew Tyler (University of Stirling) as the Hydro Nation Chair, CREW had close research connections with the Stirling team and contributed knowledge and expertise regarding stakeholder engagement, networks, and partnerships (academic, industrial, regulatory etc.) to several projects and proposals. Recognising the importance of digital technologies and the expertise held by Prof Tyler and his team, CREW organised two 'Digital Waters' workshops to identify how the digital revolution has the potential to transform water research and the opportunities for the water industry, regulators, and practitioners.

CREW is an active member of the Forth Environmental Resilience Array (Forth-ERA) steering group (led by University of Stirling). The project aims to provide the region with the world's first green recovery platform, creating a regional living laboratory across the Forth Valley. Drawing on established multi-disciplinary networks within Scotland, CREW has been instrumental in bringing the Scottish research and stakeholder community together to help the project achieve its goal "to provide communities, agencies, businesses, and organisations access with real-time environmental data which ensures the environment is at the heart of decision making."

Building on existing relationships, CREW swiftly engaged with the University of Stirling team when they were awarded the Hydro Nation Chair Research and Innovation Programme to deliver the knowledge and capability required to enable transformational change and to attain net zero carbon emissions by 2040. Since the establishment of the Hydro Nation Chair Research and Innovation Programme in 2021, CREW has engaged in joint proposals (e.g., EPSRC Digital Blueprint) with the Hydro Nation Chair, Professor Andrew Tyler, and other Scottish Higher Education Institutions. CREW and the HNIC welcomed the new initiative and invited Professor Tyler to launch the programme at the World Water Day event (2022) and worked with the Hydro Nation Chair on the production of material for the virtual pavilion here and other events (e.g., SAGES AGM).

CREW CENTRE OF EXPERTISE FOR WATERS

Centre of Expertise for Waters

Hydro Nation International Centre

James Hutton Institute

Craigiebuckler

Aberdeen AB15 8QH

Scotland UK

Tel: +44 (0)344 928 5428

CREW publications can be accessed here:
https://www.crew.ac.uk/publications

enquiries@crew.ac.uk

www.crew.ac.uk

crew_waters crew-scotland

Hydro Nation International Centre

The James Hutton Institute

Scottish Government
Riaghaltas na h-Alba
gov.scot

CREW is a partnership between the James Hutton Institute and Scottish Higher Education Institutes and Research Institutes. The Centre is funded by the Scottish Government.