World Water Day

22nd March 2019

Exploring Scotland's Resilience to Drought and Low Flow Conditions: Full Report

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Foreword by Bob Ferrier, Director, Centre for Expertise for Waters (CREW)

It is my great pleasure to present in this report the outcomes of the World Water Day 2019 Conference, held at the Apex Hotel, Edinburgh on the 22nd March 2019. The organisers of this event (CREW, Hydro Nation International Centre, James Hutton Institute, the UK Centre for Ecology and Hydrology, and the University of Stirling) brought a wide set of stakeholders together to explore the contemporary issue of drought and its impact on Scotland's environment, businesses and people.

Today, the world is facing many challenges related to the availability and the quality of water. Despite progress in recent years, access to water is not yet a universal reality: according to the United Nations, 3 in 10 people worldwide still lack access to clean water and 6 in 10 lack access to a safe sanitation facility. Quality and quantity of water are vulnerable to the consequences of global warming, including droughts and floods, and demographic shifts. In Scotland, our reserves of water are globally significant, but we need to heed the warnings implicit in the drought during the summer of 2018. The challenge for us all – scientists, regulators, practitioners and the public – is to create innovative solutions to ensure that our resources meet demand, even when water is scarce.

Disclaimer

Unless otherwise indicated, the ideas and opinions expressed by the speakers do not necessarily represent the views of their organisations. Please note that the views reported from group discussions cannot be assumed to be the views of the entire group. As such, the appearance of these views in this report does not imply that all participants agree with the views expressed, although group consensus was sought where possible. The contributions in Section 2, are edited versions of the text shared by presenters after the workshop, except for sections 2.3 & 2.6 which are texts based on the presenters' slides. The results of the group discussions in Sections 3-5 derive from the notes made by group rapporteurs and rewritten by the report authors.

This report has been provided to the participants for review prior to its publication.

1.0 Introduction

The World Water Day Conference 2019 brought together 100 scientists and practitioners from across Scotland in an event that combined presentations, from a diverse set of key stakeholders in Scotland's water sector, with focus-group discussions (see Appendix I: Conference Programme).

Photo courtesy of Carol Taylor

Section 2 summarises the expert presentations by the UK Centre for Ecology and Hydrology, Scottish Water, Chivas Brothers, Citizens Advice Scotland, cbec, Ness District Salmon Fishery Board, National Farmers Union, and the Fraser of Allander Institute, among others. The topics included drought risks, consumer and system resilience, water resource management strategies and the interplay between environmental change and water's role as an economic resource.

Three group discussions were held concurrently, and delegates were invited to contribute to each as part of a discussion carousel. The discussion themes included:

1. Resilience planning and adaptation strategies;
2. Emerging issues for drought and low flow conditions; and
3. Enhanced monitoring through technical innovation and citizen science;

In each group the allocated theme was explored by way of discussion of the following questions:

- What lessons have we learnt from recent experiences?
- What lessons can we learn from our national and international counterparts?
- How can we work more effectively across disciplines to enhance resilience?
- How can communities support monitoring and adaptive management?
- Identifying the 'need' for research– what, when, why and how?

2.0 Summary of expert presentations

2.1 What areas in Scotland are most susceptible and at risk to drought and why?

Presenter: Stephen Turner
(Hydrologist, UK Centre for Ecology and Hydrology)

In 2018, the UK received slightly below average rainfall, and less than this in some regions. Areas of northern and eastern Scotland received less than 75% of the expected rainfall. River flows for 2018 reflect the rainfall, or lack thereof: whilst the majority of monitoring sites were in the normal range, there were a number of rivers "below" and "notably below" normal flows in northern and eastern Scotland.

Concentrating on the dry summer period, June – July 2018, the rainfall was very low. There was an increase in interest from the media, and front-page stories about the heat and dry weather were commonplace. This engaged the wider public. For the same June to July period, record low flows were recorded at a number of index sites including the Boat O' Brig, River Spey (a record since 1952) and Whiteadder, River Tweed (a record since 1969). The data show that the lack of rainfall in these areas, beginning in March, led river flows to plummet for consecutive months, recording below average flows consistently for this period. For Great Britain as a whole, total river outflows for July 2018, were ranked third driest in a record going back to 1961, after the notable drought years of 1976 and 1984. In Scotland, impacts of the dry weather were beginning to be seen. For example, wildfires were reported in Torridon and Skye and agricultural impacts were felt. Farmers reported pressures on yields and warned of impending crises e.g. for many farmers, silage crops meant for the winter periods were underperforming. Landowners witnessed the drying of fords and streams on their land and some reported that they had not witnessed such conditions in their lifetimes. There were calls on the public to conserve water.

The winter of 2018 represented the third consecutive, dry winter half-year (October to March), notably so in northern Britain. Whilst water resource concerns, since then, were allayed to some extent by rainfall in March and early April 2019, low groundwater levels highlighted the need for additional rainfall to alleviate potential water resource pressure later in 2019. However, increasing evaporation rates limit the effectiveness of rainfall and potential for recharge, suggesting below normal groundwater levels were likely to persist through the summer, 2019, in the south-east of Britain.

Monitoring and early warning to support the resilience of drought in the UK is vital to understand what is happening, how the current situation reflects historical patterns, and to predict what may happen in the future. The UK Water Resources Portal[1] is a web-based tool to help visualise the current meteorological and hydrological conditions across the UK and to understand the severity and magnitude of drought at different spatial scales over the past half-century. River flow data are updated in near real-time, and rainfall data monthly and can be viewed in the raw observed format as well as standardised indices within river basins and individual catchments.

The About Drought project[2] is working with water managers to demonstrate the benefits of drought forecasts and to overcome barriers to their uptake through the co-design and evaluation of the forecast reliability, uncertainties, spatial/temporal scales. The project engages key stakeholders to overcome these barriers which in time will benefit the monitoring and early warning systems which will support enhanced resilience to drought in the UK (See Section 5.0).

Howden Reservoir, Peak District, 28th July 2018 © Katie Muchan, UK Centre for Ecology & Hydrology

2.2 Drought and its effect on agriculture and irrigation practices – England and Wales

Presenter: Paul Hammett
(National Water Resources Specialist - National Farmers Union)

A picture of what's happened down on the farm was based on a drought survey carried out in August 2018, and a further recently completed survey (February 2019) that reviewed prospects for the current farming year.

The surveys were modest in terms of the sample size (600 farmers August 2018 and 150 February 2019) but the surveys achieve good coverage across all regions and commodities, and some rich anecdotal text from conversations with farmers. Whilst questions focused on the drought, the impacts on farmers were, of course, a combination of water scarcity and heatwave. The greatest impact, common to all farmers, trying to manage land during extreme weather conditions is the higher business running costs incurred, including higher labour costs.

The surveys confirmed that farmers are very vulnerable to extreme weather risk and have few tools available to help them manage that risk.

1 *https://eip.ceh.ac.uk/hydrology/water-resources/*
2 *http://www.aboutdrought.info/*

Impacts on production

Arable crops faced a difficult growing year in 2018 starting with the freeze/thaw at the start of the growing season followed by the drought. Crop quality and yields were affected, but these losses were partly counter-balanced by increased global wheat prices.

Photo courtesy of Paul Hammett

Livestock farms suffered a range of problems including reduced animal fertility, heat stress, and heat related diseases. Two-thirds of the farmers still experience (March 2019) a shortage of forage as a result of growing conditions in 2018. Of the farmers who reported shortages, two-thirds have been able to extend the grass growing season, two-thirds needed to buy in fodder, and half of them have sold off livestock. Looking forward, many farmers point out that they survived a major fodder shortfall in 2018 because of high reserve stocks already on the farm; but those surpluses have now been depleted.

Photo courtesy of Paul Hammett

Dairy farmers struggled with falling milk yields and animal welfare issues, as well as grass and fodder shortages. Dairy farms have a relatively high demand for water and many farmers were concerned about potential water shortages in 2019, both in the case of private supply and (in a few cases) mains water.

Horticultural production was badly hit in 2018 through a combination of insufficient allocation of water and an inability to provide sufficient water to meet crop needs.

At the height of the 2018 summer, crop growers of all kinds struggled with operational capacity issues caused by the limits of machinery and labour in applying regular and sufficient volumes of water to meet the needs of the crop.

Prospects for growers in 2019

As the vegetable planting season began in 2019, growers were already experiencing dry soil conditions, and there was general concern about potential yield reductions (some significant) and possible difficulties in meeting the irrigation requirements of crops. At the time of writing [2019] groundwater sources seemed secure, but many river abstractions were subject to 'hands off flow' (meaning abstractions have to stop when the river flow falls below a particular flow) constraints and NFU feared the early imposition of restrictions in some catchments. Much depends on the timing of rainfall and whether, when and to what extent the Environment Agency applies abstraction restrictions.

An increasing number of field vegetable growers have built winter-fill reservoirs to manage the risk of summer abstraction restrictions. However, due to dry winter weather and low river flows, a number of growers have been unable to fill their reservoirs [March 2019]. The Environment Agency recently agreed to offer some flexibility by allowing reservoirs to be filled if there is sufficient river flow. The current rules stipulate that reservoirs can only be filled in specified winter months, ending on 21 March.

Like the arable sector, many growers expected 2019 to be very challenging for farming operations and for staff morale amongst those working in extreme conditions.

Access to water

Three quarters of farmers in England are connected to a mains water supply, often as one of a range of water sources on the farm. Mains supply disruptions from low pressures and bursts are reasonably rare but have a major impact when they do occur.

Photo courtesy of Paul Hammett

In common with many other rural dwellers, many farmers rely on sources of unregulated private water supplies from wells and springs. In England, a licence is not needed where the abstraction is less than 20 cubic metres per day. It is difficult to gather information on deregulated water sources, but, given the typically shallow depth of the water abstracted, there is increasing concern about the vulnerability of isolated rural settlements to supply interruptions.

Contingency planning and adaptation

In agriculture, drought impacts are normally restricted to irrigated fruit and vegetable production in the south and east. But in 2018, such was the intensity of hot and dry conditions that many farmers representing all sectors across England were affected and few had contingency plans in place.

In times of hardship, the farming community comes together and the NFU often acts as a co-ordinator for various self-help schemes. The NFU re-activated the fodder bank, a web-based message board that helps to put livestock farmers in the west in contact with arable farmers in the east who might have straw available. It worked well with localised events such as floods where east-to-west transport is focused into one delivery area, but the logistics struggled with the spread of the drought.

In 2018, the NFU also launched the water bank as a match-making service to put farmers in contact with each other to potentially trade licenced water. This was part of NFU's ongoing discussions with the Environment Agency in searching for flexibility in the enforcement of regulations during an emergency.

One of the outcomes from the 2018 survey were requests for a scheme for forward planning in horticulture where crops' values and investment costs are very high and where water is a vital input. NFU found a high level of measures being put in place to mitigate against the impact of water scarcity.

- A third of irrigated crop growers made changes to the types of crops grown;
- A quarter reduced the planted area of particular crop types;
- A half invested in new irrigation equipment to increase efficiency and optimum use;
- A fifth invested in new or additional reservoir storage capacity;
- One-sixth explored opportunities for trading (of water and/or land with water rights);

One-sixth of farmers, however, were not taking any particular measures to manage risk of water shortage.

Prices and markets

Whenever the weather does anything remotely unusual, the media asks NFU about impacts on food prices. NFU economists are reluctant to comment given the global nature of the food supply chain. It's difficult to make a link between local droughts and food prices. For example, in 2018 the supply chain accepted lower quality – below spec – UK produce simply because it wasn't possible to import anything better because of the pan-European spread of the drought.

Policy

Putting drought in the context of farm policy, NFU are worried about how farmers will be protected against market and weather volatility after the UK leaves the Common Agricultural Policy. The current system of farm payments is not universally popular, but payments do provide a vital safety net to erratic farm incomes.

In terms of policies that address the lessons learnt from the drought, the focus of NFU is on a package of measures that protect farmers, help them to plan and adapt, and incentivise them to do so. For example, NFU would like to see:

- More water storage capacity to secure plentiful water for use when it is scarce;
- Better soil management techniques to lock in moisture;
- And a flexible approach to abstraction regulation.

Conclusion

A continuing drought could have a major impact on the delivery of home-produced primary agricultural products into the UK food supply chain at a time of trade distortions arising from our departure from the EU.

The NFU believes therefore that we cannot and should not be complacent about our ability to produce our own food. And we think there is a strong case to recognise water needed by farmers who grow our food as an 'essential use'.

2.3 Scottish Water's planning, preparation and response to the 2018 drought

Presenter: Mark Hunter
(Strategic development manager, Scottish Water)

Photo courtesy of Scottish Water

2018 witnessed the least rainfall in approximately 40 years. Despite this, Scottish Water managed to maintain raw water storage levels to the extent that it was able to avoid impact on public supplies. The management of the system's resilience has been key to this. Resilience has been generated through a range of activities, including:

- Continuous monitoring of raw water sources and weather forecasts;
- Proactive management of such sources and engagement with the Scottish Environment Protection Agency (SEPA);
- Water efficiency measures and working with customers and industry to reduce future water demand;
- Reducing leakage in the water network.

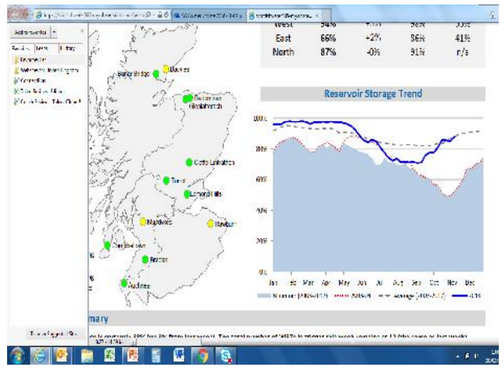


Photo courtesy of Scottish Water

Prompt drought impact response capabilities have also been important. Two examples of response activities have been the tankering of water to the Isle of Arran and the temporary installation of pumps to supplement Fifes water supplies. Additionally, in response to drought impacts on private water supplies (PWS), a range of activities were carried out, including the tankering of water, the setting up of temporary connections, bottled water deliveries, and the use of portable water tanks. However, in terms of PWS, there are limited options available for resolving the problem easily in the long term due to the fact that PWS tend to be in remote, hard-to-service areas. Any long-term resolution of the issues will need large amounts of money to be invested, along with high quality research and innovation.

The key messages from the 2018 drought are that climate mitigation action must be a priority for society, as must be dealing with predicted increases and geographical shifts in Scotland's population over the coming years. More work is required on understanding how to change consumer behaviour.

2.4 Private Water Supplies: the consumer perspective on improving resilience and water quality

Presenter: Rebecca Millar
(Policy Officer, Citizens Advice Scotland)

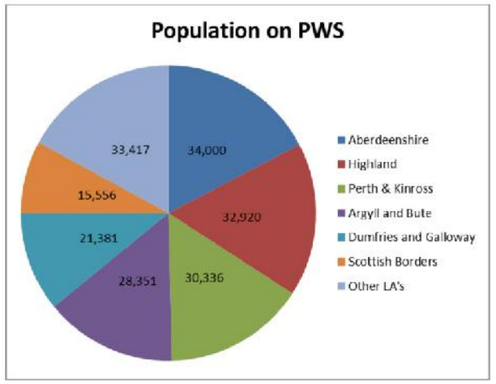


Photo courtesy of Citizens Advice Scotland

In 2018, Citizens Advice Scotland (CAS), in partnership with the Drinking Water Quality Regulator (DWQR), conducted qualitative research with 61 people reliant on either regulated or unregulated private water supplies across Scotland. The purpose of the study was to understand the type of support that communities reliant on private water supplies need to help them achieve a safe and sustainable water supply.

The need for resilient private water supplies was highlighted during the summer of 2018, which saw many communities running out of water. Running out of water can particularly be an issue for vulnerable customers, such as families with young children or people living in isolated locations. It is anticipated that climate change will result in more droughts and changes to rainfall patterns in future years, which will place further pressure on the sustainability of private water supplies. This is not an acceptable or sustainable situation and must be addressed.

The findings of the research provide a unique consumer perspective into the factors that those responsible for managing a private water supply need to consider, and what they need in terms of resources to maintain their supplies to a compliant standard. Citizens Advice Scotland aim to publish recommendations regarding frameworks in 2020 here[3], in order to inform ongoing Scottish Government policy to improve the quality and resilience of drinking water within private water supplies.

2.5 The effects of drought on freshwater fish and river restoration options to mitigate impacts

Presenters: Hamish Moir
(UK Managing Director, Cbec)
and Chris Conroy
(River Director and Clerk to the Ness District Salmon Fishery Board)

Photos courtesy of cbec

Climate change is likely to result in more hydrological extremes, including both floods and droughts. Those extremes are made worse by human management of the land and river environments (e.g. enhanced drainage efficiency, reduced forest cover, increased grazing pressure, river engineering, etc.) which results in an enhanced impact on both physical and ecological processes. However, a process-based and catchment-scale strategy to restore natural hydrological/ geomorphic processes can mitigate this effect, providing resilience to the river environment in response

3 https://www.cas.org.uk/publications

to climate change impacts. Natural Flood Management (NFM) actions (and especially those relating to land-use change) can attenuate flood hydrographs but, importantly, also increase base flows by storing water throughout the catchment and gradually releasing it into the river network. The reinstatement of natural floodplain-channel processes will increase physical diversity, enhancing habitat variability and provide resilience to both high and low flow situations. It is important to think big, as 'piecemeal' efforts dotted through a catchment will not have an appreciable effect. However, land and river managers do need to start somewhere and a few small projects can often have a 'domino effect' in a catchment (e.g. Eddleston Water[4]), ending up with large-scale works that have a measurable benefit.

2.6 Managing production in water dependent industries

Presenter: Ronald Daalmans (Environmental Sustainability Manager, Chivas Brothers)

Photo Courtesy of Chivas Brothers

The Scottish Whisky industry has annual exports worth 4 billion GBP and employs 40,000 people in the UK (10,800 of them in Scotland). Distillery usage of water is divided into two types: process water mainly from springs, which should be of high quality and steady temperature; and cooling water mainly from rivers and burns. Process water represents about 20% of a typical site's daily requirement, with 80% of the volume used for cooling. The latter is generally returned to the watercourse from which it was taken, acting solely as a carrier for waste heat that cannot be recovered on site.

Operational impacts on malt distilling during the last drought have included both slowed and ceased production due to either temperature limits having been reached or for reasons of insufficient water flows. The industry has been focussing on responsible water use by reporting process water consumption per litre across the industry and has agreed a 10% reduction target between 2012 and 2020. Chivas Brothers use a process of water mapping and benchmarking to compare water use for each process at its sites and so identify wastage or reduction opportunities. Future Flow models have also been used to assess the likely headroom or risks to surface water supplies at each site. However, no known tools are currently available to do the same for spring water supplies. A lack of representative data on potential surface water temperature variation, both current and future, has been identified. A network of data loggers has been installed across its water assets to gather better data on potential water temperature constraints. Some distillers are also significant landowners, which may provide an opportunity to influence upstream water temperatures and base flow volumes by managing the land better for water resources. A research project has been commissioned with Aberdeen University and the James Hutton Institute to investigate the potential for this using nature-based solutions.

Looking to the future, the business is working to enhance its knowledge and preparedness for changes in local water availability characteristics by focussing on the following key issues:

- opportunities for joint vulnerability assessments of spring water supplies
- updates to the Future Flows Model
- opportunities for a simple water scarcity planning framework
- improvements to legacy infrastructure
- developing temperature profiles and distribution datasets
- testing mitigation measures involving, for example, payments for public goods
- calling for better strategic development planning information.

Photo Courtesy of Chivas Brothers

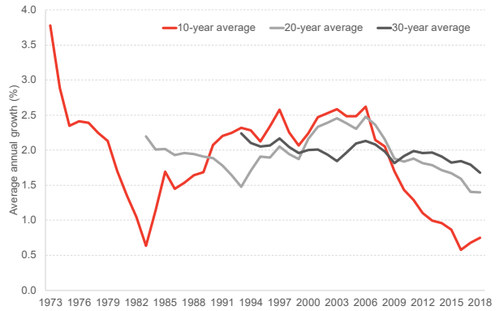
4 *https://www.nfm.scot/case-studies/eddleston-water-tweed-catchment*

2.7 The future challenges of environmental change on water as an economic resource in Scotland - Impacts of Drought and Low Flows & Future Preparedness

Presenter: Scott McGrane (Strathclyde Chancellor's Fellow, Fraser of Allander Institute)

There is an intrinsic interconnection between natural resources and the success of regional and national economies. Freshwater resources support economic activity across the globe, and when access is diminished as a result of a changing climate or poor stewardship, our key economic sectors face substantial challenges. The "perfect storm" of growing demand for water, energy and food to support a growing population, in conjunction with the worst impacts of climate change present a unique challenge to our economic sectors.

The Scottish Economy



Fraser of Allander Institute Economic Commentary 2019, Vol 43, No. 1, pp.5.

Despite the seeming abundance of water in Scotland, vulnerability to future climate change remains a substantial area of concern. Indeed, the consequences of the 2018 summer conditions across Scotland were dramatic and highlighted some of the challenges that Scotland may face as a consequence of future changes to rainfall and resultant water availability. The prolonged period of low rainfall resulted in a depletion of freshwater resources that had profound regional impacts for Scotland upon the key economic sectors that rely on water. Some key observations were:

- A marked increase in the price per tonnage of crop produce, as well as a reduction in yields.
- An increase in the rate of cattle slaughter because of reduced grass and drinking water systems
- Temperature- and water-resource-induced shutdowns of a number of whisky distilleries in Islay and parts of the Highlands (particularly around the Blair Atholl and Pitlochry area).

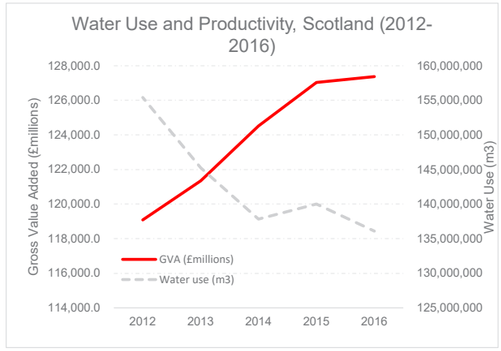


Figure produced by Fraser of Allander Institute (using economic data from Scottish Government and water consumption data from Scottish Water)

A key strategy for developing resilience against future changes is to assess how other regions or nations have responded to increasing frequency and magnitude of droughts from an economic perspective. For example, Cape Town recently faced a stark scenario of reaching "Day Zero", whereby water resources would have run out. Poor water management, in conjunction with drought conditions, resulted in a marked reduction in both regional and national Gross Domestic Product (GDP), particularly in the agriculture, viticulture and tourism sectors. By contrast, the economy of California continues to flourish despite repeated exposure to drought conditions. Diversification of economic activities in California, and technological innovation to reduce unnecessary water waste were key strategies in maintaining output. However, certain sectors (especially agriculture and viticulture) were still impacted by a reduction in available surface water. This led to significant increases in abstraction from groundwater resource, which in turn resulted in land subsidence, saltwater intrusion and an increase in arsenic levels in groundwater aquifers.

Scotland has the enviable luxury of being a water-abundant nation, and this is something that places Scotland at an economic advantage compared to other regions of the world. To best utilise this rich resource, we need to better understand the current ways we use water and what opportunities are available to reduce our external water footprint (from imports of fruits, vegetables and materials from water-stressed regions of the world). Furthermore, we need to better understand the potential impacts of climate change at a regional level. There are significant uncertainties in the potential impacts of seasonal climate change across Scotland. This is where advances in meteorology and data processing science can help us understand how these changes may manifest at different spatiotemporal resolutions, and what mitigation/adaptation options are most suitable to tackle these changes.

3.0 Group Discussions[5]: Resilience planning and adaptation strategies

Facilitator: Kathleen Stosch
Rapporteurs/Text Authors: Carolin Vorstius/ Lucille Groult, Elliot Hurst

3.1 What lessons have we learnt from recent experiences?

- **Public perception**

The general consensus was that Scotland is perceived as a water-rich country and water is often assumed to be abundant and good quality. Drought is therefore not envisaged by the public as a serious risk and the events in 2018 were largely unexpected. However, Scotland isn't as wet as the general population think, and some areas have greater water availability than others.

Photo Courtesy of Carolin Vorstius

There is an inherent resilience within the Scottish water system from recent successes in reducing water loss, and the ability to transfer water. Improved operational practices can tap into this resilience and the lack of losses of mains water supply during the 2018 drought have shown enhanced resilience of operational systems. Short periods of drought were considered manageable whereas in extended periods of water scarcity these systems can start to fail with escalating consequences. Transporting water is expensive, with energy, carbon and water quality considerations. Preventive responses such as water conservation and reuse should therefore be encouraged.

- **Public supply vs. the environment**

In 2018, public water demand was prioritised over environmental need, but this statement was questioned by the discussion groups as the emphasis should be more towards trying harder to reduce the demand on precious water supplies. Trade-offs between public usage and ecological impacts were considered to not have been properly managed. 'The environment takes a hit' because more work needs to be done to change public behaviour.

Questions were also raised about whether this is a water supply/abstraction issue, or a general ecological issue. It was highlighted that streams with and without abstraction had fish kills during the drought. What does this tell us about fish kills being 'natural' or being exacerbated by abstraction? Such river systems can't be classed as resilient – Further discussion is required regarding the practical definition of 'ecosystem resilience' and the 'reference levels of ecosystem resilience', i.e. undisturbed systems to be used as a basis for comparison, as well as level of acceptability, were raised.

- **Scottish institutional learning and collaboration**

Institutions are well connected, networked and sharing information effectively in Scotland.

SEPA learnt several lessons on drought management in response to events in the period from 2015-2018. 2018 taught the organisation more about the ecological impacts of droughts and how better to manage these events. At the time of writing, SEPA is working on a longer-term vision to limit the impacts of climate change so water is used wisely and efficiently to meet our future needs. The impacts of water scarcity can be reduced if water users plan ahead and adapt to provide greater resilience.

- **Behaviour change**

Due to Scotland being a small country, awareness campaigns, such as those of Scottish Water, can lead to fruitful outcomes. Campaigns for reduced water usage invoked a public response, although it is difficult to attribute that directly to specific efforts. It was thought that campaigns and messaging need to be local rather than national, and 'place-based'. Campaigns, however, so far tend to be reactive rather than proactive.

Even if people are aware of issues - they might not necessarily act. Behaviour change is difficult. Also, it is still too early to say whether this is an extreme or a new reality for the future, however recent reports (UKCP18) from the Meteorological Office suggest that the summer of 2018 will become our new reality, with such summers occurring on a 1 in 2 return period.

3.2 What lessons have we learnt from our national and international counterparts?

- **Importance of not decoupling flood management from drought management, and of re-establishing natural processes**

Water-sensitive urban design in Australia is a best-practice example and aligns to what has already been accomplished in natural flood management in Scotland. There are links between drought and flood, because both are about water leaving the catchment too quickly and the need to slow water flows. Keeping water in the environment addresses both. Reducing the amount of compaction in catchments (agricultural catchment management) is key to easing infiltration, as is having mature trees in the catchment that can transfer water to depth and enhance 'natural' recharge processes. However, as trees need a long time to mature, we need a suite of measures.

- **Policy integration**

The example of California shows that a legal framework is key. California has legislation for sustainable management of groundwater. Scotland might need to look at a similar improvement of policy frameworks for surface water. The tracking of agricultural uses could be part of a solution even though difficult to monitor and control. Close collaboration with farmers is required to improve data quality and accuracy.

- **Water charges**

The idea of Scotland adopting a model of water charges (e.g. metering) to encourage industrial/domestic use of raw water (e.g. ponds, rainwater harvesting), and reuse of greywater for less quality-demanding uses (toilet flushing, washing car, plant irrigation) was discussed. The introduction of water charges in Ireland in 2014 was very unwelcome and the discussion group agreed that a similar response would be likely in Scotland. Scottish Water are not considering metering and pricing potable water use, at this time.

- **Catchment management**

The necessity for water resource management at catchment scale was mentioned repeatedly. The example of Catskill mountains (New York State) successfully integrated catchment thinking.

3.3 How can we work more effectively across disciplines to increase our resilience?

By the time water levels decrease, it's already too late for action. We need to put more resources into future-proofing habitats and consider Nature Based Solutions to enhance the resilience of catchments to drought.
In order to make a significant change to hydrology, a holistic approach to catchment management is required. However, firstly, this means working on decadal timescales – the time taken for impacts of measures on the ground to be realised (e.g. to restore natural catchment functioning by planting upland and riparian native woodland). Secondly, there is potential resistance to taking land out of agricultural production for woodland. This is one of many examples that demonstrate the need for stakeholder engagement. Co-construction of research/policies with stakeholders is key.

There remains a need to crack the 'whole-catchment thinking' approach – this has been an objective of regulatory authorities/public bodies since the 60s and 70s and there is still a long way to go. The rural-urban divide remains an issue when considering catchment management solutions. Progress has been made on this for flooding - already good groupings and co-working arrangements exist here - so it is important to build on this for creating forums for drought management too. Industry could be more involved in supporting these projects.

3.4 How can communities support monitoring and adaptive management?

- **Co-design, risk awareness and community management**

Ownership and responsibility are key for ensuring effective community involvement. Communities should be involved from the beginning of the planning process and be engaged in co-designing strategies. They can also engage through citizen science (i.e. rain gauges, or level loggers in private water supplies) (see Section 5 for more details). For this to be successful, communities need to have an awareness of the challenge to be overcome. The reactive feature of awareness campaigns is inevitable but risk awareness, and consequently a more proactive approach, has to be built up over a long time. Could this be done in areas that have been impacted in the last year by drought. For example, allowing communities to decide when to impose a hose-pipe ban, or how to manage their water, e.g. working out how to share water when supplies are limited, rather than having a regulator-driven approach. Engaged members of the public could play a key role, for example, as community water champions.

- **Education and behaviour change**

Behaviour change is needed to make water efficiency a "natural behaviour", i.e. to value water and good water use. This could be through education and awareness campaigns. It was mentioned that water management should be part of school education and that children could become ambassadors for change in promoting a water wise society. Awareness campaigns are generally mostly effective for direct contact (people touched by the drought). Such an approach is often preferred instead of changing infrastructure since it is perceived as simple with minimal cost, while infrastructure change is costly and time consuming. However, the reality is not that simple.

Photo courtesy of Laurence Carvalho

- **Grey Water Use**

Future house designs and construction should potentially consider the feasibility of dual water systems, but there are many issues around cost and cross-contamination. At present it is not mandatory, but worthy of further consideration. Grey water use could also be better integrated into building designs. Consideration of rainfall harvesting for non-potable use was suggested as a possible future option for both new and old developments (house/commercial/

5 *Note that the small group discussions described in Sections 3 – 5 are based on carousel discussions, by which conference participants are given the opportunity to move between small groups. The views presented here are from individuals visiting the small groups for shorter or longer times, and information on particular topics should not be seen as being comprehensive descriptions of the state of the art.*

industrial premises and operations etc). In the Loch Leven catchment, new-builds must reduce the export of phosphorus (a nutrient that enhances algal blooms in lochs) from septic tanks by 125%, by enhancing treatment elsewhere in the catchment. It was proposed that similar schemes for water quality management could be initiated in other parts of Scotland.

3.5 Identifying the 'need' for research - what, when, why, how?

The need for stakeholder-driven research was emphasised to encourage efficient and appropriate measures.

- **Discussing and defining resilience**

What is resilience? Do we want to keep doing what we are doing now or are we open to different approaches?

Maintaining the current system and the role of engineered infrastructure

The use of infrastructure for bringing water from water abundant areas to water scarce areas needs to be challenged, especially with regard to costs, energy consumption and water quality impacts. What are the options for sustainable rural provision (off- or local-grid)?

- **Study and restoration of natural cycle**

Restoration of natural hydrological regimes allow for improved water infiltration and storage recovery. It is important to future-proof resources over longer time scales. Research into methods to improve the understanding of recharge rates, geological processes and structure is required. We need to understand the relationship between water quality and quantity better, as well as seasonal variability. The challenge is to find a balance between maintaining a natural seasonal water cycle without curtailing/impacting economic activity.

- **Similarities in flood and drought mechanisms**

Upstream-downstream relationships should be investigated in order to understand how high flow adaptation mechanisms could be applied to low flow conditions.

- **Implications of a catchment restoration approach**

In the past, land management focused on draining land to remove water as quickly as possible to rivers. More recently, the focus is on slowing the flow and retaining water especially in the upper reaches of catchments. Therefore, it is hypothesised that over the past 20-30 years, ecosystems in the lower parts of the catchments will have adapted to higher flows, as catchments have higher runoff. So, as we alter hydrology to store more water in the upper catchment, we will be reducing the average flows. Generally, there is a poor understanding of these cascading impacts.

- **Field data collection**

Better quality data is required to understand current abstraction patterns, as users are asked to estimate their water usage, but the aim is to improve the accuracy of this data. The effectiveness of water efficiency measures will also need to be assessed and monitored over longer periods.

4.0 Group Discussions: Emerging issues for drought and low flow conditions[6]

Facilitator: Karin Helwig
Rapporteurs / Text Authors: Sughayshinie Samba Sibam, Victoria Porley & Kerr Adams

4.1 Introductory Presentations on the Emerging Issues of Pharmaceutical Pollution and Zoonotic Pathogens from Livestock

4.1.1 Pharmaceutical pollution - What happens in extreme weather conditions?

Presenter: Karin Helwig
(Glasgow Caledonian University)

Many pharmaceutical products such as antibiotics enter the water network after leaving the body. This occurs either as parent compounds or as metabolites after processing in the body. These pharmaceutical residues are often not routinely removed in water treatment works. As low flows become more frequent and last for longer periods of time, there is less water available in the river to dilute the effluents containing pharmaceutical waste, resulting in higher concentrations.

The consumption of pharmaceutical products is increasing due to a growing and aging population. This indicates that pharmaceutical pollution is likely to become an increasing issue in the future. Currently, there is limited knowledge of the effect of changes in flow; for example, there may be greater photodegradation or increased sequestration into sediments. There is a need to better understand the transport and environmental fate of pharmaceutical drugs.

Pathway of pharmaceuticals into the environment

Photos courtesy of Karin Helwig

4.1.2 Zoonotic Pathogens from Livestock

Presenter: Beth Wells
(Moredun Institute)

Photo courtesy of Hannah Shaw
Testing rivers during a project investigating Cryptosporidium transmission in a whole

Issues associated with the parasite Cryptosporidium on human health and water quality were presented. Responsible for the disease cryptosporidiosis, this pathogen is ubiquitous throughout the environment and is resistant to chlorination treatment due to its very durable and robust outer wall. Evidence from developing countries indicate that zoonotic pathogens (defined as pathogens that are naturally transmitted between animals and humans) are problematic if livestock come into contact with water bodies that are used by humans as a drinking water source. In developed countries, similar problems can occur which may be amplified in drought conditions but drinking waters can also become contaminated by water sources from field run-off and wastewater.

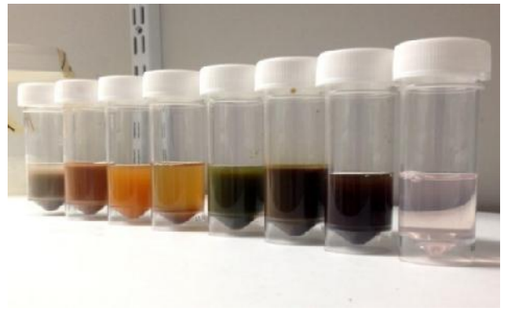


Photo courtesy of Hannah Shaw
Laboratory testing Scottish water samples for the zoonotic parasite Cryptosporidium

The impacts of pathogens are increased during low flow and drought conditions when concentrations of Cryptosporidium can increase. In the event of extreme precipitation following drought, increased pathogen loads can be transported from terrestrial areas to water courses via overland flow. High turbidity (exacerbated by drought and livestock entering the water) and increased concentrations of bacteria and parasites, can reduce the effectiveness of water treatments.

6 *Note that the two final talks in section 4 (4.1.1 and 4.1.2) provided first examples of emerging issues which could result from drought-like and low-flow conditions. These talks prompted discussion on other emerging issues as well.*

In summary, the increased likelihood of drought could mean that this is an emerging issue for water quality and human health. This is especially pertinent for rural communities in Scotland who rely on private water supplies. Here ultraviolet disinfection is a recommended treatment, but UV disinfection is only effective where the parasites are not attached to other organic materials or pollutants.

More research is required into the impact of drought on the transport pathways and mechanisms of pathogens and the performance of treatment technologies (when processing highly turbid water over time and in circumstances where the parasite is attached to organic materials or pollutants).

4.2 What lessons have we learnt from recent experiences?

Photo courtesy of Sharon Pfleger (NHS Highland)

There is a need to monitor water quality as an input for drought plans as currently there is a paucity of water quality monitoring during low-flow events. More data would contribute to enabling people who live in drought prone areas to become more resilient. There is also a need for increasing awareness of seasonal variations. For example, pathogen pathways will be different when livestock are grazing and when they are being housed during colder months. In addition, the movement of zoonotic pathogens through catchments during extensive periods of low flow requires improved understanding. Pharmaceutical pollution may also be subject to seasonal effects, for example due to changes in consumption – coughs and colds are more common in winter – and changes in removal processes due to temperature variation.

It was emphasised that reducing pollutants from entering water bodies should be the main focus, rather than responding to the impacts of reduced pathogen dilution during low flow events ("the solution to pollution is not dilution"). The prevention of pathogens reaching water bodies is more important than the reliance on river flow dilution.

SEPA's controlled activity permits do not have any mitigation consideration during low flow events. This means there are no restrictions on extractions during low flow events. It was recommended that low flow protection permits should be put in place, however, it was not known if this would require a legislative change.

Hydrological models for high flow should similarly be adapted to account for changes that occur during drought conditions.

4.3 What lessons have we learnt from our national and international counterparts?

Zoonotic pathogens provide an example of the need for responsible treatment of waste from animals, at point of source, by using filtration methods. The potential of testing other methods in these settings was discussed. Examples from an agricultural catchment were mentioned, since it is often the case that a diffuse pollution issue is more complex than point source examples.

Furthermore, the use of natural processes such as buffer strips to prevent pathogenic outbreaks was raised and specifically the use of soil filters as widely used in Germany. Countries with hotter climates often use sand filters as a preliminary treatment method (e.g. in India and some African countries).

A citizen science example from the United States was discussed where sampling strips were used to test water quality. Whilst it is important to consider data quality in citizen science projects, they provide an opportunity to enhance public understanding of pollution issues. Education and training could encourage a sense of responsibility in society.

4.4 How can we work more efficiently across disciplines to enhance resilience?

A collaborative approach, involving pharmaceutical industries, healthcare providers, water managers and environmental experts is the way forward to better understand sources and pathways of pharmaceutical pollution and to mitigate impacts on the water environment. Specific questions to answer would include: what quantities are being consumed? what types of water treatment technologies are needed?

In addition, care homes may also have a role to play in monitoring the quantities of medications that residents consume. Alternative approaches such as reducing the amounts of medications prescribed and increasing outdoor activities (Blue/Green Prescribing) should also be considered.

There also needs to be a better understanding of diffuse pollution. Parasites such as Cryptosporidium parvum are complex to model. Increased collaboration is required between researchers, water management bodies and government for the creation of more robust models, evaluation and policy.

4.5 How can communities support monitoring and adaptive management?

There may be potential for the public to participate in the testing of private water supplies, through making testing kits available to the public. However, there were also concerns about public participation as it is important that tests are accurate and reliable and conducted correctly. This reinforced the need for the further education of communities to gain a sense of social and environmental responsibility with respect to protecting our water resources.

Potential ways to improve the quality of data collected could be through involving schools or by involving retirees with relevant experience. Research projects could aim to find solutions to water quality issues by using multi and trans-disciplinary teams. For example, involving social and engineering students.

4.6 Identifying the 'need' for research - what, when, why, how?

There is a need to increase student participation and collaboration within the field and inspire a new generation which will continue this work and address future issues.

Methods need to be enhanced to improve the effectiveness of water treatment, such as the resistance of Cryptosporidium to chlorination disinfection. Research is required to find ways to actively remove pollutants. For example, new methods to deactivate pathogenic bacteria that are currently resistant to many methods. Photocatalysis is a potential candidate for this.

Existing models need to be better utilized across projects and research problems. This needs to be done across sectors to better understand available models.

The transportation of pathogens under different concentration conditions needs to be better understood, such as what happens during the transportation process. The causes of pollution in different areas needs to be mapped out more effectively. This will result in more targeted solutions, as a particular pollution reduction method may only be relevant in certain areas.

Another area of emerging interest is the role played by antibiotic residues in water treatment and the environment, in engendering or exacerbating environmental antimicrobial resistance.

5.0 Group Discussion: Enhanced monitoring through technical innovation and citizen science.

Facilitators: Laurence Carvalho and Claire Neil
Rapporteurs / Text Authors: Jonathan Fletcher, Matt Hare

5.1 What lessons have we learnt from recent experiences?

Citizen science could be usefully applied to:

- The collection of photographs of dry/drying water courses;
  Notifying authorities of algal blooms - this is currently being done through the Bloomin'Algae app[7], developed by UK CEH. Its use in 2018 was boosted by media coverage of widespread algal blooms linked to drought conditions and enabled SEPA and local authority environmental health officers to respond rapidly to blooms.

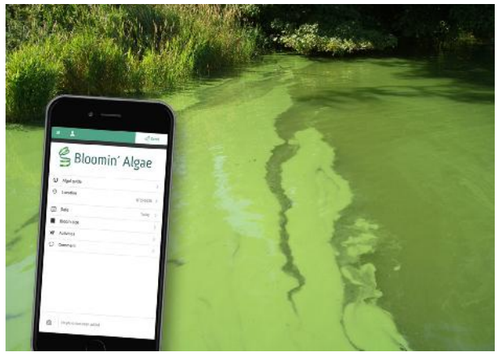


Photo courtesy of Laurence Carvalho

The above supports ongoing routine monitoring efforts by SEPA, water industry and other agencies. More widespread monitoring is required to better identify drought and spatial rainfall patterns which are currently highly variable. More hi-tech, real-time monitoring of abstractions and impacts on river ecology (fish kills, and temperature, for example) would permit real-time SEPA support for businesses to ensure abstractions can carry on as long as there is no risk to the environment. However, the use of low frequency monitoring systems and cheaper technologies for the monitoring of lower priority (lower risk) catchments is worth considering as well as citizen-led monitoring.

5.2 What lessons can we learn from our national and international counterparts?

Our national and international counterparts have shown us the success of citizen science driven activities, it is very important to ensure that the reasons for, and end-product of, any data collection activity is highly visible from the outset. Additionally, it was thought that multi-scale monitoring and validation in the context of remote sensing was essential – e.g. from satellite to drone to citizen / researcher.

5.3 How can we work more effectively across disciplines to enhance resilience?

The goal should be to enable more, better targeted and risk-based monitoring so that predictive capacity for future trend analysis can be improved e.g. with respect to surface runoff, baseflow, rainfall. This would require, in turn, the development of methods for efficiently handling, processing and storing very large and complex datasets.

Another issue that arose in discussions was the applicability of different monitoring techniques. For example, whilst national-scale methods are useful, most users (e.g. agriculture, industry) are more concerned with local-scale monitoring. Additionally, the use of smart sensors might be worth considering in order to create a water tracking scheme for big abstractors.

Finally, there is a need for integrated research, combining the social sciences and technical disciplines, to support water use monitoring based on, for example, black box, wireless, metering technologies. But we need to understand the demographic of consumers that might engage with such technologies.

Citizen Science

Photo courtesy of Laurence Carvalho

In terms of citizen science, more effective work to enhance resilience could be supported by bringing together a database of the many apps currently available for citizen science. Most apps are UK-focused, providing open data, particularly of biodiversity, and most of these data are stored in UKCEH's Biological Records Centre and the National Biodiversity Network. Issues of reporting consistency and use incentives need consideration. Already, most apps have ID guides and provide verification feedback to users so that the citizens that collect data learn from the process. However, two further issues for consideration in citizen science would be how to best make use of more specialist "citizen" knowledge – e.g. from gardeners – as well as how to ensure fair coverage of different water bodies (e.g. rivers vs. lakes) when that coverage is provided by a limited set of geographically-restricted volunteers.

5.4 How can communities support monitoring and adaptive management?

Photo courtesy of Laurence Carvalho

Smart phones are ubiquitous and can become a powerful tool for citizen reporting of issues, as well as for receiving updates and instructions on monitoring. If the problem of how to widen the geographical participation of communities in monitoring activities can be solved (perhaps through community awareness raising and empowerment/engagement activities, and the use of school involvement), it might be possible that community-driven monitoring can create broader impacts beyond data generation – e.g. citizen awareness and collective action.

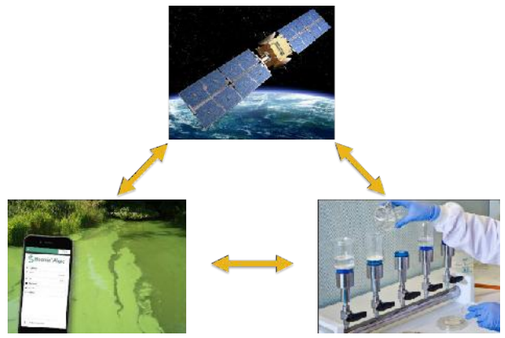
5.5 Identifying the 'need' for research– what, when, why and how?

On the whole, research questions should be co-generated with the public / schools / etc. We should be drawing on different stakeholders (community, government, academia) to drive interdisciplinary research and to articulate the societal benefits from it. Ultimately there is a need to better understand what stakeholders want from future research. This raised the question as to how this understanding can be best gained. Should we conduct surveys? If so, how?

Additionally, if citizen science projects gain momentum in the future, then what level of training do citizen scientists need? We possibly need more research carried out on attitudes and behaviours towards monitoring – does monitoring actually need to be incentivised and why should citizens engage? Further research would be also needed on assessing and ensuring the validity of citizen data, especially in terms of how to calibrate / validate citizen science data collection with more standard methods of data collection (c.f. the CrowdWater project).

Some very interesting research questions were also raised within the group regarding earth observation:

- How are we to effectively ground truth Earth Observation (EO) data?
- What is the minimum size for a water body needed to be detectable by Earth Observation?
- How should one couple spectral imaging to understand water holding / saturation with ground truthing efforts?
- How can hyperspectral imagery be best used for automated identification of algae? EO has the potential to identify total algal abundance (Chlorophyll-a) and cyanobacterial abundance, but not finer taxonomic resolution.
- How can EO data be used to compare sites of different ecological status and habitat, so as to investigate recovery times following disturbance and to ultimately enhance resilience?



The complete picture: data integration from multiple sources
Photo courtesy of Laurence Carvalho

In general, it was thought important to ensure good user-interfaces and data output for practitioners using Earth Observation.

Finally, the group identified two water quality and quantity questions:

- How should the impacts of water quality (e.g. colour, turbidity) be accounted for?
- Abstractions below 10 m3/day are not registered, with many abstractions remaining below this threshold – how can the location and number of these be captured?

7 *https://www.ceh.ac.uk/algal-blooms/bloomin-algae*

6.0 Closing words from Jon Rathjen (Scottish Government)

The drought of 2018 brought home the significant reality that Scotland doesn't always live up to its reputation of a wet country. Significant parts of Scotland were impacted, with both citizens and businesses affected. Although the national response alleviated the situation and active management minimised difficulties, it highlighted exactly how drought could have negative consequences for both the quantity and quality of our water resources. Risk-based assessment and consideration of national water resources planning are key to ensuring future sustainability.

In general, our reserves of water are significant. The challenge is to ensure that there is continuity between water-rich and water-poor regions, and to be able to act quickly and creatively, and in a manner that accepts we will need to take risks then evaluate and adjust. This is a shared challenge for scientists, regulators, practitioners and the public.

As a Hydro Nation, the common ambition for Scotland is to be more resilient and ready to respond to future water resource challenges, reducing consumption and driving down related carbon impacts.

Photo courtesy of Rachel Helliwell

Appendix 1: Conference Programme

World Water Day 2019

Resilience to Drought and Low Flow Conditions in Scotland

Venue: Apex Grassmarket Hotel

22nd March 2019

World Water Day Theme 'Leaving no one behind"

Aim

Recent evidence indicates that climate extremes are not only becoming a reality in Scotland, but their severity and frequency is increasing. The summer of 2018 was a clear example, where a drought particularly impacted the North and East of Scotland with record low flows observed in several Scottish rivers. This workshop will have a focus on the resilience of Scotland to climate extreme and, in particular, provide scientists, engineers, planners and managers with a platform to share their observations, experiences, research outcomes, and innovative ideas on building resilience and adapting to low flows and drought conditions from a Scottish perspective.

Section I: Challenges

To what extent has drought threatened the supply and provision of water for the industry (including tourism and recreation), agriculture, energy, and domestic water supply in Scotland? What measures are in place, or are being considered, to reduce risk and enhance resilience? What are the key areas of research for universities and research organisations?

Programme:

9:30-10:00
Registration (Refreshments provided)

10:10-10:20
The importance of science: policy dialogue in an ever-changing world
Bob Ferrier (Director: Centre of Expertise for Waters)

10:20-10:40
Monitoring and early warning to support enhanced resilience to drought in the UK: recent advances, challenges and prospects?
Stephen Turner (Centre for Ecology and Hydrology)

10:40-10:50
Scottish Water's Planning, Preparation and Response to the 2018 Drought
Mark Hunter (Scottish Water)

10:50-11:00
Private Water Supplies: the consumer perspective on improving resilience and water quality
Rebecca Millar (Citizens Advice Scotland)

11:00-11:30
Open discussion followed by coffee & tea

11:30-11:45
The effects of drought on freshwater fish and river restoration options to mitigate impacts
Hamish Mair (cbec) and Chris Conroy (Ness District Salmon Fishery Board)

11:45-12:00
Drought and its effect on agriculture and irrigation practices
Paul Hammett (Water Specialist National Farmers Union)

12:00-12:15
Managing production in water dependent industries: a Scotch Whisky example
Ronald Daalmans (Environment Manager Chivas Brothers)

12:15-12:30
The future challenges of environmental change on water as an economic resource in Scotland
Scott McGrane (Fraser of Allander Institude)

12:30-13:00
Open discussion

13:00-14:00
Networking buffet lunch and poster session

Section II: Breakout sessions (14:00-15:30)

Discussion Group 1: **Resilience planning and adaption strategies**

Discussion Group 2: **Emerging issues for drought and low flow conditions**

Discussion Group 3: **Enhanced monitoring through technical Innovation and citizen science**

15:30-15:45
Feedback from Hydro Nation Scholars

15:45-16:00
Final perspective and thoughts for the years ahead
Jon Rathjen

16:00 **Close**

The full report can be downloaded from the Hydro Nation International Centre website:
https://www.hnic.scot/expertise