CENTRE OF EXPERTISE FOR WATERS

Climate Crisis: Informing Scotland's actionable mitigation and adaptation response to water scarcity

Richard Gosling, Sarah Halliday, Iain Brown, Andrew Black and Sarah Hendry

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Report and Appendices

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Glossary

Term	Definition	Reference
Adaptation	Adaptation measures refer to long-term actions that aim to enhance the resilience of the system.	Wang and Asefa, 2019
Drought	A temporary deviation from long-term average or normal conditions in a hydrological context with regard to water supply.	European Commission, 2009
Evapotranspiration	The combination of two process: evaporation and transpiration. Transpiration involves the flow of liquid water from the soil (root zone), through the trunk, branches and surface of leaves.	Goyal and Harmsen, 2013
Headroom	Headroom refers to a buffer between supply and demand. Actual or available headroom is the amount of water available minus demand. Target headroom is a minimum allowance – considering critical risks and uncertainties – required to maintain levels of services for the supply-demand situation with a given level of confidence.	Anglian Water, 2024
Mitigation	Short-term actions taken before and during a drought event to minimise potential impacts.	Wang and Asefa, 2019
Q95 *(the 5-percentile flow)*	The flow which was equalled or exceeded for 95% of the flow record. The Q95 flow is a significant low flow parameter particularly relevant in the assessment of river water quality consent conditions	NRFA, 2024
Resilience	The capacity of interconnected social, economic, and ecological systems to cope with a hazardous event, trend or disturbance.	IPCC, 2022
Risk	The potential for adverse consequences for human or ecological systems.	IPCC, 2022
Vulnerability	The propensity of a system to be adversely affected by water scarcity and is determined not only by that potential impact but also by the capacity of the system to adapt.	IPCC, 2022
Water consumption	Water removed from, but not returned to, the same drainage basin.	ISO, 2014
Water Scarcity	A long-term imbalance between water supply and demand in a region (or in a water supply system).	European Commission, 2009

Executive Summary

Purpose of research

The aim of this project has been to inform and prioritise mitigation and adaptation actions to address future water scarcity challenges in Scotland. The **key questions** to be addressed were:

1. What is the current state of knowledge regarding the past trends, current situation, and future projections of water scarcity in Scotland?
2. What is currently being done to mitigate water scarcity in Scotland and how effective are these strategies?
3. In the future, will these strategies be fit for purpose under different climate change projections and the associated uncertainties?
4. What mitigation and adaptation strategies are therefore needed to address water scarcity in the short and long term in Scotland?
5. How can these proposed strategies be implemented within the current policy framework in Scotland?

Background

Water scarcity is a term used to indicate conditions where access to enough water, of sufficient quality to meet human and ecological needs, has become limited (UN-Water, 2023). It comes about when the supply of water fails to meet the demands of human and environmental systems and results in an impact on the services they provide. Water scarcity can develop from declining supply e.g. lower summer rainfall or increased demand from human activities or a combination of the two.

The rate at which Scotland's climate is changing is unprecedented in our history. We are becoming exposed to climate related risks, such as water scarcity, that were not considered significant in the past and have not been planned for. Furthermore, what are currently seen as exceptional conditions, such as the 2018 summer drought which led to significant negative impacts on aquatic ecology, agricultural production and industry, are projected to become much more frequent by 2050s as a result of climate change (UKCP, 2023). Without a concerted effort to manage Scotland's water resources through this change, those impacts will become more frequent and severe. Through extensive engagement with stakeholders in the water sector this project illuminates our current level of preparedness for water scarcity and makes recommendations to ensure we protect access to our valuable natural water resources and the services they provide.

Key findings

- Scotland's supply of natural water resource is becoming increasingly variable. There is evidence that meteorological and hydrological droughts have become more frequent in Scotland (e.g. Spinoni et al., 2017; EEA ,2020) and this has led to an increased awareness of water scarcity risk amongst those stakeholders engaged with in the project.
- The latest climate change projections indicate that drought conditions in much of Scotland are likely to increase in frequency, severity, and duration over the next few decades (e.g. Kirkpatrick Baird *et al.,* 2023).
- There is evidence that water demand in the future may increase in areas, and at times of the year, where supply is projected to decrease. Behavioural responses to the extreme events associated with the climate crisis may serve to exacerbate this if not managed.
- In the opinion of the project's participants there is a strong consensus that water scarcity in Scotland is underestimated generally, and that water is undervalued.
- Some organisations that understand the high cost of water scarcity to their business have comprehensive strategies and plans to address the risk over the long term. However, most have either no plans or plans that only mitigate the worst impacts of a short duration drought.
- There is demand for greater joined-up governance over water scarcity in Scotland. This would ensure the links are made with other high priority policy areas such as making a just transition to Net Zero and halting the decline in global biodiversity.

Recommendations

To mitigate the effects of, and, to adapt to water scarcity this project proposes a series of recommendations for delivery partners, including the Scottish Government, in the following areas:

Governance

- Set up a national water resources management structure with a core water resources group and lead agency (G.1).
- Develop a national water resources management strategy (G.2).

Management

- Develop routine monitoring, modelling, and mapping of water use across Scotland (M.1).
- Deliver water resource information to all via an existing or new portal (M.2).
- Produce and routinely update a national water scarcity risk assessment (M.3).
- Develop and implement a national water resource management plan (M.4).
- Review existing regulatory processes and monitoring (M.5).
- Review the resilience of the national drought forecasting and warning service (M.6).
- Review processes that ensure high risk water use, where risk is related to hazard, exposure and vulnerability, is protected during droughts (M.7).

Behaviour change

- Develop narratives around the value of water and benefits of water efficiency (B.1).
- Investigate embedding water literacy in national schools, F.E. and H.E curriculums (B.2).
- Evaluate which policy tools will incentivise water use efficiency (B.3).
- Target behaviour change where most beneficial to national priorities (B.4).
- Develop a monitoring and evaluation framework (B.5).

The project has also outlined key research activities which will directly address the knowledge gaps and challenges identified by water sector stakeholders. These knowledge gaps include but are not limited to: understanding the potential for water use efficiency and the efficacy of demand-side responses; research to understand the implications of climate change for environmental flows and ecosystem resilience; and work to stress test existing and potential water scarcity plans across sectors under different climate change projections.

By acting now to address the long-term risk of water scarcity we can not only protect our valued water sector but allow it to realise future opportunities and establish Scotland as an exemplar of sustainable water resource management.

1 Introduction

1.1. Background and scope

Scotland is typically considered a water rich nation, a fact recognised and celebrated in the Scottish Government's vision for Scotland to become a 'hydro nation'; a nation in which water resources are developed to bring maximum benefit to the country and to establish Scotland as a recognised world leader in water resource management (Scottish Government, 2023a). However, water scarcity is becoming a growing concern. It is estimated that globally, since 1960, per capita available water has decreased by 55% (Guppy and Anderson, 2017), and this change in water resource availability is increasingly impacting Scotland.

Across Scotland water availability is highly variable, both spatially and temporally. In each of the years between 2017 and 2023, areas of Scotland have experienced at least a moderate level of water scarcity, with abstraction restrictions required for the first time in the Fife, Eden and Tweed catchments in summer 2022 (SEPA, 2023). In Eastern Scotland, larger-scale studies have shown significant trends over recent decades in the increased frequency of meteorological drought and reductions in soil moisture (EEA, 2020; Spinoni *et al*., 2017), and consideration is already being given to how catchments within this region can mitigate and adapt to such challenges (e.g. new reservoir development; Scottish Government, 2023b). Research has also projected increases in both the severity and frequency of water scarcity in much of Scotland over this century (e.g., Visser- Quinn *et al*., 2021; Brown *et al*., 2012). These changes in water resource availability will not occur in isolation and may be exacerbated by changing water resource demand. In many parts of the world, including Scotland, there are already signs of an increase in our water demand, with the daily domestic water consumption per person in Scotland increasing to 180 litres per person per day (lpd), a 12% increase from pre-pandemic levels (Scottish Government, 2023b). These changes in both supply and demand will vary across the country resulting in hotspots where the risk of future water scarcity is particularly high.

Water scarcity planning and management in Scotland is governed by a combination of policies and legislation administered by the Scottish Government and its delivery partners and stakeholders. In addition to the policy and regulatory framework, organisations and individuals have their own specific mitigation and adaptive strategies and actions which they use at times of low water availability. As these were usually developed based on reference conditions from the past, then questions remain as to how suitable these are for present conditions and under further change.

There are also important interactions with the Net Zero agenda, particularly for achieving this goal for the land use sector and growth of a circular bioeconomy. The need to continue to ensure water availability for the natural environment is also a crucial issue to help maintain Scotland's international biodiversity commitments. In addition to its direct effects, climate change is also causing indirect effects through changes in catchment land use or management (Brown *et al*., 2011).

A recent Climate Change Committee (CCC) report to the Scottish Parliament, assessing the progress towards adapting to climate change, highlighted several areas within Scotland's current Climate Change Adaptation Programme where more work needs to be done (CCC, 2022). These adaptation gaps include those required to address water scarcity and the review highlighted a need to inform 'fit for purpose' strategies that can be urgently implemented in Scotland.

1.2 Project objectives

The project aim is to inform and prioritise actionable mitigation and adaptation solutions to address future water scarcity challenges in Scotland.

The key questions to be addressed were identified as:

1. What is the current state of knowledge regarding the past trends, current situation, and future projections of water scarcity in Scotland?
2. What is currently being done to mitigate water scarcity in Scotland and how effective are these strategies?
3. In the future, will these strategies be fit for purpose under different climate change projections and the associated uncertainties?
4. What mitigation and adaptation strategies are therefore needed to address water scarcity in the short and long term in Scotland?
5. How can these proposed strategies be implemented within the current policy framework in Scotland?

1.3 Structure of the report

Section 2 of this report presents the background literature review around water scarcity in Scotland looking at past, present and future water supply, and demand. It also includes a consideration of the policy areas that interact with actions to address water scarcity.

Sections 3 summarises the key knowledge and evidence gaps identified both during the literature review and stakeholder engagement elements of this study, some of which contribute to the challenges faced in adapting water scarcity which are detailed in Section 4.

Taking on these challenges, Section 5 presents the project's recommendations for actionable mitigation and adaptation responses to water scarcity. The recommended actions are grouped into areas of governance, management, behaviour change and research.

Finally, overall project conclusions are presented in Section 6.

2 Literature and policy summaries

2.1 Introduction – What is water scarcity?

Water scarcity is a term used to indicate conditions where access to enough water, of sufficient quality to meet human and ecological needs, has become limited (UN-Water 2023). Water scarcity is a relative concept in that restricted access to water resources results from a tightening of the balance between water supply and demand, each of which can vary over time and space. A related concept is *water security* which is having a sustainable resource (particularly of clean water) that is adequate to meet fundamental requirements of human wellbeing, present and future. Both these concepts are strongly related to the occurrence of droughts, which represent extreme events with a severely reduced water supply, although in a well-adapted society this does not necessarily mean drought risk will directly cause water scarcity or security challenges. Drought also has multiple definitions, depending on the focal issue (Section 2.2.1).

Since concern grew over the impact of droughts in 1980s, several methods have been developed to assess the degree of water scarcity experienced by a region (Hussain *et al*., 2022). These methods commonly express the degree of water scarcity as a ratio between the volume of available freshwater and the volume of water demand (e.g. Falkenmark *et al*., 1989; Seckler *et al*., 1998). Most of these measures were developed to assess long-term systemic water security issues in arid regions but, given that water scarcity can also result from episodic variations in the balance between supply and demand, any region, even one apparently rich in water resources on average, such as Scotland, can experience water scarcity.

The following Sections explore recent historical and projected future changes in conditions in Scotland that can lead to water scarcity. We consider: changes in the natural supply of raw water (Section 2.2); changes in demand by water users (Section 2.3); and how the balance in these changes has been managed in the past and whether this will be sufficient to manage water scarcity in the future (Section 2.4).

2.2 Water supply

2.2.1 Past trends and current picture of drought events in Scotland

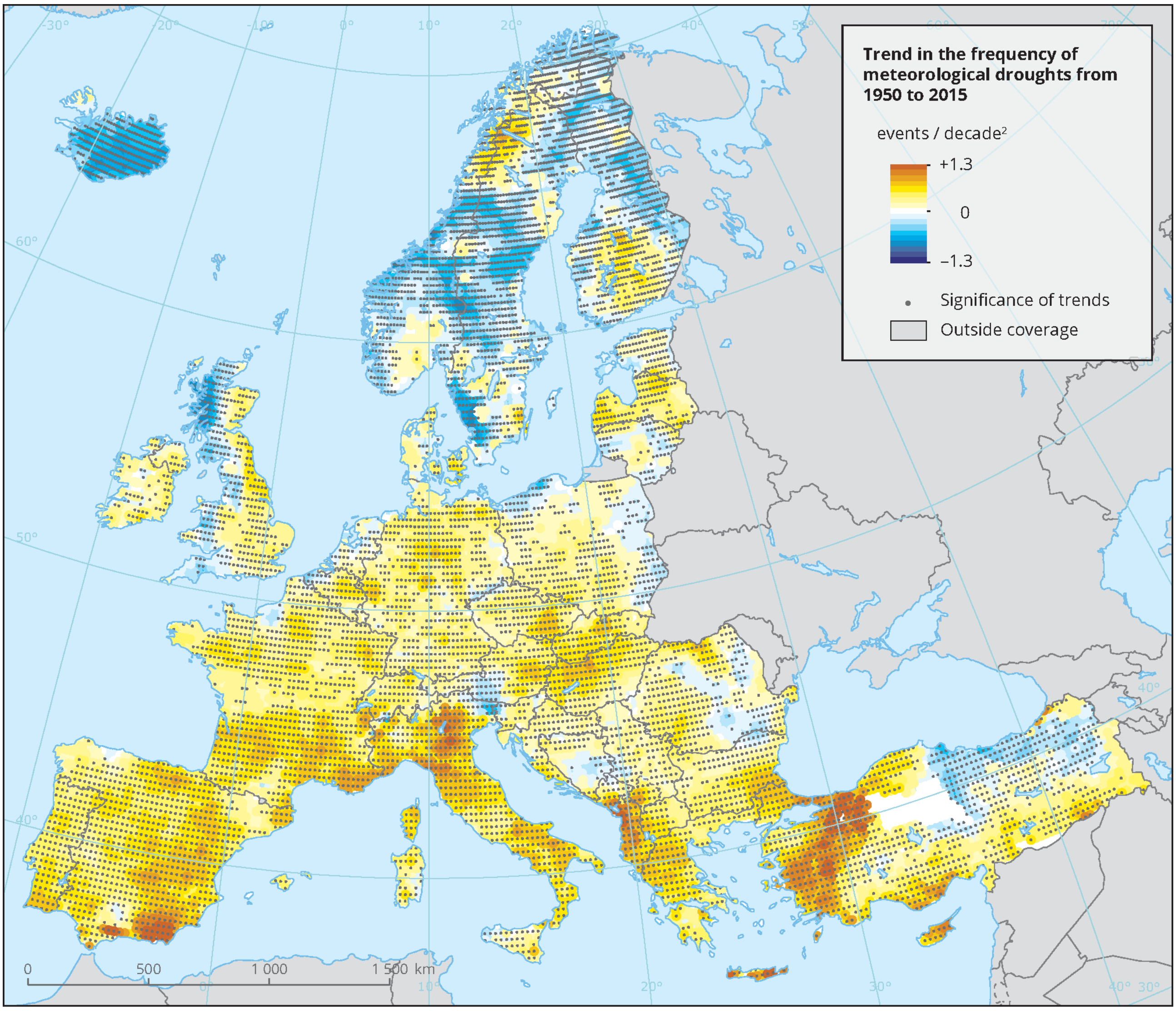
A drought differs from water scarcity in that it simply reflects an exceptional temporary reduction in water supply, typically caused by low rainfall. It is a relative concept in that it expresses a condition abnormal for the local climate. Droughts are detected, and their severity measured, in terms of a departure from normal conditions of rainfall, river flows, soil moisture or groundwater over a specific time period, usually ranging from 1 to 24 months.

Definitions of drought also depend on the focal issue. Meteorological drought is typically defined as a lack of precipitation over a region, but more relevant for water scarcity is hydrological drought which defines a period with exceptionally low surface and subsurface water resources available for established water uses. Regarding different uses, we can also identify conditions where resources are insufficient to meet basic requirements, and hence key thresholds can be characterised for ecological, agricultural and socio-economic drought.

Consequently, the choice of which parameters (e.g. rainfall or river flow) and over which time period to define a drought is dependent upon the usefulness of the indicator in describing water scarcity impacts and for assisting drought management decision-making. For example, a measure of impacts upon users relying on direct river abstractions for crop irrigation might employ a short time period, e.g. one month, flow-based drought metric. In contrast, the impact upon forestry or peatlands which are susceptible to more prolonged soil drying might require a longer time period using rainfall and evapotranspiration observations.

Drought metrics, or indices, allow us to assess the severity of a dry period in real time but also let us cast back in time to assess whether drought behaviour has changed. For example, regarding meteorological drought, an analysis of the standardised precipitation index (SPI) across Europe indicates a significant increase in the frequency of spring and summer meteorological droughts over central and eastern Scotland between 1950 and 2015 (Spinoni *et al*., 2017; Figure 1).

Although clearly important, rainfall is not the only determinant of the type of droughts that impact water resources. Supply-side issues are typically exacerbated when periods of low rainfall are also associated with higher temperatures and sunny conditions, which produce higher rates of evapotranspiration from water bodies, soils, and vegetation. These rates may be further increased by lower humidity levels. Under these conditions, soils begin to dry out and less water percolates to groundwater, the levels of which ultimately support dry weather river flows. This combination of low rainfall, high temperatures and low humidity can result in a meteorological drought propagating to agricultural and hydrological drought. Various indices have been developed to highlight this aspect of drought risk, such as the Standardised Precipitation-Evapotranspiration



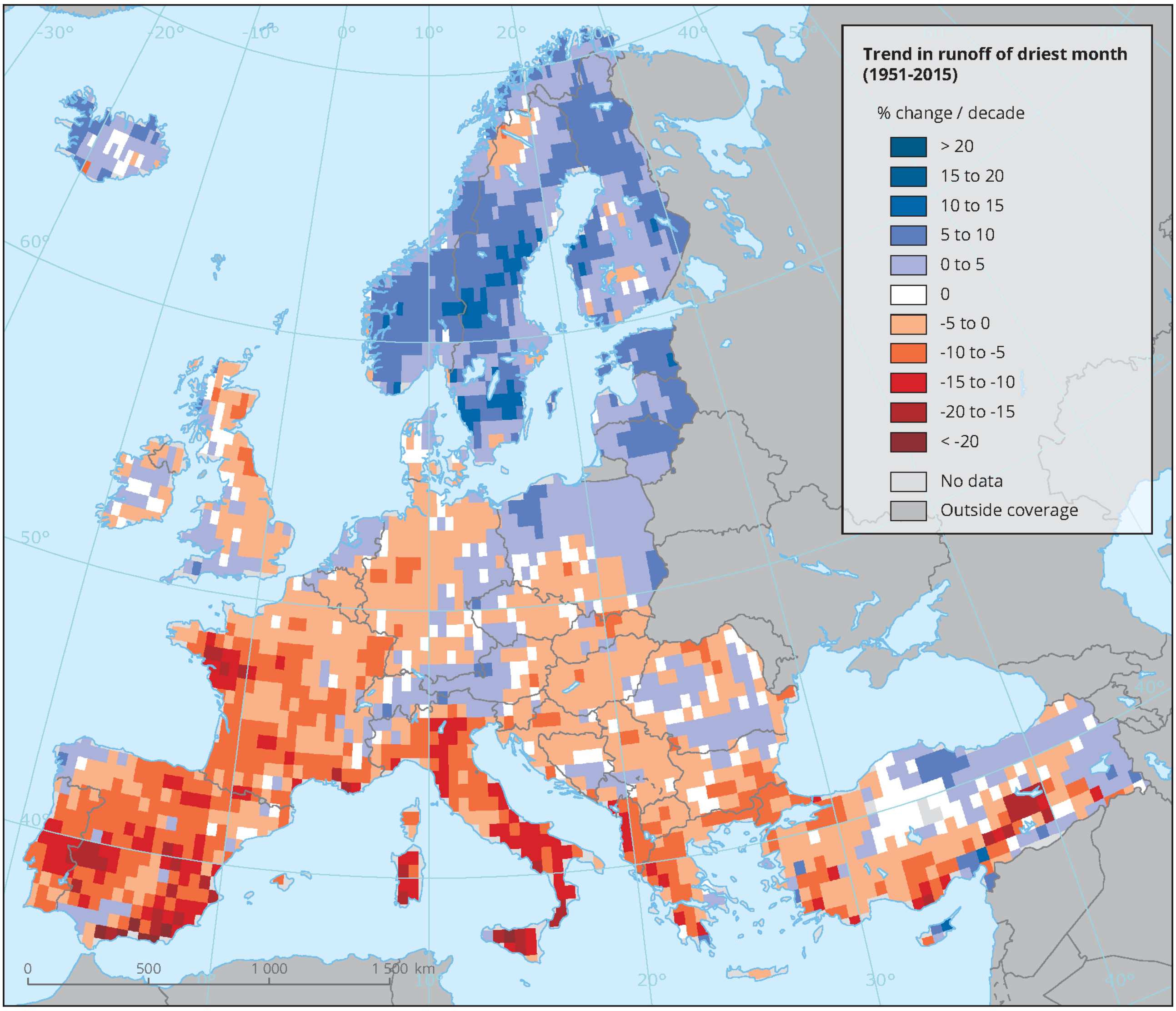
Reference data: ©ESRI

Figure 1: Trend in the frequency of meteorological droughts in Europe (1950-2015). Source: European Environment Agency (EEA), 2020.

Index (SPEI; Tirivarombo *et al.*, 2018) or Palmer Drought Severity Index (based on temperature and precipitation; Alley, 1985). It has been shown that indices accounting for increases in temperature highlight even greater changes in drought severity, particularly through the summer, than those using precipitation alone (Kirkpatrick Baird *et al.*, 2022; Reyniers *et al.*, 2023). This is a key finding given the observed and projected changes in temperature in Scotland. Indices accounting for evapotranspiration are likely to give a more robust picture of changes in water resource availability, particularly for water consumption by forestry, crops and natural terrestrial vegetation where soil water availability can be a limiting factor.

Soil moisture ground observations are typically limited in spatial extent and length of record, but it has been shown that these observations, in combination with satellite-derived earth observation data, can be effectively used to estimate soil moisture over the past few decades. An example is the soil moisture data derived from the scatterometer on board the ERS-1 and ERS-2 satellites, operated by the European Space Agency (ESA) (Wagner *et al.*, 1999). The Joint Research Council of the European Commission have developed a hydrological rainfall-runoff model whose soil moisture component has been shown to represent this soil moisture time series well (Laguardia and Niemeyer, 2008). Analysis of these soil moisture data show that between 2000 and 2019, eastern areas of Scotland have experienced a decreasing trend in soil moisture.

Evidence of a decreasing trend in runoff during the driest month of the year is consistent with the picture of increasing spring and summer meteorological drought frequency and falling soil moisture in eastern Scotland. Between 1951 and 2015, runoff during the driest month of the year in this region has reduced by 5 to 10% (Figure 2).



Reference data: ©ESRI

Figure 2: Trend in runoff during the driest month of the year in Europe (1951-2015). Source: EEA (2020) with data from Gudmundsson and Seneviratne (2016)

A crucial consideration for the resilience of water supplies and the health of the aquatic environment is not only the average frequency of droughts but the risk of back-to-back droughts which give little time for system recovery. The drought that affected Scotland during the summer of 2018 followed two consecutive winters with below average rainfall. In each of the past six years, areas of Scotland have experienced at least a moderate level of water scarcity (SEPA, 2023). Although not always in the same region, the north and east of Scotland has been particularly impacted, with long-term flow indices in Sutherland largely below normal since 2017 (Figure 3). Drought rich periods such as this have occurred before in Scotland. Reconstructed flow records extending back to the late 1800s show several such periods, notably the long drought of 1890-1910, the 1940s and the early 1970s (e.g. Barker *et al*., 2019; Rudd *et al*., 2017). Understanding the nature and scale of these historic events is valuable for assessing the severity of droughts operationally and for providing context for future projections.

2.2.2 Projections of future water supply in Scotland

Future trends are inferred based upon results from climate models that are parameterised with current knowledge of climate processes and driven by different scenarios of greenhouse gas concentrations in the atmosphere. In the UK, the current state of the art is represented by the UK Climate Projections 2018 (UKCP18) primarily based on the Met Office Hadley Centre climate models, augmented by a wider suite of other international models to give a broad representation of expected future changes (Lowe *et al*., 2018).

Although UKCP18 (as with previous reports) suggests that overall annual precipitation values may not change significantly, the general projected trends are towards hotter, drier summers on average (with rainfall occurring during shorter phase, more intense, convectional events) and warmer, wetter winters. What are currently seen as exceptional hot and dry conditions, such as the 2018 summer drought which led to significant negative impacts

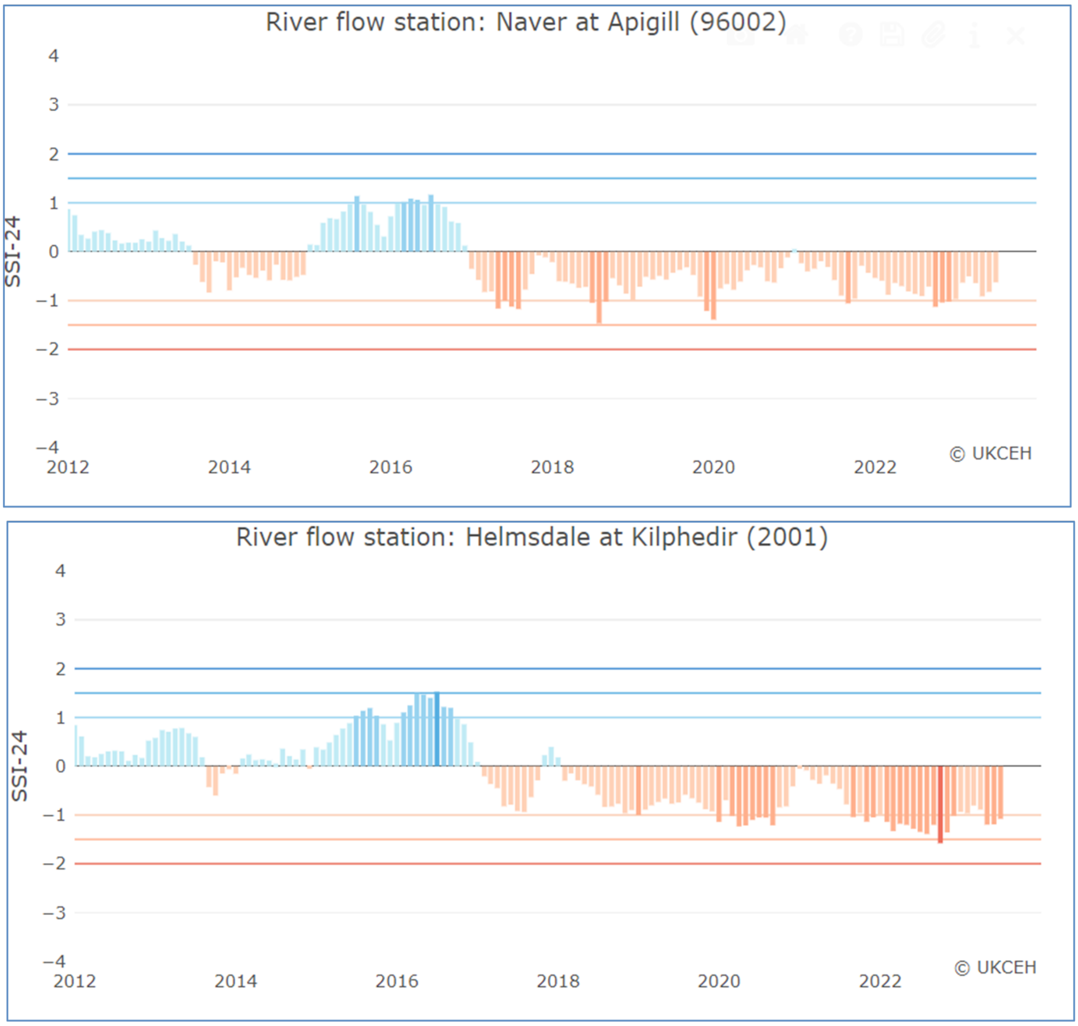


Figure 3: 24-month standardised streamflow indices (SSI) for 2 National Hydrological Monitoring Programme sites in Sutherland (2012 to 2023). Negative values indicate below normal flows. Source: Centre for Ecology and Hydrology, 2023.

on aquatic ecology, agricultural production and industry in Scotland, are projected to become much more frequent by 2050s (UKCP, 2023). This is consistent with European-scale assessments of meteorological drought which show an increasing frequency of drought episodes at continental scale, including the British Isles (Spinoni *et al.*, 2018; Böhnisch *et al.*, 2021), although this will also be strongly influenced by the degree of climate forcing (projected emissions and climate sensitivity: Lehner *et al.*, 2017).

For Scotland, these changes will be superimposed on the general oceanic climatic pattern, which typically means north-western regions are wetter than the south-east. The projected future summer drying trend therefore has a notable gradient across the UK, so that parts of NW Scotland may not experience as large a change as areas further south or east. The magnitude of change also varies across different model projections, in addition to the degree of climate forcing, meaning future projections have inevitable uncertainty particularly for the more extreme drought events. As these are projected trends for average years, individual years may significantly differ from the average (as at present).

A key area of uncertainty is the anticipated changes in drought magnitude because there is not clear consistency across different climate models. Nevertheless, a precautionary risk-based approach (informed by knowledge of the underlying processes) would suggest increased preparation for such events would be strongly advisable, especially considering the severity of the possible consequences for water scarcity.

When assessing drought risk from a hydrological perspective, we can also infer a higher level of risk because there is high confidence in projected trends towards higher temperatures and increased net solar radiation which are key factors for evapotranspiration. Some of the projected changes in evapotranspiration are significant, at least in terms of its potential assuming unlimited water availability, e.g. 30-40% increase by the 2050s, which would mean a more negative summer water balance for large areas of Scotland (Brown *et al.*, 2011; Brown, 2017). However, evapotranspiration is a complex process and the method used to calculate it can influence the results. The complexity of climate change means several factors are changing concurrently, and particularly CO_2 levels together with climate parameters. For evapotranspiration in plants, elevated CO_2 levels affect the efficiency of photosynthesis and plant stomata become less open which reduces the rate of evapotranspiration. Elevated CO_2 can lead to increased biomass through a larger leaf area which would increase the rate of evapotranspiration. At present, we do not know which of these different trends will dominate, and it will vary across different plants and ecosystems (Lemaitre-Basset *et al.*, 2022).

Finally, especially during drought episodes, actual evapotranspiration rates will not be as high as potential evapotranspiration rates because there is not enough water available in the soil. Soil water availability affects plant growth and its overall resilience. When it drops below a critical threshold known as the 'wilting point', plant roots cannot access water and plant health is severely compromised. For these reasons, some valuable crops are supplied with supplementary irrigation water at crucial times, and this may be then defined as another source of active water demand as distinct from the passive demand required to keep all plants and ecosystems healthy and functioning.

Bearing the above caveats in mind, an assessment of changing drought risk using the 6-month SPEI (potential evapotranspiration calculated using the simple Thornthwaite method) derived from UKCP18 data, provides an indication of changing risk (Kirkpatrick Baird *et al.*, 2023). This study

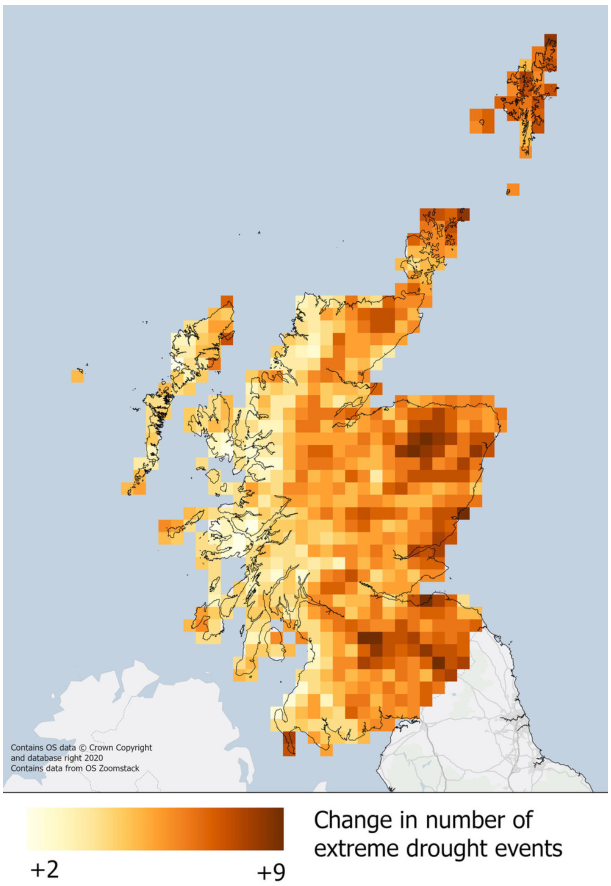


Figure 4 Projected change in extreme drought frequency by 2040 under a high emissions scenario. Source: Kirkpatrick Baird et al., 2022.

found an extreme drought event likelihood of one in every 20 years (with a maximum of one in five years in the driest locations) in the baseline period (1981-2000). This likelihood increased under a high emissions pathway to a median of 1 every 3 years by 2040 (with a maximum of 1 in every 1.7 years in the driest areas). It was also found that drought events were up to 2-3 months longer, with an average of 11 extra drought months per decade. Increases were most severe in the east, and during autumn, but changes were identified across all of Scotland. Higher risk areas were projected to have more than a doubling of average drought event duration by 2040. There is also evidence of an increased risk of unprecedented hydrological drought in the UK, although to-date analysis has mainly focused on risks for southern England (Chan *et al*., 2023).

An additional risk factor is the spatial extent of drought events. If drought conditions extend over a large contiguous area, then this will likely have more severe consequences as a conventional response based on inter-basin transfers between adjacent catchments becomes unviable. Analysis for England and Wales suggests that when a particular reservoir is at exceptionally low capacity there is a 40% likelihood that reservoirs in adjacent catchments would be at a similar level (Dobson *et al*., 2021). As the scale of a drought event increases, household level resilience can also reduce as coping mechanisms such as relying on nearby family or friends become less effective (Scottish Water, 2016).

2.3 Water Demand

2.3.1 Natural Environment

Natural ecosystems are networks of species, intrinsically linked to their habitat conditions. For aquatic plants and animals to maintain healthy levels of abundance and diversity, a set of typical, water-related environmental conditions must be maintained. In rivers, this concept is known as the natural flow paradigm (Poff *et al*., 1997). As flows and levels change from natural conditions, the pressure on ecosystem health increases. This concept underpins the method of classifying ecological status under the Water Framework Directive and in the UK this results in identifying a proportion of natural flow which is required to support ecosystem health (Scottish Government, 2014). In the context of water scarcity, the flow and level conditions required to meet good ecological status can be seen as a water demand that must be maintained in the same way as other water demands. However, this requirement may also be defined as more fundamental because the risk of ecosystem degradation affects not only priority species and habitats for which Scotland has international biodiversity obligations, but also because of the potential loss of the wide range of ecosystem services that a healthy functioning system provides for example fisheries, natural water purification, cultural and amenity value.

When the water demands of aquatic ecosystems are not met several impacts can ensue. Reduced flows and levels lead to contractions of wetted habitat and potential exposure of species unable to relocate. Lower flow velocities deposit fine material (e.g. Wood and Petts, 1994; Wright and Symes 1999), which can reduce habitat availability and diversity and clog interstitial spaces (Vadher *et al*., 2015). Declining water volumes are less able to dilute solutes, potentially increasing concentrations of pollutants, and compound effects can occur through reduced dissolved oxygen availability and increased risk of water warming (May *et al*. 2022).

The degree to which aquatic ecosystems are impacted by a deviation from natural flow and level conditions depends upon the resilience of system and the magnitude, frequency, and severity of the deviation. Ecological communities can deal with a certain amount of exposure to low flow conditions, which is recognised within the environmental standards used to determine abstraction allowances in Scotland (Scottish Government 2020). These environmental standards relate to deviations of flows and levels from a reference flow conditions (e.g. Q95, 5-percentile of flow, see Glossary) with the assumption that these deviations reflect direct human disturbance to the water environment. However, as climate change influences flows there is a question to be answered about whether the river flows (and associated depths, velocities and stream power) that must be preserved for a healthy aquatic environment should be fixed in time to preserve those hydraulic conditions or whether they should track changing flows (Figure 5).

There is scientific consensus that climate change will affect the viability of currently defined reference conditions (HR Wallingford, 2020; Berry and Brown, 2021). However, an impact assessment of changes in reference condition for Scottish rivers has yet to occur. This is a necessary precursor for any further adaptation actions that will also affect all water users.

Kirkpatrick Baird *et al*., (2023) looked at the risks of water scarcity for two priority terrestrial habitats: ombrotrophic (precipitation fed) wetlands and temperate rainforest. Ombrotrophic wetlands

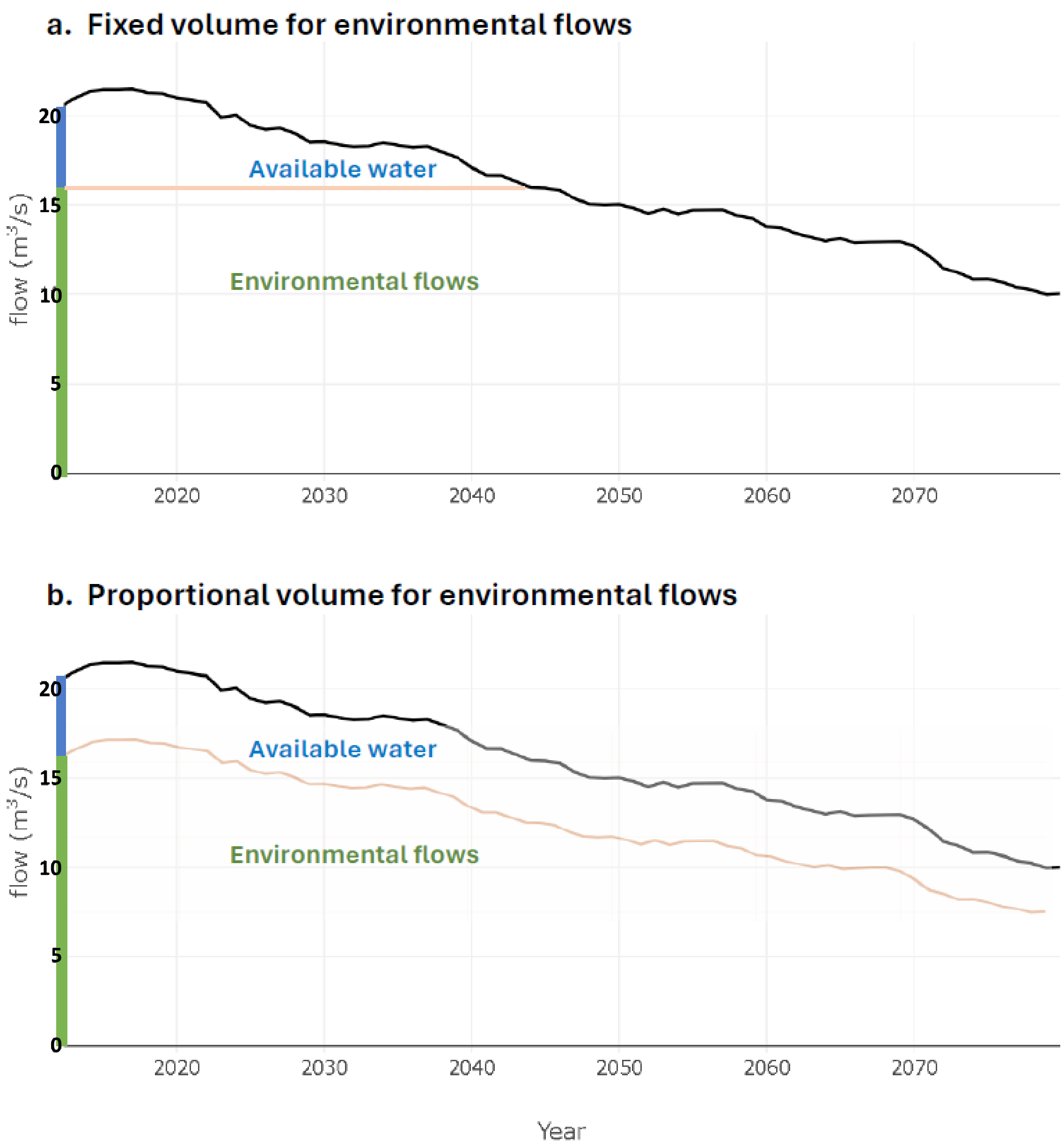


Figure 5: The impact of choice of reference conditions for environmental flows at a theoretical river section.

have some level of adaptive resilience to drought but are considered at high risk as several key sites (especially for raised bogs) are in locations identified as drought hotspots. In contrast, Scotland's temperate rainforest is primarily located in lower risk areas but is considered typically less drought resilient. The biodiversity impacts of water scarcity in these habitats include reduced breeding success for multiple taxa and increased competition among plant communities which would threaten drought-sensitive species. There are also broader implications for ecosystem services including carbon storage.

2.3.2 The Water Sector in Scotland

Scottish Enterprise defines the water sector as those businesses based in Scotland that supply products and services in which water is the main focus. It includes domestic and industrial water supply, bottled water and hydroelectric developers. This sector is estimated to generate £3.7 billion for the Scottish economy and provide almost 17,000 jobs (Scottish Enterprise, 2019). In addition, the contribution to our economy and society of agriculture, distilling, aquaculture, and numerous other sectors is dependent upon a reliable supply of high-quality natural water. Over time the demands for this resource have changed as water dependent industries have developed and as the size and distribution of our population has varied, and further influenced by changing technology and use of commodities. This Section sets out some of those changes in the recent past and expectations for changes in demand in the future.

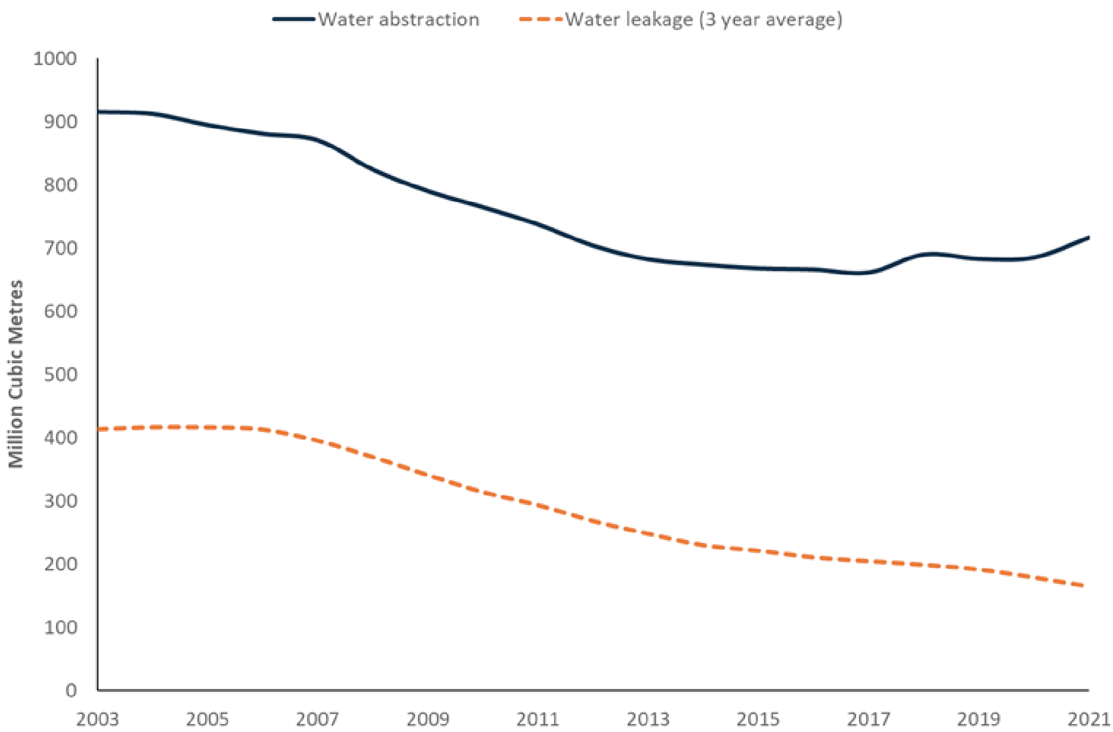


Figure 6: Water abstraction and water leakage, million cubic metres, Scotland, 2003 to 2021. Source: Scottish Government, 2023c.

2.3.2.1 Public water supply

The majority of potable water demand in Scotland comes from domestic properties. Between 2003 and 2021, the population supplied by Scottish Water increased by 7% to just under 5.2 million people (WICS, 2023). Over this same period, abstraction volumes for public water supply in Scotland have decreased by 22% (Scottish Government, 2023c). Much of this decrease has been due to reduced leakage from the supply network (Figure 6). In 2019/20 Scotland had an overall annual positive water supply/demand balance of around 300 Megalitres per day (MLD^{-1}Ml day^{-1}) (HR Wallingford, 2020).

Across Scotland, not all customers experience the same risk of supply failure from a resource shortfall. The volume of public water supply varies geographically depending on factors such as rainfall amount, reservoir storage and river flow. Drought resilience or security of supply is typically assessed against a notional yield-level and expected 'level of service', beyond which additional measures may be required. The variable geography of Scotland means that some locations have intrinsic challenges in terms of drought resilience. This was highlighted in 2014/15, when an assessment at the water resource zone level, showed lower yield level in some areas of western Scotland (notably the islands). Although these locations normally have relatively high rainfall, they are constrained by smaller catchment size and limited storage capability (Figure 7).

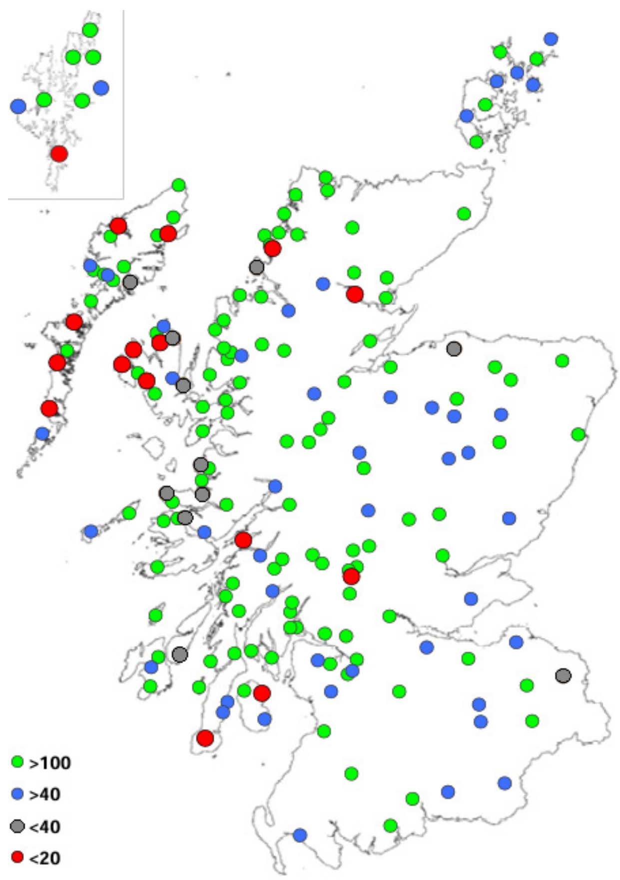


Figure 7: Water resource supply zone yield level of service (years) in 2014/15. Source: Scottish Water, 2015.

A key factor which also needs to be considered for future demand is the projected population of Scotland. The most recent population projections indicate that the central estimate of population in Scotland is expected to peak in the early 2030s and then decline so that by mid-century there may be little or no change from 2023's values. However, under a high population projection scenario, Scotland could see an increase of up to 12%. If this were realised, even with planned leakage reduction measures, demand could exceed 2023 values (HR Wallingford, 2020). Furthermore, it is projected that the distribution of population in Scotland is expected to see a broad shift from west to east i.e. wetter to drier water resource zones (Figure 8).

Water demand is also not stationary. Recent data have shown that since Covid, in Scotland general domestic demand has risen to 180 lpd from 165 lpd (Scottish Government, 2023b), which is significantly higher than other UK and many European countries (i.e. Germany = 125 lpd; Denmark = 105 lpd). In addition, household demand can vary seasonally in response to the weather and changes in local population numbers (see Section 2.3.6). During one week in 2020, demand increased by 22% in some areas, with operational challenges for water treatment works and distribution networks (Scottish Water, 2021). Demand is also not equal across socioeconomic groups, with more affluent populations shown to have significantly higher water consumption rates (e.g. Harlan *et al*., 2009; Xenochristou *et al*., 2020). A contributing factor to these trends is that most households underestimate their water use by a significant amount (Scottish Water, 2021). Whether current trends in consumption are likely to continue remains an important issue to investigate further.

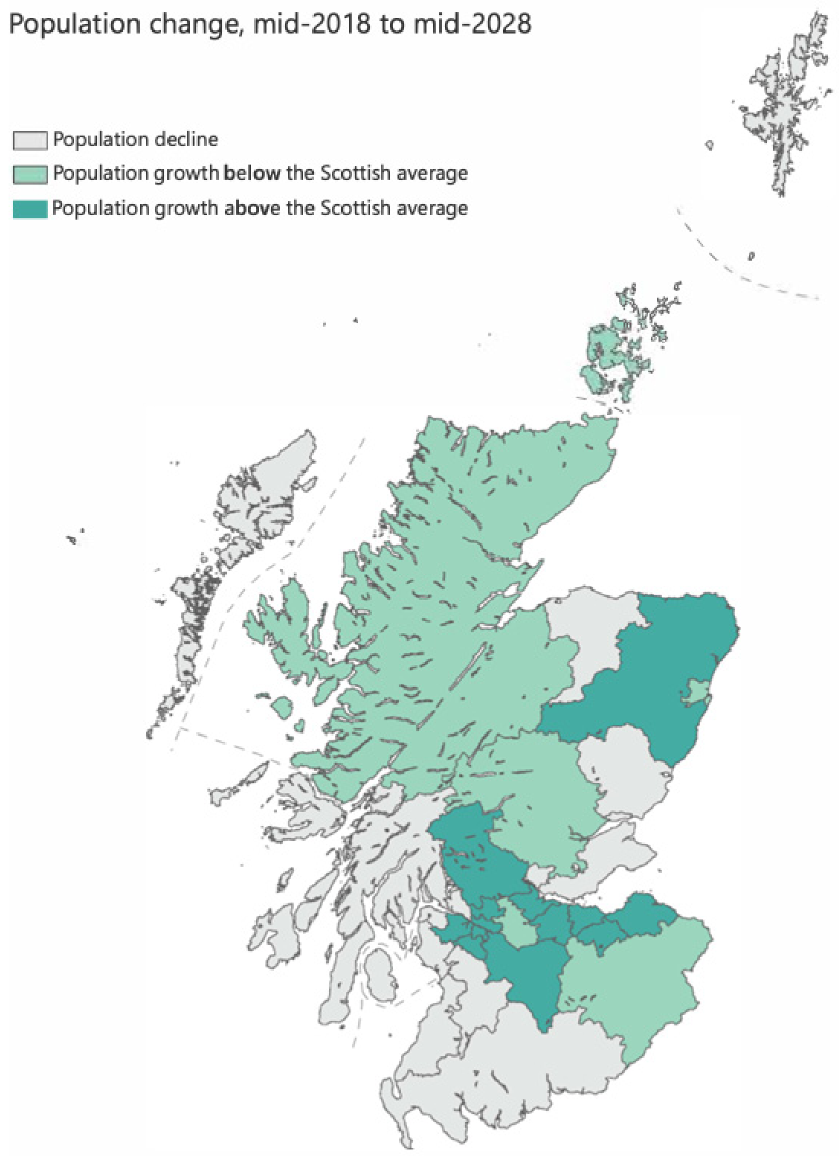
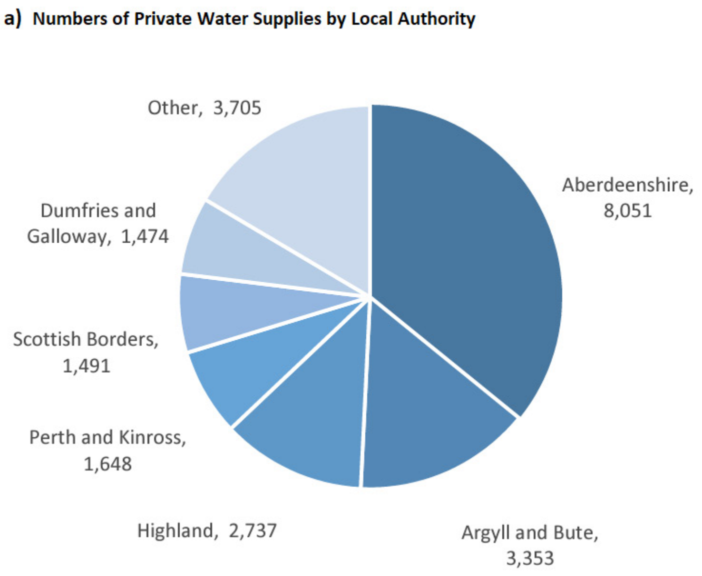


Figure 8: Projected percentage change in population, by council area, mid 2018 to mid-2028. Source: National Records of Scotland, 2020, p.2.



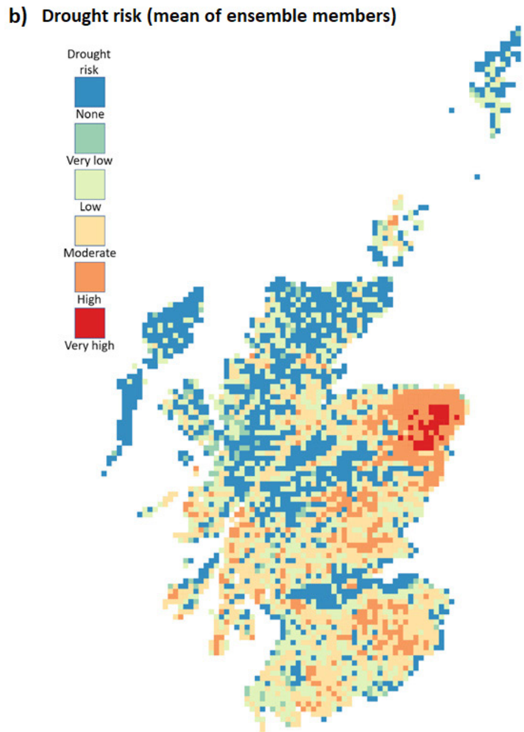


Figure 9: Private water supply distribution and risk in Scotland: a) Numbers of Private Water Supplies by Local Authority; and b) Ensemble mean Meteorological Drought Risk Indicator for private water supplies.
Source: a) DWQR, 2022, Figure 2; b) Rivington *et al*., 2020, Figure 15.

2.3.2.2 Private water supplies

3.6% of Scottish households, typically in more remote rural areas, rely on private supplies of water, including from streams, lochs, groundwater springs and boreholes (Scottish Government, 2019). Approximately three quarters of private water supply by volume comes from groundwater, typically via shallow boreholes (Rivington *et al*., 2020). In 2021 there were 22,459 registered private water supplies serving around 185,850 people (DWQR, 2022). This is a 19% increase over figures reported in 2010 (DWQR, 2011) although it is unclear how much of this represents a real increase in the population served and how much is an increase in number of supplies registered. Almost 85% of private water supplies are registered within six local authority areas (Figure 9a) and the number of people served by them varies seasonally with demand from tourism.

The smaller scale of these supplies often means that they are more vulnerable to drought episodes (DWQR, 2018). For example, the hot dry summer of 2018 led to the loss of some private water supplies, with over 500 incidents requesting emergency assistance recorded, notably in NE Scotland where 165 supply failures were reported through Aberdeenshire council, and with bottled water was provided as an emergency contingency (Rivington *et al*., 2020). An analysis of the interaction between the distribution of private water supplies in Scotland and the projected changes in meteorological drought between 2020 and 2050 has generated a drought risk indicator for private water supplies. This risk mapping clearly shows the areas of highest risk in Aberdeenshire where a high density of private supplies is located in a region with significant projected increases in drought (Figure 9b).

2.3.3 Energy

Energy production has historically required large amounts of water, mostly for cooling (Table 1). The shift from coal to gas and the increase in renewables over the last few decades should already have led to lower water consumption from this sector.

Table 1: Water consumption in l/MWh for the different electricity generating technologies for the Minimum (Min) and Maximum (Max) cooling water consumption scenarios.

Source: Vandecasteele *et al*., 2016 - The assumed cooling technologies are given where relevant: (D) = Dry; (O) = Once-through; (T) = Tower/closed-loop.

Fuel Type	Min	Max
Coal	721 (O)	2684 (T)
Biopower	132 (D)	2272 (T)
Natural gas	8 (D)	2461 (T)
Nuclear	947 (O)	2699 (T)
Solar (PV)	180	180
Wind	22	22

Hydropower uses water from rivers and reservoirs to generate electricity, accounting for over 90% of the total licensed abstraction volume in Scotland (Visser-Quinn *et al*., 2021; Scottish Government 2023c). This use can be non-consumptive, in that the water used is returned to the environment within the same catchment. However, this can be many kilometres from the point of abstraction resulting in depleted stretches of rivers. In some schemes, water withdrawal is considered consumptive where diversions discharge water across river basin boundaries. For example, a proportion of rainfall that would naturally flow through the Spey is diverted into the Tay catchment via aqueducts to feed a series of hydropower stations (Payne, 1988). Rather than flowing out to the North Sea at Garmouth, this water ends its freshwater journey at Perth over 140km away.

Between 2008 and 2018, there was an increase in the installed capacity of hydropower in Scotland of around 15% resulting in an increase in the amount of water abstracted (Department for Energy Security and Net Zero, 2023). However, since the removal of the Feed-in Tariff as an incentive to develop small and medium sized schemes, this growth has all but ceased.

There are plans in place to develop more pumped storage schemes over the next few years to help manage variations in customer demand and fluctuations in renewable energy generation. Again, these are non-consumptive and typically result in relatively short, depleted river stretches. However, the increasing need for longer term storage and refilling in newer pumped storage schemes, to better balance other renewables, may have impacts on lower reservoir and loch levels that could influence outflow river flow rates over weeks rather than the hours or days of historical schemes.

In our drive towards Net Zero, hydrogen production is expected to play a significant role in both energy storage and fuel for transport. With water as a key resource in both the raw material for electrolysis and the generation of electricity to power the process, there is the potential for this growing demand to have a major local impact upon water availability. Several studies have shown that the impact upon water scarcity within a region of hydrogen production is highly dependent upon the method of production and the source of energy (e.g. Simoes *et al*., 2021, Shi *et al*., 2020, Mehmeti *et al*., 2018). Production processes powered by renewables and using wastewater or seawater will have significantly lower impacts on water scarcity than other methods. Currently, the costs of green hydrogen production in Scotland are expected to be relatively high compared with other countries due to the cost of renewable energy generation (Kerle *et al*., 2023). However, as Scotland moves forward with scaling up offshore and onshore wind power, the price of hydrogen produced in Scotland should become more competitive. As the hydrogen industry develops, the impact on water resources must be an important consideration for the siting and method of production.

There is a separate CREW project looking specifically at the impacts of windfarm development on drought risk in Scotland (Geris *et al*., 2024), and the outputs from this will be accessible here in April 2024.

2.3.4 Agriculture and Forestry

Agriculture is a major water user in some locations of Scotland (mainly in the east) and the time of peak water use for irrigation usually corresponds with the driest time of year, which can exacerbate water stress. Water is also used in processing of crops and livestock production (especially cattle) and requires continued availability. Regarding irrigation, typically only high value crops are irrigated, notably potatoes, and fruit and vegetables, using licensed water abstracted from both surface water sources and boreholes. Currently, licensed agricultural abstraction amounts to a total daily value of 0.79 x 106 m^3, which is roughly half the rate of water abstracted for public water supply (Visser-Quinn *et al*., 2021; WICS, 2023).

The additional water required for irrigation highlights active water demands for the agriculture sector, which varies from year to year, and needs to be considered together with the natural (passive) water demands that all plants (in agriculture, forestry, or ecosystems) require for growth and other functions. There is a general trend over recent decades towards increased water demand for agriculture due to pressures to maintain the quality of high-value crops. A further factor to consider is that some abstraction for agricultural irrigation occurs in small catchments in drier areas (e.g., Fife; Angus; Tayside; East Lothian) and their size means they are more sensitive to periods of low summer rainfall, unless supplemented by groundwater aquifers (Brown *et al*., 2012). There is a separate CREW project looking specifically at the impacts of water scarcity on agriculture (Glendell *et al*., 2024), and the outputs from this will be accessible here in April 2024.

At present, only a very small proportion of Scotland's land is used to grow energy crops, but proposals have been developed to expand this sector as a key component of pathways to Net Zero, especially through 2nd/3rd generation crops that do not compete with food supply (e.g. miscanthus; short rotation coppice). However, the fast growth rates of energy crops are typically associated with relatively high water demands. There is potential for expansion in Scotland, largely in eastern areas (ClimateXChange, 2020). Whether this results in an increase in water demand depends upon what land use the energy crops replace (Holland *et al.*, 2015).

As with energy crops, some trees used in forestry have a relatively high water-demand (including short-rotation forestry which has also been proposed for expansion), and some species are drought sensitive, notably Sitka spruce (the predominant productive species in Scotland). Hence, projected trends in increased drought frequency, suggest that Sitka spruce in the drier east of Scotland may become less productive and more vulnerable. Damage due to stem-cracking was previously observed on mid-rotation Sitka spruce in Aberdeenshire after the 2003 summer drought (Green and Ray, 2009). These sensitivities can, at least partially, be alleviated by good management practice (especially adapted to local soil properties) and evidence from recent low summer rainfall years (e.g. 2018) indicates there is some resilience to dry conditions, although the limits of this resilience need to be further investigated. Miscanthus

Plans for land use change in Scotland particularly highlight continued woodland expansion, with increased emphasis on 'the right tree in the right place' to deliver Net Zero together with other policy objectives. This highlights the need to include interaction with water resource issues in these plans. A further issue in this context is that recent research has shown that larger-scale woodland expansion can modify not just the local site hydrology, but also through interactions with the atmosphere can modify rainfall patterns and water availability in the direction of the prevailing down-wind environment (i.e. usually to the east in Scotland). This is a focus of active research at present (Geris *et al.*, 2024), and demonstrates the need to develop systems-based assessments to represent the interacting effects of climate and land use change on water scarcity.

2.3.5 Aquaculture

The Scottish aquaculture sector and its supply chain supported an estimated 11,700 jobs in the Scottish economy and generated £885 million gross added value in 2018 (Scottish Government, 2023d).

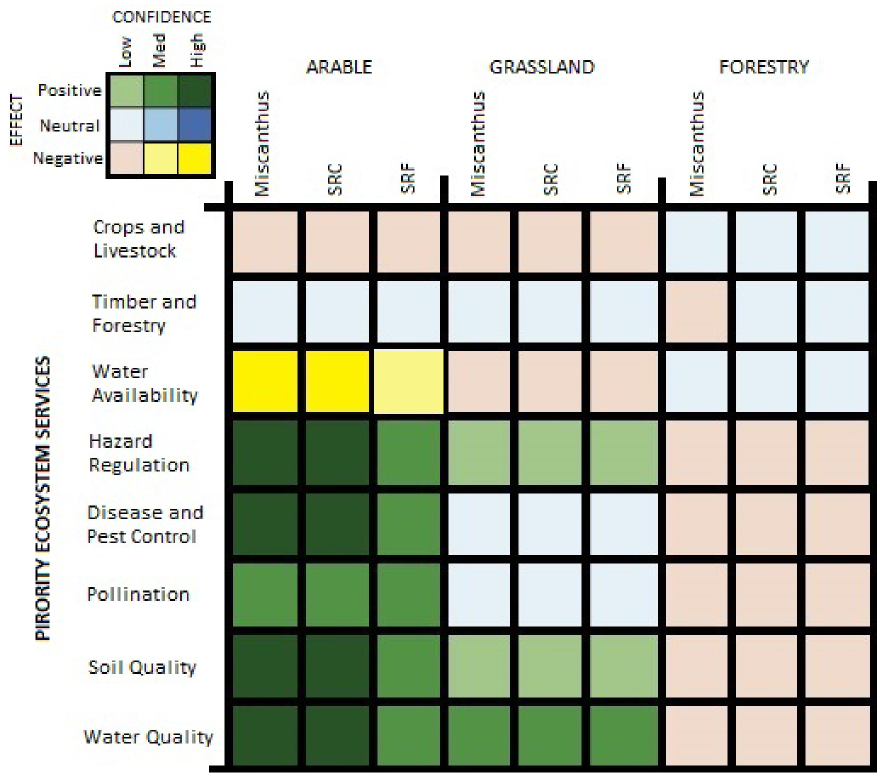


Figure 10. A synthesis of the ecosystem services impact of second-generation bioenergy crop production. SRC - Short-rotation coppice, and SRF - Short-rotation forestry feedstocks. Source: Holland et al., 2015, Figure 1.

Aquaculture is a major user of freshwater for fish farms and hatcheries, and this is especially notable where the industry has a significant footprint as in NE Scotland, Highland region, and locations in central Scotland The rate at which aquaculture abstracts freshwater is similar to that of agriculture (Visser-Quinn *et al*., 2021), however, more than 90% of this abstraction is non-consumptive in that it is returned to the catchment after use. Aquaculture is especially vulnerable to water scarcity because of the specific needs of fish for clean oxygenated water, and the requirements for freshwater in non-chemical sea lice treatment. Under its "Vision for sustainable aquaculture", the Scottish Government wish to see aquaculture expand in a sustainable way, and to achieve this the implications for local water demand must be central to any planning (Scottish Government, 2023d).

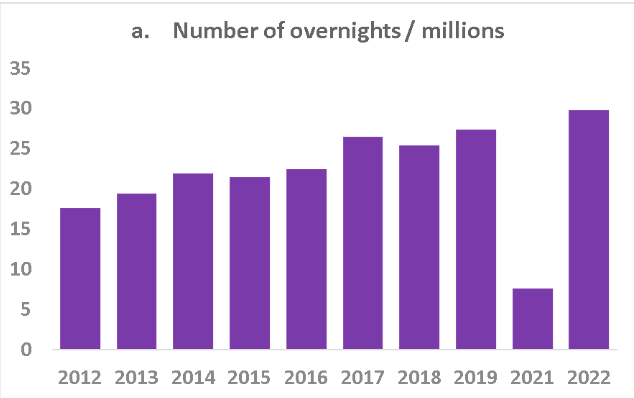
2.3.6 Leisure and Tourism

Tourism is a growing industry in Scotland. The number of nights spent in Scotland by international visitors has grown steadily between 2012 and 2019. Following the removal of COVID-19 restrictions in 2022, visitor numbers recovered reaching a highest on record that year (Figure 11).

Tourism behaviour differs markedly from the general population. Only around 20% of Scotland's resident population is found in small towns and villages (< 5000 inhabitants) or rural areas (National Records of Scotland, 2022). In contrast almost 50% of overnight tourism trips made to Scotland were to these small settlements (Visit Scotland, 2023). Tourism also favours the summer months, with peaks in July and August, and more than half of stays are in serviced or self-catering accommodation requiring frequent cleaning and laundry. Water supply networks are principally developed to serve the needs of the general population. In comparison, tourism water demand is growing faster, more likely to peak during the summer months and is biased towards regions less well served by large storage reservoirs. As one example, during 2018 on Arran, demand increased by 30% due to a period of warm dry weather, requiring water tankers to deliver extra supplies from the mainland by ferry.

2.3.7 Industrial users including distilleries

Although heavy industrial use of water is declining in Scotland, there are still some notable large users, including material, food and chemical production and manufacturing (Allan *et al*., 2020). The distilling sector is also a significant water user. Since 2010, there has been a major expansion of the distillery sector in Scotland, with 22 of Scotland's 32 local authorities now having a distilling business presence (up from 15), with 60 gin distilleries and 128 malt and grain distilleries (O'Connor, 2018). The Moray area (NE Scotland) has the highest intensity of distilling related firms with ¼ of all activity based there. The whisky sector, as a whole, is licensed to abstract more water than Scotland's agriculture although approximately 40% of this is returned to rivers after use in cooling (from Visser-Quinn *et al*., 2021). A further challenge for the distilling sector is that some distilleries rely on local abstraction from relatively small catchments with limited alternative sources (notably for island locations). A separate CREW project is looking specifically at the impacts of water scarcity on distilleries (Glendell *et al*., 2024), and the outputs from this will be accessible here in April 2024.



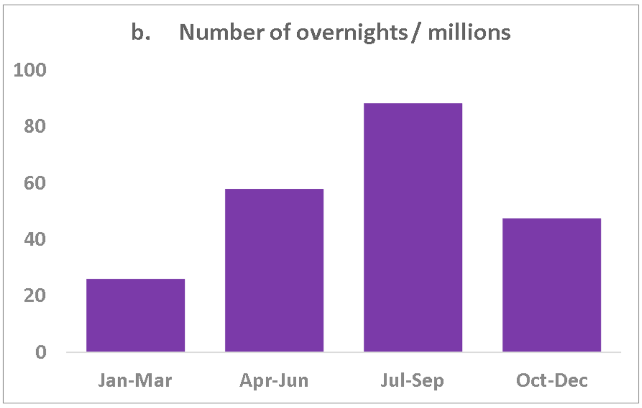


Figure 11: a) The number of overnights; and b) Seasonality of visits, in Scotland by international visitors 2012-22. Source: Scottish Tourism Observatory, 2023.

2.4 Water scarcity

2.4.1 The supply-demand balance

In the previous 2 Sections we have considered changes in water supply and water demand, respectively. Water scarcity results from a shrinkage in supply and/or an increase in demand to the point that some users' needs are not met. Typically, these conditions occur during droughts which are driven by periods of exceptionally low rainfall which can be exacerbated by high rates of evapotranspiration. Water scarcity, then, is signified by impacts on water use and several studies have generated catalogues of water scarcity impacts and related these to meteorological and hydrological droughts (Barker *et al*., 2019; Gosling *et al*., 2012).

Water scarcity impacts can be felt across a number of sectors, depending upon the nature and scale of the event. For example, the drought of summer 2018 in Scotland resulted in water scarcity impacts on private water supplies, distilleries, agriculture and the health of river and loch plants and animals (Figure 12).

In Section 2 we highlight several studies that have used climate model outputs to project the future risk of meteorological and hydrological drought in Scotland. Fewer studies are available that project both the supply and demand side of water scarcity. Brown *et al*., (2012) used climate projections to model both supply and demand of indicator crops to explore potential changes in irrigation demand. By looking at both supply and demand the study was able to highlight those areas at highest risk of water scarcity (notably Fife, Angus, and Tayside) assuming that land use and management continues as at present (i.e. no further adaptation). Visser-Quinn *et al*., (2021) used climate ensemble data together with current sectoral abstraction data to model both drought hotpots and impacts of abstraction. An increase in hotspot catchments was identified in central and eastern Scotland, notably major rivers such as the Spey, Tay and Tweed. Abstraction acted to amplify the projected impacts of climate change both regarding duration and frequency of drought risk, although intensity impacts were more equivocal. Also noteworthy was that projections for the hydropower sector were highlighted as having large uncertainties. These results highlight the importance of further adaptation of abstraction practices (e.g. timing; collaboration).

For the third UK climate change risk assessment, assumptions were made about various socioeconomic scenarios to project future demand for public water supply in Scotland (HR Wallingford, 2020). Using these in conjunction with UKCP18-based projections of water supply, the report highlights some scenarios where the supply demand balance could lead to public water supply issues in the future (Figure 13).

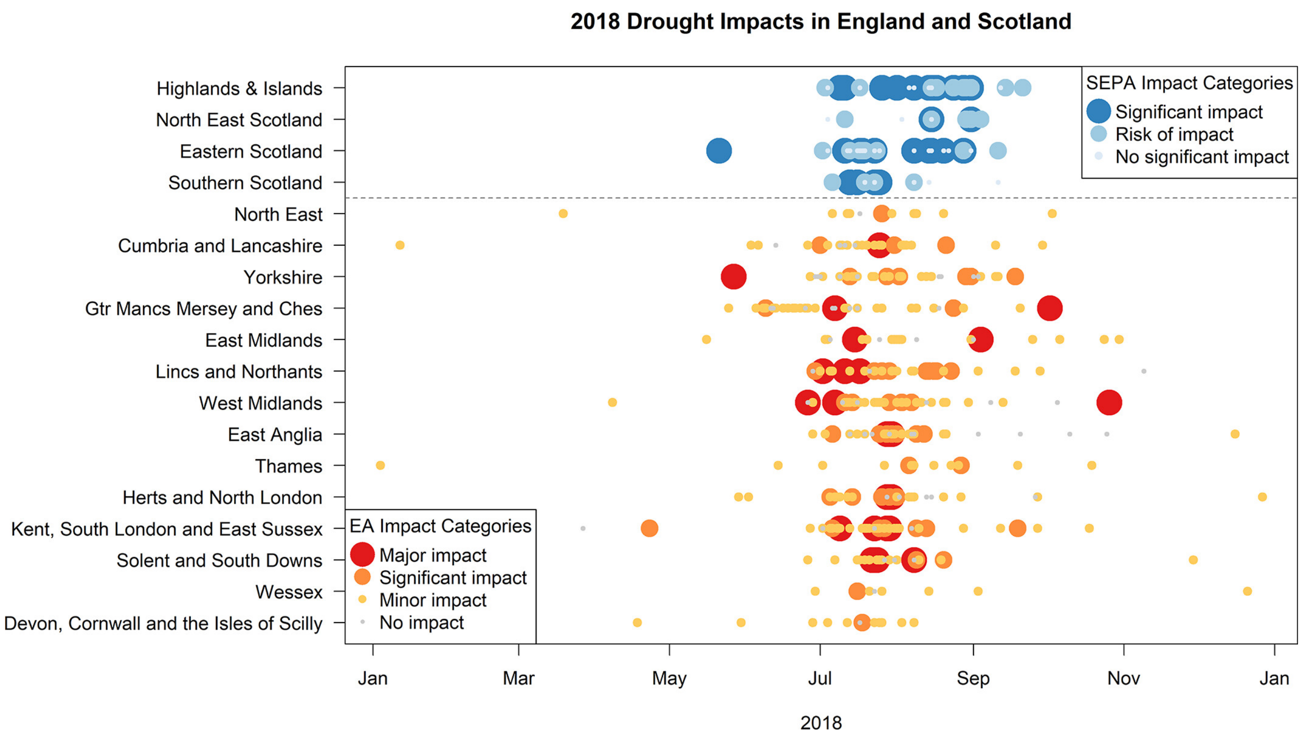


Figure 12: Timeline of 2018 drought impacts in England (EA) and Scotland (SEPA). Source: Turner *et al*., 2021, Figure 1.

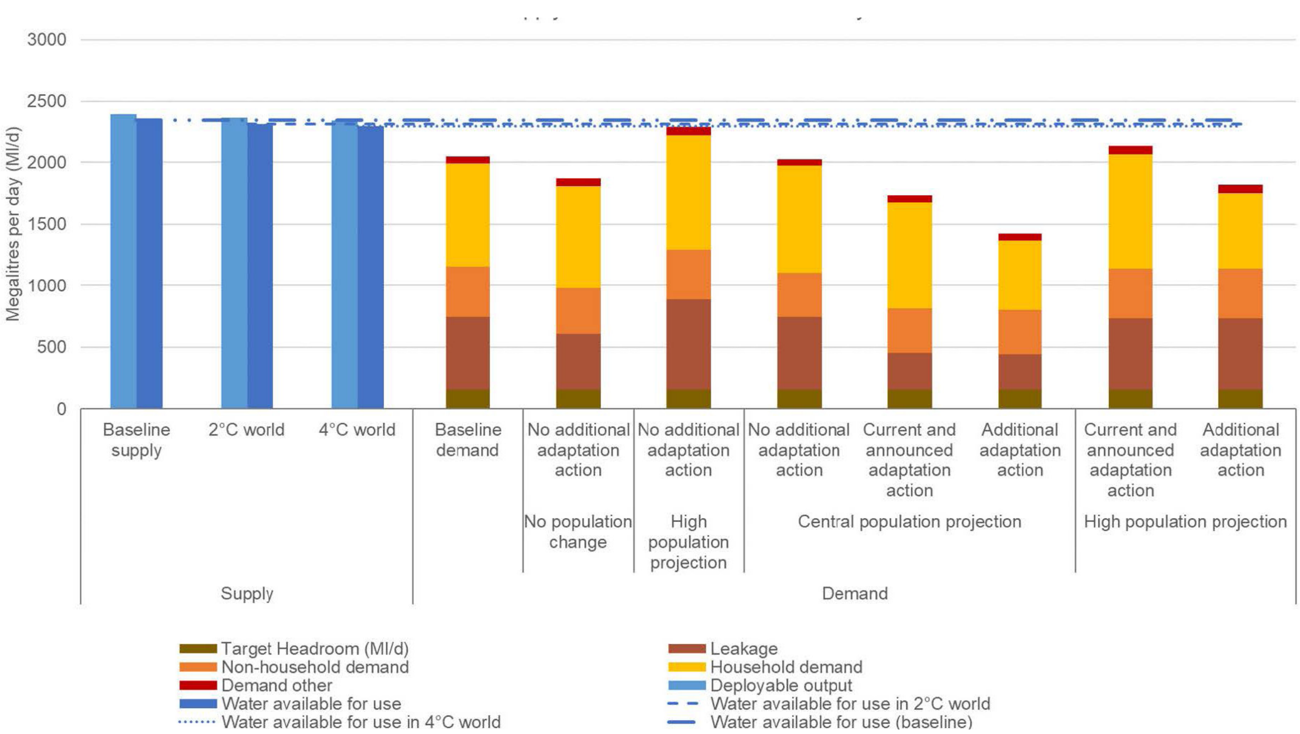


Figure 13: Scenarios of water supply and demand in the mid-century in Scotland. Source: HR Wallingford, 2020, Figure A5.

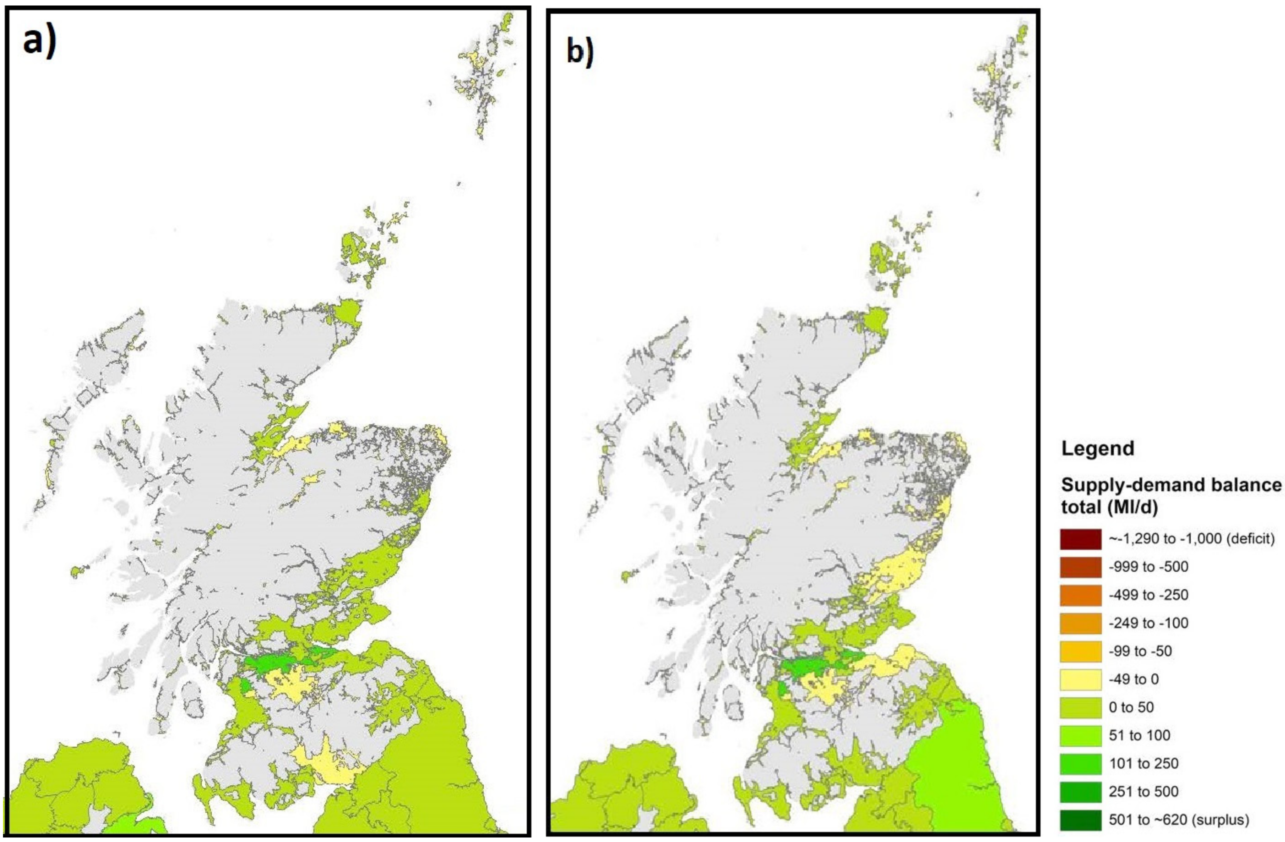


Figure 14: Supply-demand balance in (a) 2020 and in (b) the mid-century, in a 2°C world, central population projection and assuming no additional adaptation action. Source: HR Wallingford, 2020

The HR Wallingford (2020) study used water resource zones (WRZs) as its focal unit to assess the changing water balance under an indicative 'average' risk profile (notably as the 50th percentile for the period 2040–2069 to represent 'mid-century'). Presently, there are a few WRZs in Scotland that are currently in deficit (Figure 14a) and this assessment showed (based on its underlying assumptions) how this deficit could expand in future (Figure 14b).

Scottish Waters 2024 Climate Change Adaptation Plan has also indicated that without adaptation, the national deficit during drought conditions would increase to around 240 Ml day^{-1}, compared to 60 Ml day^{-1} today (Scottish Water, 2024a).

One of the most significant findings of the HR Wallingford study was the high sensitivity of the results to assumptions made regarding setting of 'environmental flows' (as further guided by the Future Flows analysis: Prudhomme *et al.*, 2013). Hence, as summer river flows decline in most locations in future, the issue of whether to maintain environmental flows at the same volume as present, or to reduce the volume as a proportion of the future overall flow, makes a large difference in terms of the deployable resource available. Conversely, a reduction in the volume of environmental flows (and associated impacts on water quality, as potentially further exacerbated by temperature increases) may have severe consequences for aquatic ecosystems, especially in the most sensitive locations. As many of these sensitive locations have protected status (notably as Special Areas of Conservation), a reduction on environmental flows could be in conflict with obligations to maintain them in favourable condition from a conservation perspective.

2.4.2 Systemic Risks of the Changing Supply-Demand Balance

At a basic level, a forward projection of the changing supply-demand balance implies water scarcity issues will become more severe for eastern Scotland, without additional adaptation actions. This general pattern is a consequence of projected reductions in summer rainfall particularly in the drier east, and assumptions on increased demand from key sectors which may be further exacerbated by a general demographic shift in population from west to east. However, the reality is likely to be more complex than this. As shown by Figure 15, some of the water resource zones that are already facing a negative or constrained supply-demand balance are in central and southern Scotland. Even small incremental changes could exacerbate this situation unless further actions are implemented at the WRZ scale. Furthermore, these general projections are based upon average changes: it is quite possible that changes in the magnitude of extreme events are just as pronounced in western and central Scotland as in the east, albeit more sporadically. This last issue is a key area of uncertainty at present but one which needs to be recognised by any risk assessment.

Systemic risks from water scarcity can happen due to synchronous peaks in demand from several sectors during times of low supply, especially during multi-seasonal drought events. This may lead to potential conflict between different water users in a specific location, particularly when demands from consumptive uses significantly increases (e.g. irrigation, tourism, cooling water). Although there have been several sectoral assessments of supply-demand imbalances, including with climate and socioeconomic projections, there has not to-date been a full assessment of these potential synchronous impacts, including implications for environmental flows and Interactions with water quality (temperature, dilution effects, dissolved oxygen etc.). Systemic risks may also interact through multiple sectors from indirect impacts, such as the increased risk of wildfire associated with periods of water scarcity. This can occur because water scarcity typically leads to large soil moisture deficits accompanied by low atmospheric humidity. Such extended 'soil moisture droughts' are a notable climatological feature of continental Europe, and projected to be further exacerbated by climate change (Rudd *et al.*, 2019). A key issue for Scotland is whether its future climate will shift more towards such a continental influence for some years during summer (and possibly autumn too) which, without further adaptation, increases the risk of unprecedented systemic risks.

2.5 Current Policy and Regulatory Framework

Water abstraction in Scotland is largely governed by the Water Environment and Water Services (Scotland) Act 2003 (as amended) and the Water Environment (Controlled Activities) (Scotland) Regulations 2011. These set out the way SEPA will authorise water abstractions to enhance the protection and improvement of the aquatic environment. Water abstraction authorisations are made under the condition that water is used efficiently and that the combination of allowable abstractions within a water body maintain sufficient flows and levels to support at least good ecological status (Scotland has committed to continuing the obligations of the Water Framework Directive). Rivers and lakes of high biodiversity value may have additional requirements as defined under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended) and its commitment to maintain 'favourable conservation condition'. These environmental requirements have been further reinforced by commitments made by Scotland and the UK through the post-2020 Global Biodiversity Framework.

The process of water management to address environmental protection and improvement is set out each six years within River Basin Management Plans (RBMPs). These plans identify the measures required to address existing pressures on the water environment. The cyclical nature of the plans' processes i.e. water body classification, instigating a programme of measures and monitoring the effects, arguably lend themselves to an adaptative management approach which can be used to account for a changing environment. However, there is no specific provision in the Water Framework Directive (from which the RBMPs derive) on how to account for the long-term impacts of climate change in measures such as those that address the impacts of low flows and levels and the 'reference conditions' which signify good status. Having said this, scope is being used within Scotland's RBMPs to set out ambitions around encouraging the sustainable use of water and minimising material use with the aim of reducing contaminants in the water environment, both of which can be seen as actions that would reduce the impacts of water scarcity in the future.

As well as addressing the long-term needs of a healthy aquatic ecology, in times of drought, regulation 19 of the Controlled Activities Regulations allows the temporary suspension of abstractions to maintain environmental flows. Further provision is made within The Water Resources (Scotland) Act 2013 to ensure that public water supplies are maintained during droughts through the making of "water shortage orders" by Scottish Ministers. These orders can be used to restrict or prohibit the abstraction of water by any person from any source specified in the order or impose conditions or restrictions on any abstractions or discharges. They can also allow Scottish Water to abstract from alternative sources and can relax conditions on existing authorisations to secure further supply. These provisions are incorporated into Scotland's National Water Scarcity Plan (SEPA, 2020) which is designed to improve drought resilience through improved communication between SEPA, Scottish Water and the Scottish Government. The plan also sets out an indicative hierarchy of action to manage water resources during droughts.

In addition to the holistic approach to water resource management that river basin management plans aim to deliver; many other policies are relevant to integrated water management. Scottish Water has set out its vision for the next 25 years in its strategic plan (Scottish Water, 2020). This sets out how it will work with the water sector to deliver the services it supplies in a way that aligns with Scotland's National Performance Framework and the UN sustainable development goals. Key to this plan is ensuring that high quality water is available for future usage even during extreme droughts.

Other policies include those for safety of drinking water, bathing water, and waste-water releases. However, some policies only make passing reference (if at all) to the challenges of water scarcity. In its summary of consultation responses to the 2019 Significant Water Management Issues Report, SEPA highlights that many responses called for stronger integration and alignment of river basin management plans with other plans and policies to deliver multiple benefits such as climate change adaptation and biodiversity actions (SEPA, 2020). Examples of linkages specifically required to address water scarcity were those could incentivise land use change through the Scottish Land Use Strategy and Scottish Forestry Strategy, and potentially implementation of the new Agriculture & Rural Communities Bill. Although land use change can have a significant influence on water supply and demand within catchments, it was felt that these changes are not accounted for within the flows and levels element of the ecological status classification of water bodies and, as a result, do not directly drive measures within the RBMP that interact with the land use strategies (Chartered Institute of Ecology and Environmental Management, 2016).

The Water Resources (Scotland) Act 2013 sets out a duty for Scottish ministers to:

- take such reasonable steps as they consider appropriate for the purpose of ensuring the development of the value of Scotland's water resources, and
- do so in ways designed to promote the sustainable use of the resources.

These duties underpin the formation of Scotland's Hydro Nation strategy which promotes actions within the RBMPs, Scottish Water's plans and through research, education and innovation that support the sustainable use of Scotland's water resources.

Inherent in the Water Resources Act is the requirement for actions to be consistent with the requirements of the Climate Change (Scotland) Act 2009. As such, there is a clear legislative driver to promote the sustainable use of Scotland's water resources in a way that does not compromise the drive towards Net Zero. A requirement of the Climate Change Act is the production of a Scottish Climate Change Adaptation Programme (SCCAP) that sets out policies and proposals to prepare Scotland for a changing climate. The most recent programme highlights the importance of adaptation to increasing water scarcity, notably in the creation of a sustainable and inclusive economy and the supporting systems required by society that are resilient to climate change (Scottish Government, 2019). A new SCCAP is intended to be published in 2024.

Beyond these key pieces of legislation and policies there are numerous policies that interact across the space where mitigation and adaptation actions to address water scarcity lie (e.g. Scottish Government, 2024; Scottish Water, 2024a). These sit under a set of national strategies that set out national outcomes and the principles that underpin them which, in turn, aim to deliver on Scotland's contribution to the global Sustainable Development Goals. A representation of the relationships between strategies and policies relevant to the management of water scarcity is shown in Figure 15. This is not intended to be an exhaustive list, rather it demonstrates the cross-cutting nature of water resource management.

2.6 Knowledge Review StoryMap

A Water Scarcity Knowledge Review StoryMap (Gosling *et al.,* 2023) that summarises the literature and policy review in this section was developed as part of this project's stakeholder engagement work. It can be accessed as an independent resource here.

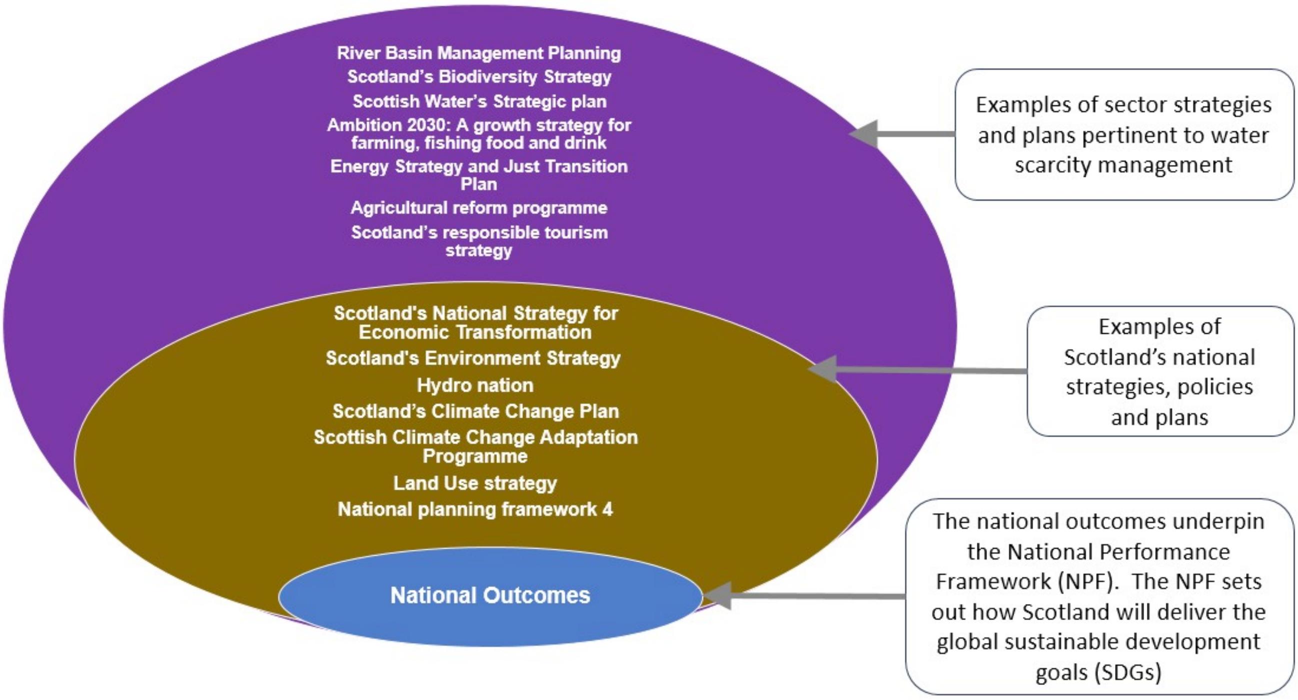


Figure 15: An example of relationships between policies, strategies and plans relevant to water scarcity in Scotland.

3 Key Knowledge Issues and Gaps

Based upon the overview presented above, we can summarise the following key issues regarding current knowledge of changing water scarcity risks:

i. Although projected changes in the supply-demand deficit are available, both changes in supply and demand have important uncertainties that require further combined evaluation. These include changes in the magnitude and frequency of drought events, and the impacts of socioeconomic changes such as demographic shifts and land use patterns.

ii. With regards to resilience planning and stress testing of water supplies, further consideration needs to be given to reference levels and the appropriate inclusion of supply-demand buffer, including potential uncertainties (e.g. water supply industry 'headroom').

iii. Setting environmental flows to protect aquatic ecosystems from over-abstraction during low flow episodes will require reappraisal. This includes consideration of whether to set flows as a proportion of future flows or to maintain their present volume. The hydroecological impacts of different options for changes in environmental flows has yet to be fully assessed across the full variety of rivers present in Scotland.

iv. Water scarcity risks for groundwater supplies remain an important source of uncertainty for Scotland, especially in the context of a changing climate. The suggestion that this represents a prospective additional unrealised resource, shared by some stakeholders, needs evaluated in this context.

v. The full range of interactions between water scarcity and water quality remain to be fully evaluated, especially the existence of key thresholds in water availability which lead to exponentially increased risks from impacts such as deoxygenation, thermal stress and pollution. Some water bodies, such as small lochs and ponds, may be particularly vulnerable.

vi. The robustness of current and future inter-basin transfers needs further stress testing. Testing should consider multiple drivers of inter-basin transfers, including but not limited to hydro-energy transfers and as a prospective measure to increase the resilience of water resource zones.

vii. Although sectoral assessments of water scarcity have been developed, cumulative impacts across multiple sectors remain to be developed and included in forward planning. Additionally, some land use change interventions may have additional effects beyond their immediate area (e.g. possible changes in hydrological cycles downstream of major areas of woodland expansion).

viii. We still have limited information on the effectiveness of different schemes to change the behaviour of water users, including to improve efficiency of use, such as water sharing/re-use options. Although information is available from other countries, it remains to be established whether they would operate in the same way in a Scottish context (e.g. water meters).

ix. Alternative governance arrangements, such as stronger links between water scarcity planning and River Basin Management Plans, or the role of catchment partnerships in collaborative planning, also requires further evaluation in Scottish contexts.

x. The interaction of changing water scarcity risks with major policy issues such as decarbonisation and Net Zero, or the Food & Drink Strategy, requires further systematic appraisal and evaluation across different options. For example, further options appraisal using a nexus-type approach, integrating food-energy-water, or across the full range of ecosystem services provided by the natural environment to society.

4 Challenges

Our assessment of the current level of knowledge of changing water scarcity risks in Scotland, as provided by the literature review and complemented by stakeholder engagement (individual interviews and collective workshop – Appendices 1 and 2) has identified a series of challenges. These are related to both key knowledge gaps and in individual and collective awareness of the issues through knowledge exchange. We can summarise the current position as follows:

- Amongst many organisations, and particularly the general public, there remains a general lack of awareness of water resources issues and water scarcity risks.
- Most organisations consulted in this study perceive that water scarcity and associated risks have become a growing problem, particularly over the last five years, often influenced by their recent exposure to the impacts of water scarcity during drought events.
- Initial responses have been to seek to mitigate these impacts, when they occur, such as through modifications to production schedules or restrictions (e.g. the operation of canal locks).
- Stakeholders identified: (i) a lack of a joined-up approach to water management; (ii) a lack of data and evidence availability; and (iii) a lack of information on the costs of water scarcity responses relative to effectiveness and benefits, as important barriers to further actions.
- Based on forward projections of greater risks of water scarcity from climate change, current risk mitigation activities, which often happen in a reactive response mode, are very unlikely to provide a sufficiently robust response as the risks become more severe or frequent. Also, they could potentially lead to increased risk of conflict between different users if implemented in isolation.
- The changing nature of water scarcity risks requires approaches that also adapt, with the objective to manage risks before they become more severe and damaging as much as possible. Current approaches are typically reactive and are informed by historical events rather than future projections.
- Current approaches do not sufficiently operate across the full range of water users to maximise opportunities and synergies for water efficiency and demand reduction.

We have framed our recommendations to address water scarcity challenges through requirements to enhance both individual and collective **adaptive capacity** (Figure 16). Many current approaches focus on mitigating the impacts of droughts over the short-term. A clear message from some stakeholders has been that Scotland needs a more long-term approach, as droughts become more frequent, and the impacts and recovery periods become more challenging.

This framing highlights the need for a strategic approach to evaluate and integrate a suite of co-ordinated actions that can improve decision making on water scarcity. Adaptive capacity is defined by both the degree of awareness of the challenges, and the ability to implement effective responses to them, both individually and collectively. Actions should therefore include those which aim to improve knowledge of the issues together with knowledge sharing and learning, but also improved governance to co-ordinate plans and responses, integrating both supply-side and demand-side measures more effectively. Learning which types of responses work best in the wide variety of different environmental and socioeconomic contexts that exist in Scotland should be an essential component of this capacity building.

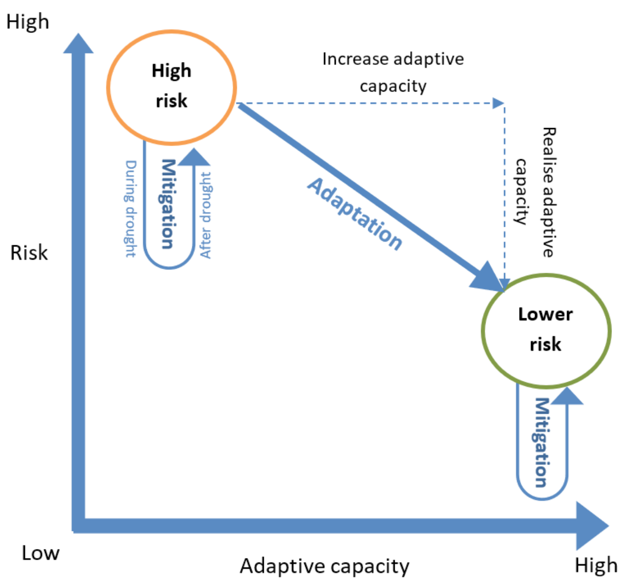


Figure 16: The role of adaptive capacity in reducing water scarcity risk

5 Recommendations

The challenges identified by stakeholders summarised in Section 4 expose an adaptation gap. This gap is the space that stakeholders saw as needing to be bridged for Scotland to manage future changes in supply and demand. This adaptation would allow Scotland to continue the sustainable development of the environmental, social, and economic benefits of our water resources.

5.1 Developing an actionable plan to address water scarcity

Our recommendations on strategies that should be taken forward to increase Scotland's adaptive capacity and ultimately close the adaptation gap are presented in the form of a logic model. The model identifies actions to address the challenges and the outputs that those actions would deliver. Importantly, the model attempts to demonstrate a chain of logic of the form "If this…then that", to link actions to outputs and show how these will go on to contribute to a set of outcomes which describe the benefits Scotland is aiming to achieve in addressing water scarcity.

The actions set out in the model are specific but not detailed. They do not attempt to solve all the issues that may have to be considered in delivering the actions. Indeed, a thread running through stakeholder feedback and one which we have adopted here, is the need for a collaborative approach to addressing water scarcity. As such, it will be up to groups of stakeholders to come together to decide the best approaches to delivering these actions. For stakeholders to do this we make recommendations on developing clarity around the governance for implementing the actions. Numerous examples of national and international plans to address water management issues highlight the importance of setting out clear systems of governance with inclusivity as a key principle (e.g. French Government, 2023; Gregorič *et al.*, 2019). The recently published national water management plan for France highlights 53 measures set out in 3 main action areas (Figure 17) and includes expanding participation in the National Water Committee to have more representation of water users and underrepresented sections of society.

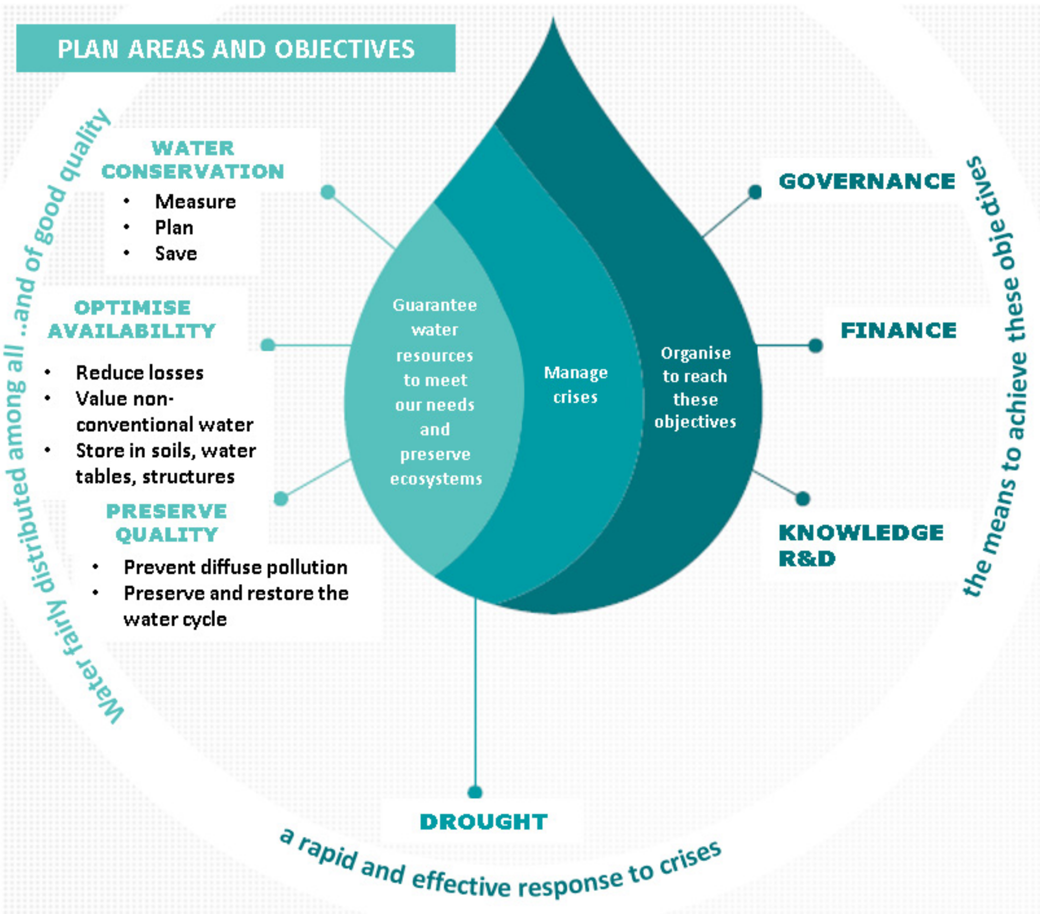


Figure 17: France's water management plan set out in 3 main plan areas. Translated from: French Government, 2023.

5.2 Logic Model

A high-level summary of the logic model is presented in Figure 18. It outlines the key action areas identified and prioritised by stakeholders during the project workshop. These actions will deliver a set of outputs, which are assumed to be necessary preconditions for producing the outcomes that would indicate a water scarcity resilient Scotland.

The subsequent Sections present a breakdown of the three main recommended action areas and the research that would support them.

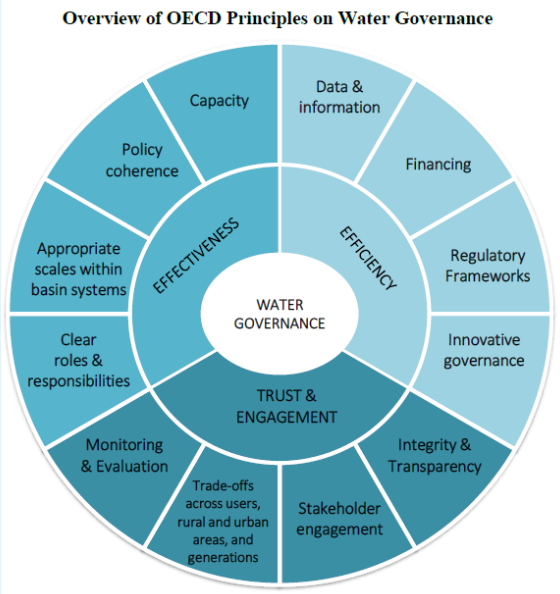
5.2.1 Recommended governance actions (G.1-2, Figure 19)

There is a recognised tendency for water scarcity management to be reactive and event driven (e.g. Gregorič *et al.*, 2019). To address the long-term underlying causes of water scarcity a more permanent governance arrangement is required. Here the recommended governance actions seek to deliver a proactive and holistic approach to water resource planning and management. The Scottish Government would lead on establishing a governance structure that includes roles and participation opportunities for all water sector stakeholders including government agencies, industry partners and community representation. The structure would include a core management group[1] with a lead agency whose first role would be to oversee the development of a water resources management strategy.

The strategy would set out the principles under which water resource management in Scotland should operate (see Box 1. for an example).

The strategy would set out the long-term goals for water resource management which would include those of ensuring resilience to water scarcity. The water resources management strategy should be developed in a way that allows the maximum feasible participation by water sector stakeholders. The strategy should be developed in a way that includes participation by policy makers from other policy areas e.g. Net Zero. This is critical to ensuring that the implementation plan which sets out how the strategy will be delivered, maximises the opportunities to inform other policy actions and outputs.

Box 1. Organisation for Economic Co-operation and Development (OECD) principles on water governance



The OECD set out a set of 12 principles for government to implement water policies and actions. These principles were tested in Scotland in 2017 (Scottish Government, 2017).

5.2.2 Recommended management actions (M.1-7, Figure 19)

Following the set-up of a governance structure, the first set of management actions (Figure 19: M.1. to 4) would deliver a national water resources management plan that will assist coordinated water scarcity adaptation actions by all stakeholders. It is envisaged that the water resource management plan would consider the full range of uses of water resources at a catchment/WRZ level and include consideration of both water quantity and quality. This would require collating existing information on actual and maximum allowable abstraction and discharge (quality and quantity) information from licensed locations. Where collectively they are deemed significant, it may also include modelled estimates of unlicensed activities. It would also require estimates of any significant impacts caused by land management changes such as woodland regeneration. Combining this water quantity and quality information with current seasonal river, loch and groundwater flows and levels will produce an assessment of the pattern of exposure to water scarcity that currently exists.

To determine water scarcity risk and identify priority areas for action, it will be necessary to

[1] This may not need to be a new group; it could instead build on one of the existing groups already established, Water Scarcity Group or Water Resource Group, as discussed at the Workshop (Appendix 2).

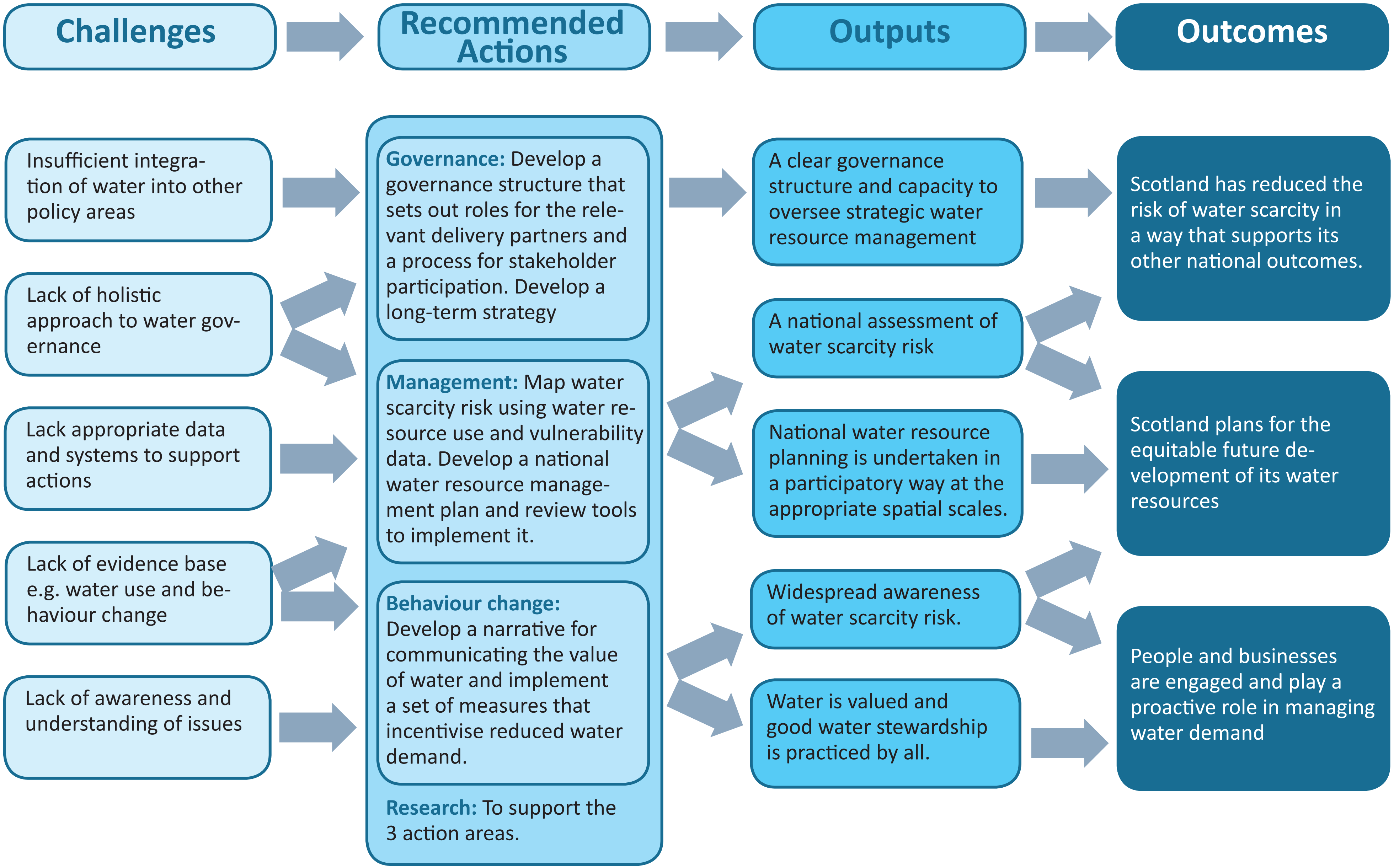


Figure 18: The logic model (summary)

Box 2. Actions to reduce existing water scarcity risk.

There is a wide range of potential options to address existing risk of water scarcity in a catchment. Which ones are chosen will depend upon local circumstances but could include:

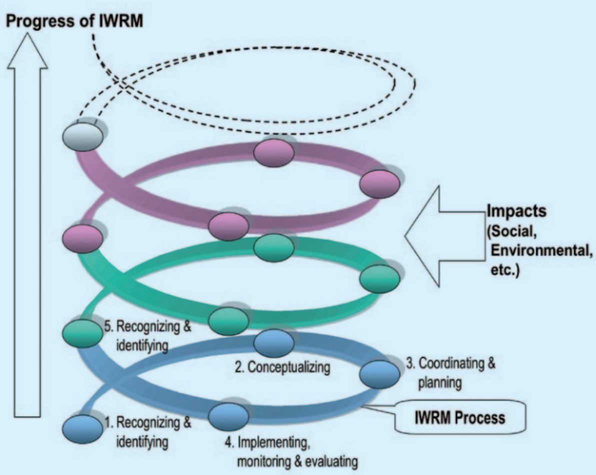
- Reducing licensed allowable abstraction volumes
- Switching to a more reliable water source
- Intelligent demand management systems
- Change of crop type
- Promoting better soil management
- Addressing historical alterations to the natural flow regime e.g. through changes in land cover
- Invest in infrastructure (storage).

understand receptor (e.g. species, businesses, domestic supply) sensitivity to water scarcity. This information would feed into the national water resources management plan (Figure 19: M.4). This plan would inform actions to reduce existing risk (Box 2) and identify capacity to inform strategic decisions on evolving water sector developments e.g. hydrogen production.

In line with guidelines for implementing Integrated Water Resource Management it is envisaged that the risk assessment and plan would be reviewed on a regular basis and adapted as impacts and understanding change (Box 3). A key step in developing the plan is determining how much of it can be accomplished within existing legislative frameworks, such as the River Basin Management Plans and non-statutory water resource planning by Scottish Water.

A review of existing regulatory processes and monitoring should be undertaken to ensure they meet the needs of the water resource management plan (Figure 19: M.5). A key element of this would be to seek a resolution on the way forward to determine the reference flow and level conditions against which environmental standards are assessed (Section 2.3.1). There are also likely to be increased information demands to inform the kind of planning that has, up to now, not been carried out in Scotland. The benefits of low-cost sensors, Internet of Things communication technology, unmanned aerial vehicles and other remote sensing, as well as the decision-making support that machine learning and artificial intelligence can deliver, should be assessed. It is also recommended that this action includes developing a public-facing process for post-drought event reporting to validate or update the national water scarcity risk assessment.

Box 3. The spiral model of Integrated Water Resource Management planning.



Water resources development in a basin evolves over time, as new demands emerge, understanding changes and innovative solutions are trialled. Source: UNESCO, 2009, Figure 1.

Actions M.5 and 6 (Figure 19) would further develop the existing mitigation actions that are deployed during droughts. They would ensure that current systems of early warning of drought risk are robust and can disseminate this information to the right people in a timely way. This development may require further research into user behaviour and greater coordination between agencies such as the UK Met. Office, the British Geological Society and the UK Centre for Ecology and Hydrology. The national water resource risk assessment (Action M.2) would identify those demands for water (ecological or human) that are at highest risk – with risk resulting from the combination of exposure to water scarcity and the vulnerability of processes to it. This information should inform a review of mitigation actions planned during drought to ensure those businesses, communities, habitats, and species at highest risk are protected (Action M.7).

5.2.3 Recommended behavioural actions (B.1-7, Figure 19)

There is a body of research and evidence to support programmes wishing to influence behaviour and the starting point in this action area is to use these to develop a narrative, or set of narratives, that reframe the conversation about the value of water in Scotland (Figure 19: B.1.). In addition, it would be beneficial to look at a range of policy tools to assist in encouraging better use of this valued resource (Figure 19: B.3.). These include systems of metering domestic and non-domestic water use. The increased understanding of actual water use, whether that be raw water by abstractors or potable water use by households can be valuable in highlighting the causes of high water demand, whether that be through high usage or leakage (Box 4). A requirement of abstraction licensing is the demonstration of sustainable water use. Further guidance on how to assess this for all sectors could be beneficial to identify potentially inefficient processes or unused water allocation that could be utilised elsewhere.

With a narrative in place around the value of water and the appropriate policy tools to encourage more efficient water use, effort to minimise resource use should be targeted at areas of highest risk of water scarcity and also where multiple benefits could be realised, such as NetZero and biodiversity gains (Figure 19: B.4.).

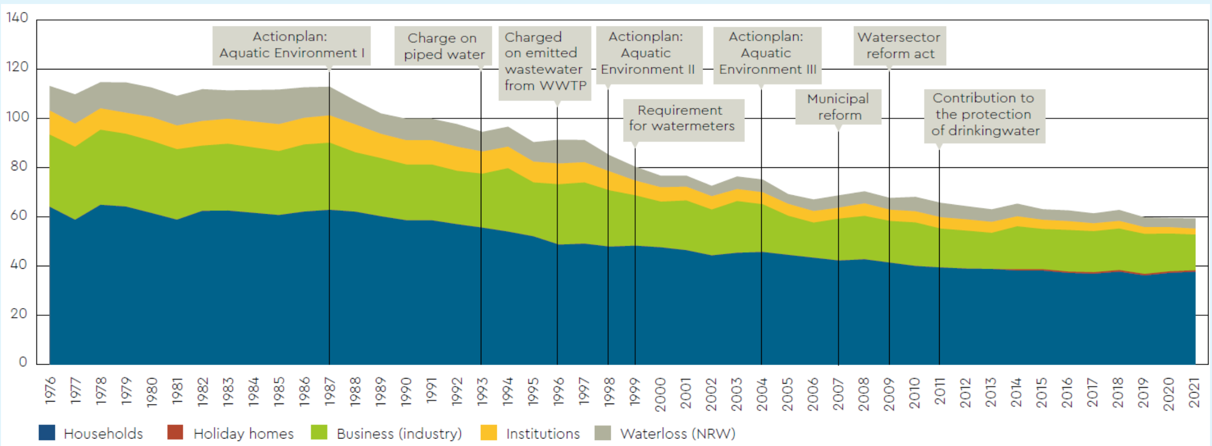
In this context, new methodological approaches that have been applied in other countries, including analysis of Google trends and text mining during periods of water scarcity (Sodoge *et al*., 2023; Wilby *et al*., 2023), may be combined with conventional surveys to better understand attitudes and behaviours in Scotland.

A logic model is based upon a set of assumptions or hypotheses about behaviour change that, where possible, are supported by evidence. These hypotheses explain how actions are expected to lead to desired outcomes. Theories of behaviour change typically identify a range of influencing factors that may need to align to produce change (Department for International Development, 2009). For example, social cognitive theory (Bandura, 1986) might suggest that a combination of delivering an effective narrative around the benefits of water saving (personal factors), supported by policy tools to incentivise that behaviour (environmental factors) may be required to produce a reduction in water demand. We recommend a monitoring and evaluation programme that will not only test the underlying theories of behaviour change but track any influences from external pressures (e.g. economic or social) on the effectiveness of actions. In line with the management actions, the behaviour change actions should be reviewed and adapted over time as knowledge grows.

5.2.4 Turning actions into a plan

The actions set out in these recommendations are high level. Detailed actions will require the relevant expertise in each field to assess the options available to deliver them. Many of the actions should be delivered by a partnership between agencies and the water sector and it is through this partnership, informed by expert knowledge, that options should be chosen. To assist with this process, we recommend an action plan that specifies the logical order of actions and the suggested participants who will deliver them. This action plan is presented in Figure 19. The plan also indicates how those actions would deliver outputs and highlights how monitoring these will assist with the future development of the plan. This is necessary part of the learning that will inform ongoing adaptation.

Box 4. Denmark's reduction in water consumption



Consumption of drinking water in Denmark, 1976 – 2021 (m^3/person/year). Consumption of water use has dropped from 172 litres in 1987 to 100 litres in 2022. This behaviour change has been attributed to a programme of water saving campaigns, water saving taps, toilets and shower, increased charges and water metering. Source: DANVA, 2022

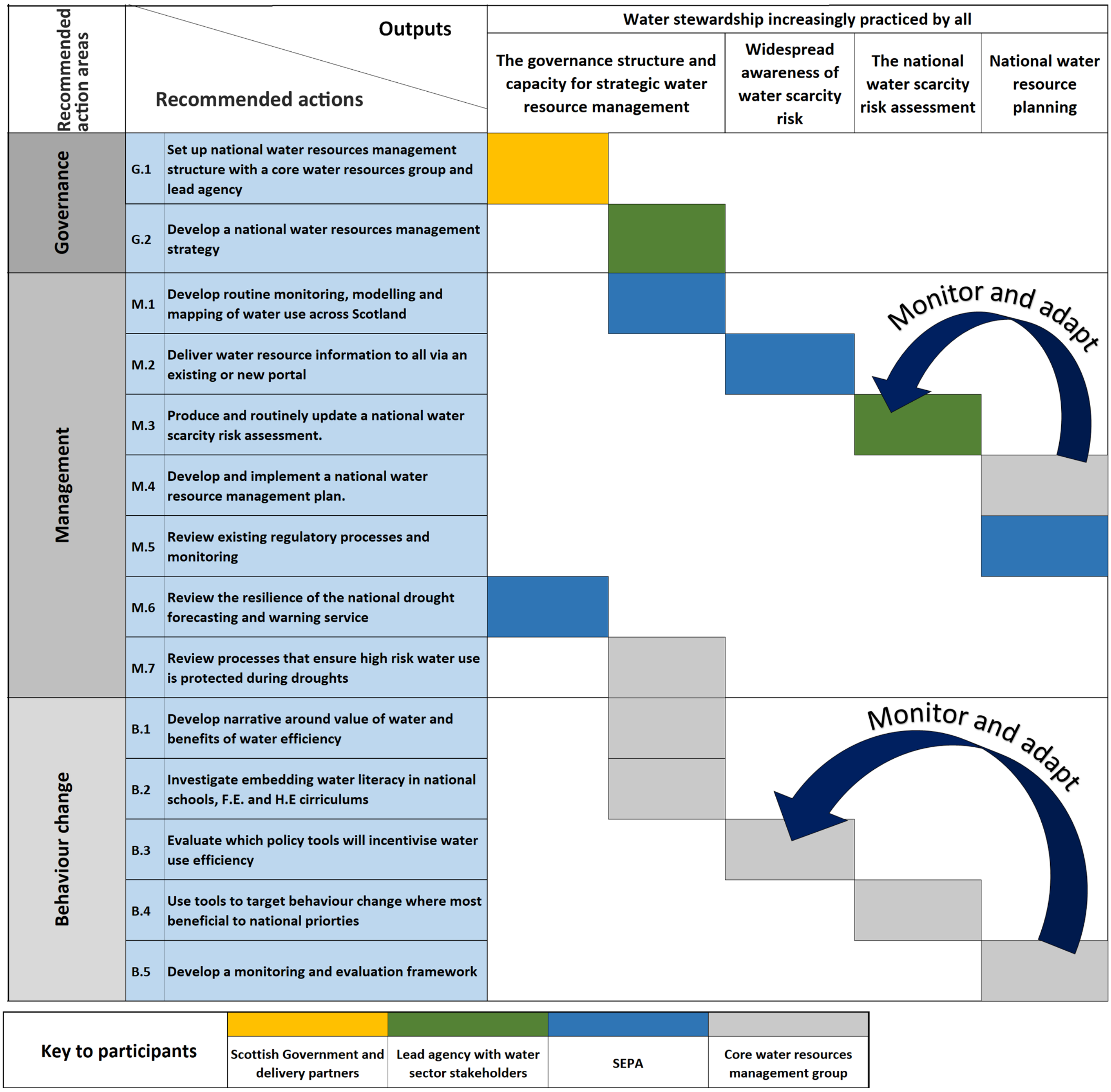


Figure 19: The recommended action plan

5.2.5 Supporting research actions

Table 2 highlights the key research areas identified from this work. This is not an exhaustive list of all potential research activities which could be beneficial within the water scarcity space. Rather, it provides an overview of key research activities which will directly address the knowledge gaps and challenges as identified through this project. For example, a need was identified to have a more detailed understanding of the capacity of Scotland's most heavily used aquifers to provide an alternative source of supply without impacting surface water resources. Addressing this gap would be valuable for informing the management actions related not only to developing a water scarcity risk assessment and plan but also assisting with drought warning. By linking the water scarcity research needs to the actions within the action plan, it should be possible to coordinate the research from across the water sector and ensure a direct link between the research and policy. As the action plan develops, it is likely that some research priorities will change. A coordinated plan of research needs that anticipate the upcoming actions in the action plan should be updated as required.

Table 2: Research needs and the actions they would support

Research	Associated actions Figure 19
Investigate water use efficiency and the efficacy of demand-side responses across all sectors with the aim of building on Scotland-specific good practice guidance	B.1, B.3, B.4
Further develop understanding around how consumers change water use behaviour and how water-related learning can influence behaviour change	B.1, B.2, B.3, B.4
Further research to understand the implications of climate change for environmental flows and ecosystem resilience	M.3, M.5, M.7
Groundwater modelling of highest risk aquifers to understand capacity as an alternative source and to inform drought warning	M.1 – M.7
Run climate change projections through existing and potential water scarcity plans across sectors. Stress test and evaluate cost/benefits of mitigation/adaptation and the viability of inter-basin transfers	M.3, M.4
Improve understanding of synoptic conditions associated with large-scale drought events in Scotland in a changing climate	M.3, M.6

6 Conclusions

Through both a review of literature and stakeholder engagement, we have looked at water scarcity issues in Scotland through the lens of a changing water supply-demand balance. This has shown that Scotland is at increasing risk of water scarcity, especially from climate change reducing the availability of raw water supply from rivers, lochs and groundwater at times of the year, but also as a result of socioeconomic factors that are influencing water demand.

Following several years where extended periods of low rainfall and high temperatures have impacted the reliability of natural water supply, there is evidence of increased awareness of the changing risk of water scarcity. This is particularly the case in the public and, to some extent private water sector, and amongst larger water users. However, more widely, there is still a broad lack of awareness around the risk in Scotland. There is also limited knowledge and awareness on the cumulative demand on water availability across the full range of users in a catchment or water resource zone, especially during more extreme drought conditions.

It is clear from the demand and supply information that we do have, along with reports of impacts during droughts, that water scarcity risk is variable across Scotland. More work is required if we are to fully understand the nature of this variability and how it might change in the future.

From what we have found we can identify a strong need to increase adaptive capacity to address future water scarcity. A starting point for building this capacity involves the development and sharing of knowledge around the risk. This will require a more systematic approach to evaluate and communicate water scarcity issues through the changing supply-demand balance. From stakeholder feedback and by looking at examples of water resource management in other countries, we also identify the need to develop governance capacity that extends beyond mitigating the impacts of droughts to addressing long-term water scarcity. This governance structure should also allow better integration between the policies and actions that address water scarcity and those that support other national priorities such as a just transition to Net Zero and addressing the biodiversity crisis. A particularly notable challenge will be ensuring that enough water is retained within rivers and lochs to maintain aquatic ecosystems and the rich biodiversity and wide range of ecosystems services that they provide.

We have provided a logic model showing how the range of water scarcity challenges that have been identified can be addressed through a suite of potential responses. This should be seen as a starting point for the development of a comprehensive implementation plan that is developed by the relevant agencies working in partnership with the water sector. We recommend that such a plan gives sufficient weight to addressing the demand side of water scarcity even though some of these behaviour change approaches may come with greater uncertainty around their effectiveness. It is likely that demand-side measures will fit well with other national priorities like achieving Net Zero. To address the uncertainties we recommend a set of coordinated research actions and, perhaps just as importantly, the development of monitoring and evaluation of the desired outputs and outcomes. In this way the plan of actions can adapt as climate, demand and technology change in the future.

Scotland is in the fortunate position of having had a climate and natural environment that, on the whole, has provided us with the clean and plentiful water resources to support a thriving way of life. This has allowed us to develop a successful water sector with expertise in water science and management and created the ambition of a Hydro Nation that would further develop the potential of our water resources. However, as recent experience is showing us, to realise this potential we require a plan to manage the increasing variability of this resource. We are already experiencing the impact of the climate crisis on our water environment. By acting now to address the long-term risk of water scarcity we can not only protect our valued water sector, but allow it to realise future opportunities and establish Scotland as an exemplar of sustainable water resource management.

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Appendices

Appendix 1: Pre-workshop stakeholder interviews

1.1 Methodology

In advance of the stakeholder workshop, participants were invited to a 1:1 interview by a member of the project team. The aim of the interviews was to better understand how water scarcity impacts a broad range of stakeholder organisations and to collect information on what plans and actions these organisations have in place to address water scarcity now and in the future. The interviews also gave stakeholders the opportunity to identify barriers and knowledge gaps that are hindering better water management to reduce the risks resulting from water scarcity.

The interviews were semi-structured in that although a set of questions were developed, they were grouped into themes around which the conversations flowed. These themes were:

Theme 1: Current water scarcity impacts

- How does water scarcity affect your business including the people you represent?
- Which areas of business/locations are worst affected?
- Do you think the risk is increasing (exposure or vulnerability)?

Theme 2: Current water scarcity plans and actions

- How do you currently plan for water scarcity episodes, particularly extreme events?
- How do you co-ordinate your actions with others?
- What is the role of policy and regulations in your plans and actions?

Theme 3: Planning for the future

- How do you factor in climate change (present and future) into your planning and actions?
- How do you factor in socioeconomic changes (present and future) into planning/actions?
- How can we better manage water resources against scarcity risks?

Theme 4: Barriers and knowledge gaps

- Are there any notable barriers or lock-in factors acting against improved adaptation strategies?
- What do you think are the key knowledge gaps – both knowledge availability and knowledge exchange?

Interview responses were summarised, and summaries were sent to each participant for approval to ensure they accurately represented the conversation. 30 stakeholder interviews were conducted across a range of stakeholder types (Table A1.1). Using content analysis, key points were identified from the interview summaries by each of the 3 interviewers. These were collated and a consensus was arrived at on the main findings. This approach aimed to minimise any bias from individual analysts.

Table A1.1: Stakeholders engaged through the project either at pre-workshop interview stage and/or the workshop stage.					
Organisation	**Interview**		**Workshop**		
	Interviewed	**No.**	**Day 1**	**Day 2**	**No.**
Amphibian and Reptile Conservation	■	1	■	■	1
British Geological Society			■		2
British Trout Association	■	1			
Consumer Scotland	■	1	■	■	1
CREW			■	■	2
Drinking Water Quality Regulator	■	1			
Environment Link	■	1			
Forest Research	■	1		■	1
Highland Spring Group	■	1	■	■	1
Historic Environment Scotland	■	1	■	■	
James Hutton Institute			■	■	3
NFUS	■	1			
Natural Resources Wales	■	1	■	■	
NatureScot	■	1	■	■	2
Ness District Salmon Fishery Board			■		1
Public Health Scotland	■	1	■		1
Salmon Scotland	■	1			
Scottish and Southern Energy	■	1			
Scottish Canals	■	1	■		1
Scottish Government	■	2	■	■	3
Scottish Forestry	■	1	■	■	2
Scottish Water	■	3	■	■	4
Scottish Whisky Association	■	1	■		1
SEPA	■	3	■	■	3
University of Aberdeen			■	■	2
University of Manchester			■	■	1
University of Newcastle			■	■	1
University of Strathclyde			■	■	1
Visit Scotland	■	2			
Water Industry Commission for Scotland	■	1		■	1
WaterWise	■	1			
Welsh Government	■	1		■	

1.2 Findings from the stakeholder interviews

1.2.1 Theme 1: Current water scarcity impacts

1.2.1.1 Impacts and evidence of change

Most stakeholders stated that water scarcity can, and has, led to notable impacts on their business. Impacts included:

- frequent, temporary failures of supply; impacting business production and potable water.
- ecological impacts including pond drying affecting sensitive amphibian and dragonfly life cycle stages, and low flows leading to fish and freshwater pearl mussel deaths.
- water quality impacts leading to ecological impacts or increased treatment costs.
- business uncertainty because of the increased threat of supply failure.
- impacts on water-dependant product quality and reliability of supply.
- increased staff resources to enact water scarcity plans.
- reputational risk and/or risk to carrying out statutory duties.
- increased costs e.g. water pumping or switching to alternative sources of water.

Almost all stakeholders stated that the risk of water scarcity was increasing, based either upon their direct experiences of impacts or their perceptions of meteorological/hydrological changes. 2018 was referenced by many as particularly notable, providing almost a breakpoint in drought behaviour. Before this time water scarcity was seen as rare, whereas since then it has become a recurrent feature, impacting across their organisations. Some organisations were able to give clear evidence of recent changes in the impacts due to water scarcity (Table A1.2).

1.2.1.2 The regulatory response

Several stakeholders explained that issues have been more notable in the last 2 years because of the actual or potential imposition of abstraction restrictions by SEPA in response to the dry weather and low river flows. SEPA have a process that identifies abstractors within regions of significant water scarcity and contacts them to give warning of potential upcoming restrictions to protect water resources. SEPA instigated this process in both 2022 and 2023 and some responses indicate that this has led them to review their business risks due to water scarcity.

1.2.1.3 Increasing variability

Several stakeholders highlighted that their long-held assumptions on when, where, and how frequently water scarcity can happen in Scotland are being challenged. Recent experiences have shown scarcity events can happen anywhere and not only during the summer. Some private water supplies ran dry early in spring 2019 following a dry winter on the back of previous summer's drought and, in 2023, abstraction restrictions

Table A1.2 Evidence of recent changes in impacts of water scarcity in Scotland

Organisation	Water scarcity impacts	Evidence of change
Aberdeenshire council	Failure of private water supplies due to low water tables	Before 2018, it was only a handful of properties on private water supplies impacted, but now its hundreds each year, many with recurring issues.
Scotch Whisky Association	Lack of surface water available for cooling	Historical measures used to manage periods of low flow, through quiet season summer closures, are becoming less effective as low flow periods are occurring outside of the traditional late summer low flow season (i.e. May/June) and the periods of low flow are lasting longer.
National Farmers Union of Scotland	Lower soil moisture leading to impacts on crop health	Something like a 1 in 20-year event seems to be occurring more often with resultant greater impacts on the farming sector.
Historic Environment Scotland	Scheduled monuments drying out and waterlogged archaeology put at risk	The well at Glasgow Cathedral and the ponds at Traprain Law and Stroanfreggan Craig fort now dry out when they never used to.
Scottish Canals	Low water levels resulting in canal use restrictions and closures. Risk to infrastructure from drying out.	Up until 2018 water scarcity issues were rare. For 3 out of the last 5 years measures have been required to address water shortages including costly reservoir pumping and canal closures.

were being considered as early as May by SEPA. Unpredictability is an issue because the potential impacts result from a combination of exposure to drought and the sensitivity of the receptor. Where adaptation measures (i.e. species behaviour such as smolt migration, or business closure periods) have been developed based on historical seasonal patterns, changes in these dynamics can increase vulnerability.

1.2.1.4 Changes in demand

Evidence discussed highlighted that spikes in demand can result in water scarcity issues, either immediately or through reduced resilience to further demand- or supply-related shocks later in the year. For example, good weather during Easter holidays has, at times, led to extra demand for potable water in tourist hotspots. If storage doesn't replenish during late spring/early summer, then vulnerability to further dry spells can persist until autumn. The synchronicity of high demand and low supply during the summer months, makes water supply to tourist areas, agricultural irrigation, and canal navigation particularly susceptible to water scarcity.

1.2.1.5 Wider impacts on ecosystem health

Reduced river flows, low loch levels and slow circulation rates can increase concentrations of contaminants and nutrients leading to ecological impacts. This may also lead to enhanced water treatment requirements, with both financial and carbon costs. As water scarcity often coincides with high air temperatures, which are themselves on a rising trend, there is an increasing risk of elevated water temperatures. This leads to the risk of exceeding the thermal tolerances of species or impacts due to the drop in dissolved oxygen concentrations that occurs in warmer water. Exceptionally low river levels lead to shrunken wetted habitats and may result in drying out habitats, impacting species who are unable to relocate e.g. plants and macroinvertebrates, including freshwater mussels. Reduced depths, velocities, flows and higher air temperatures during droughts can all be compounded by other pressures on the water environment such as over-abstraction, channel modification, pollution pressures and a lack of riparian tree shading.

1.2.2 Theme 2: Current water scarcity plans and actions

The stakeholders identified a range of existing plans and actions for addressing water scarcity. The nature and extent of planning was dependent on how directly impacted organisations are by a lack of water and how much resource capacity they have to mitigate and/or adapt to the risk (Figure A1.1). The risk from water scarcity is a function of the hazard from, and exposure to, reduced water availability and the vulnerability of a system to

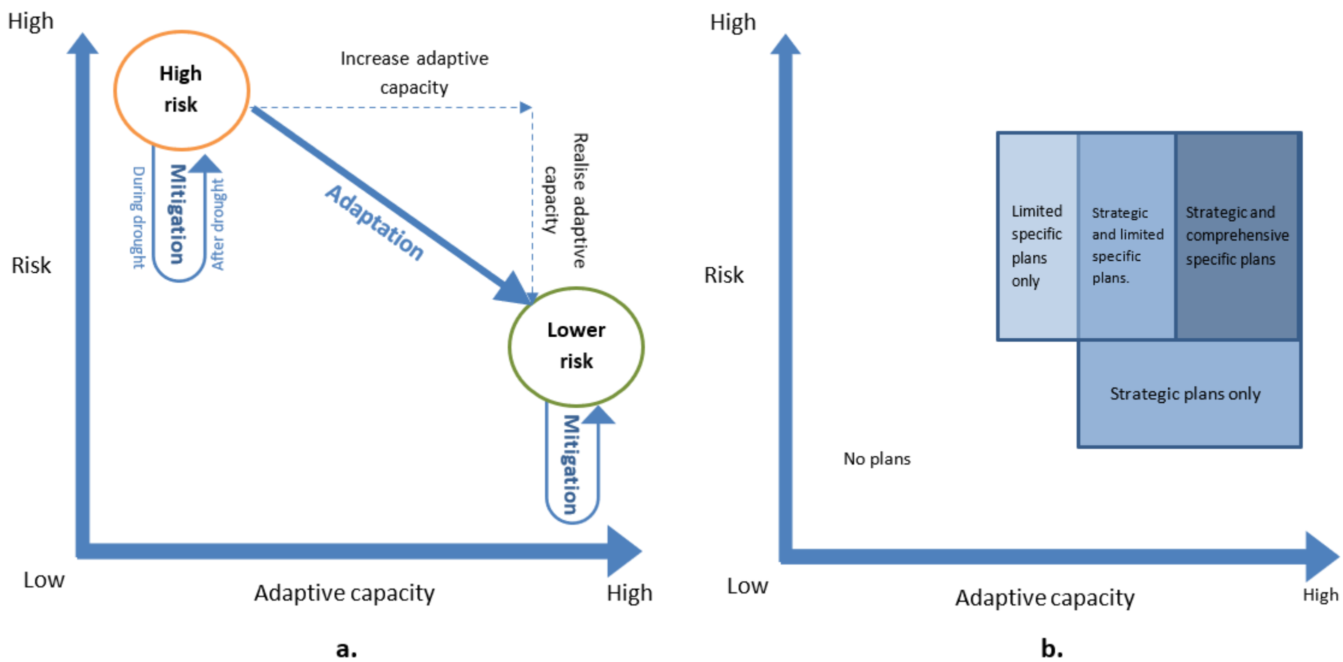


Figure A1.1: The role of mitigation and adaptation actions in addressing risk from water scarcity. a) Conceptual model of risk and actions, b) a characterisation of the different plan types identified in stakeholder interviews and their broad relationships with water scarcity risk and adaptive capacity.

that reduction. Vulnerability is the propensity of a system to be adversely affected by water scarcity (IPCC, 2022).

Actions to reduce the risk from water scarcity aim to build adaptive capacity that will reduce the exposure and vulnerability of a system to a situation where water resource demand outstrips its supply. The concepts of mitigation and adaptation have clear definitions in risk management but water scarcity actions that address exposure and vulnerability can often fall under both. In drought literature, mitigation measures tend to refer to short-term actions taken around a drought event, while adaptation is more likely to refer to long-term actions that aim to enhance the resilience of the system (Wang and Asefa, 2019). For example, temporary demand reduction measures in response to drought events such as might be included in a water shortage order or abstraction suspension can mitigate the impact of a drought but do not necessarily reduce the underlying risk of society to water scarcity (Figure A1.1). Without adaptation, these reactive mitigation measures will be reached for more frequently and over time their effectiveness in mitigating impacts may reduce. However, it is unlikely that adaptation measures alone will be the most effective response to a risk like water scarcity (IPCC 2022). The most comprehensive plans for water scarcity identified by stakeholders tend to have both adaptation and mitigation measures.

1.2.2.1 Current and future risk and its impact on planning for water scarcity

Those stakeholders who rely on water as a key component of the service or product they supply are potentially highly sensitive to water scarcity. Evidence from the interviews indicates that these stakeholder's plans and actions to address water scarcity tend to be specific and address both supply and demand. They also tend to have these specific actions embedded within more strategic plans that aim to increase water scarcity resilience (Figure A1.1b). Examples include both Scottish Water and Scottish Canals drought plans which include details on actions to reduce demand from their customers, sources of alternative supply and communications plans. They may also have triggers based upon their own monitoring to instigate these actions. Arguably, water dependant species fall into this category, as represented by SEPA and NatureScot, who have detailed water scarcity plans on their behalf to protect them and the ecosystem services they provide.

Other stakeholders have less capacity to adapt or feel less exposed to the risk. They may have more limited supply-focussed actions such as the use of storage ponds or lagoons (i.e. irrigators and distilleries). Depending upon the product's shelf-life or flexibility in the markets they sell to, some may be able to reduce exposure to the hazard from dry periods by delaying or bringing forward water use to de-synchronise peaks of demand and troughs of supply. Distilleries and bottled water manufacturers are examples of stakeholders who can achieve this. Some of these stakeholders also have strategic water scarcity plans to build further capacity and/or develop processes/supply chains that are less sensitive.

A third type of stakeholder were those with a lower direct sensitivity to water scarcity. These tended to be bodies which either represented water sector stakeholders or those with a remit indirectly related to water resources. For those with adaptive capacity, such as resources, skills and remit, there was some evidence of a degree of strategic planning. These were often embedded within wider planning either as part of their sustainability or general corporate plans. Some of this strategic planning might capture water scarcity only in the most general sense such as around minimising resource use or promoting general adaptation planning amongst its members. Examples include Historic Environment Scotland and Tourism Scotland.

Finally, some stakeholders have little or no evidence of plans or actions to address water scarcity. The most vulnerable of these are those with a high sensitivity and exposure to water scarcity but little capacity to adapt. Those households on private water supplies fall into this category, particularly those on springs and boreholes not owned by themselves or those who have limited control over upstream land use. Other examples include some freshwater fish hatcheries, which are highly sensitive to water shortage and but may not have the capacity to increase or reuse their water supply.

1.2.2.2 Changing exposure and the impact on risk

Some stakeholders identified that the recent changes in climate experienced in Scotland, have highlighted the inadequacy of their current water scarcity plans and actions. With little historical exposure to water scarcity or the regulatory consequences of dealing with droughts; or with water scarcity risk not being identified as an insurable risk, some stakeholders noted that they have not felt sufficient pressure to address these issues. As drought frequency has increased, those with some capacity to minimise the impacts during an event have done so, but with no plans in place, their actions tend to be reactive. Some organisations have little expertise around water scarcity and are new to taking these actions and have highlighted their dependence upon key agencies such as SEPA and the Scottish Government for information, advice, and direction.

1.2.3 Theme 3: Planning for the future

The prevalence of forward water resource planning for climatic and socio-economic changes largely follows a similar pattern to that of existing plans. Stakeholders with well-developed future plans, also had comprehensive existing plans. For example, Scottish Water continue to develop both climatic and socio-economic forecasts to inform future investment decisions. Some of those with existing plans for water scarcity, and the appropriate skills, indicated they intended to develop projections in the near future, such as Scottish Canals and Scottish and Southern Energy. These stakeholders have existing operational models of their water use which can be adapted to run with climate projections to inform long-term decision-making.

The capacity to develop the understanding about future change, and just as importantly, enact actions to address changes is a key factor in whether planning for changes in climate and demand is undertaken. Larger agri-businesses are starting to factor the security of their water supply into future planning, but smaller-scale farmers less so and therefore they tend to respond more reactively. Similarly, forestry is incorporating general drought resilience into forward planning, but exactly how to do this (e.g. species choice) remains less established.

Some of the larger businesses do their own monitoring of water resources with the aim of continuously assessing risk and using this to inform actions. An example of such an adaptive management strategy to secure supply was using these data to assess whether the number and locations of abstractions are sufficient to avoid over abstraction at each site. However, it has been highlighted that there is a tendency for forward planning to be based on average changes rather than changes in extremes, despite the latter having the potential to cause the greatest impacts. To date, plans and actions have tended to be based upon historical data or accepted norms of behaviour. To quote one response, they have "… been using lessons from the past for planning for the future, but these aren't good enough." This may point to a lack of awareness around how existing plans make assumptions about stationarity in the degree of exposure or sensitivity to water scarcity.

For most stakeholders there is little existing capacity to develop quantitative projections of water resource supply and demand to inform plans for addressing water scarcity. Stakeholders identified this lack of capacity as a result of: insufficient information and the expertise to analyse it, resources, institutional culture or a lack of awareness/importance given to the issue. These barriers are addressed further in the following section.

For those who did not have future plans, some stakeholders indicated that they are awaiting a stronger government lead, including more specific policy statements through Scottish Climate Change Adaptation Programme and current water sector policy development. They felt this needs to take a cross-cutting approach, linking with other key policy objectives such as Net Zero, agricultural reform, land use strategy, and flood risk management, so that they are planning on a consistent and coherent basis.

1.2.4 Theme 4: Barriers and knowledge gaps

1.2.4.1 Understanding water and water scarcity

A very high proportion of stakeholders identified the lack of awareness or concern about water scarcity as a key barrier to adaptation. This lack of awareness was not just with the public but within their own institutions. Most felt that the general perception across water users is that Scotland is a wet country and therefore we don't have water scarcity issues, so there is little impetus to adapt. Again, most stakeholders felt that water was generally undervalued or not valued at all and treated as a free resource. The perception is that there is little public understanding around the cost of supplying raw (e.g. irrigation) or treated water.

Several stakeholders felt that we needed a better national assessment of water scarcity risk i.e. the combination of exposure to a drought hazard and the receptor (i.e. canal operations; whisky production) vulnerability to water supply issues. This would help a better, more widespread understanding of the issue and target actions and potentially facilitate a more community-based approach to water scarcity issues.

In terms of public supply, Scottish Water have oversight of the general patterns of water use across in Scotland, with the average person using over 180 litres of tap water every day (higher than any other UK country and many European countries – Germany 125 l.p.d), and the clear differences in water use linked to sociodemographic characteristics of areas (Scottish Government, 2023b). However, a lack of widespread metering of domestic use was identified as a key knowledge gap that reduced confidence in localised assessments of water consumption. This could hamper the identification of the causes of a water resource issue and impede the resolution of issues. A lack of domestic metering also impacts our understanding of current household water use behaviour and the monitoring of behaviour change. Allied to this was a need to understand the relative use of water from all sectors, not just public and private water supply. Those who raised this issue felt that there is currently no easy way to access water use information from across the sector which is seen as vital for integrated water resources management.

For public water supply there is a lack of understanding of the value of water, with little public awareness about where people's water comes from, or the scale of the challenge faced by the water sector due to climate change. The logistics of the challenging water supply system within Scotland are also not well understood. This can also be the case on shared private water supplies (PWS) where tenants don't have control over their own supply. There is also a lack of understanding about what can be done once a supply has run dry. Advice, information, and support for PWS users can also be quite piecemeal, and this can be exacerbated by the fact users may be experiencing challenges with their supplies for the first time.

1.2.4.2 Water management

A key barrier noted by several stakeholders is a lack of a joined-up approach to addressing water scarcity by the relevant agencies. Related to this was the issue that currently there is no requirement to produce water resources management plans for all water uses in Scotland. There is no assessment of whether water supply is sufficient for all desired uses now and in the future. "Planning should be done as part of 'Team Scotland', said one interviewee.

One particular concern was that all water sector businesses sharing a resource needed to take responsibility for using the water resources as efficiently as possible. If this is not seen to be the case then there is the perception that the playing field is not level, which could reduce the enthusiasm for mitigation actions.

A number of water sector businesses and industry representatives have highlighted the water resources regulatory process as a barrier to more innovative solutions to addressing water scarcity. It was felt that the regulatory framework could be a "blunt instrument" and not always proportionate. Examples of how the process could better facilitate more catchment-based integrated water resource management were: more flexible licence conditions, the ability to trade water or share an allowance. In more general terms it was felt by some that the current first come, first served system of water allocation is hard to justify and that water management should be reimagined using a set of more equitable criteria.

1.2.4.3 The cost of adaptation

The cost of adaptation is an issue, and some smaller businesses are waiting to see whether this cost is justified by the impacts, in other words, taking a reactive approach. This is understandable where the strength of the evidence available to these businesses isn't sufficient to allow complete assessments of the risks associated with inaction. This has also been influenced by the economic slowdown and rising costs. The cost of water is relatively low, and it's a stable predictable business cost, therefore there was seen to be limited financial incentive to save/reduce water use when other pressing issues are continuingly arising (energy price surges, raw material availability & price increases etc.). As a result, one stakeholder suggested that "people do not adapt until it is already too late".

One adaptation available for PWS is to move onto the public supply network. However, stakeholders noted that people are often unaware of this option and don't know where to access information about what is involved in making this change. The costs involved in connecting to the main supplies are determined by where a property is located and how far a property is from the existing mains network and can vary hugely from £2500 to over £100k (Scottish Water, 2024). For some homeowners this cost is a significant barrier and can in some cases be significantly higher than the costs of installing a new private supply. Many people on PWS also do not wish to move to the public supply network.

1.2.4.4 Knowledge gaps

A key knowledge gap identified, was around how effective behavioural change, both for domestic and business users, will be and how it can be achieved. Some research has been done on this and some businesses have been learning from others in the same sector through trade bodies and coordinating research. However, it is still seen as an area that needs more understanding if we are to reduce water consumption.

To aid with addressing drought impacts, several stakeholders indicated that Scotland needs both better drought forecasting tools and a better understanding of groundwater. Groundwater was suggested by some stakeholders as an option for providing a more reliable source of supply but generally little is known about the reliability of the resource, and the impacts of utilising this. Yield tests conducted for developing private water supplies, for example, relate to a particular point in time and water level and there is uncertainty about how these inform the user about the risk of water scarcity.

It was suggested that as well as better monitoring and modelling of water resources it might be particularly useful if, following specific events, there would be a summary report of the scale and magnitude of the event and who was affected, together with a reflection of the lessons learned and how this might feed into further policy and regulatory strategy development. It was felt this could help improve awareness of the issues and their implications in a similar way to the reporting that already occurs following major flood events. Such an approach might help address what one stakeholder described as a loss of "institutional memory" when an extreme drought does not occur for several years.

Appendix 2: Workshop

The project sought to bring the stakeholders together in a facilitated knowledge-exchange workshop to build on the information gathered through the knowledge review and stakeholder interviews, to develop a logic model which will provide the roadmap to effectively addressing the challenges posed by water scarcity in Scotland. All interviewed stakeholders were invited to the workshop, as well as wider stakeholders identified by the Project Steering Group (PSG). The workshop ran over two days, with 22 different organisations represented (Table A1.1).[2] The workshop was facilitated by Dr Halliday and was designed to ensure that the core principles of co-production: collaboration, diversity, respect, empowerment, and involvement, were fully embedded. The interactive engagement tool Mentimeter was used to collect stakeholder responses and questions during the workshop.

Workshop Day 1 – Knowledge-exchange plenary

Day 1 of the workshop was a half-day online knowledge-exchange plenary, which aimed to build a collective understanding of the water scarcity challenge in Scotland. At the start of the plenary representatives from the Scottish Government, Hollie Armstrong and David Johnson, provided an update on current water policy development in Scotland, and how this work on water scarcity links into this policy developed. This update also highlighted the forthcoming "Water, wastewater and drainage policy consultation", which has now launched. Representatives from SEPA, Ellen Willmott and Michael Wann, then provided a brief overview of the current Scottish water scarcity regulatory framework.

The project team then provided an overview of the project knowledge review and initial the findings from the pre-workshop stakeholder engagement. The project knowledge review was shared with stakeholders in advance of the workshop as an ArcGIS Story Map (Gosling *et al*., 2023), and looked at both the supply and demand perspective. Most attendees felt the review had covered the key topics related to scarcity, and that the consideration of supply and demand was beneficial (93%, Figure A2.1). A number of questions were raised in

[2] NFU Scotland and VisitScotland were registered to attend, but unable to make it on the day, however both organisations have been interviewed.

relation to the review (Appendix 3: Workshop FAQ), some of which were covered in the review but not in detail in the overview provided, but also wider questions which were out with the scope of this project. There are two additional CREW projects currently underway however, which are focused on specific aspects of water scarcity (see below) and all workshop outputs will be shared with these project teams:

- CRW2022_05 Understanding the relationship between water scarcity and land use in private water supply catchments – a review | CREW | Scotland's Centre of Expertise for Waters
- Future predictions of water scarcity in Scotland: impacts to distilleries and agricultural abstractors (CRW2023_05), PI Miriam Glendell, James Hutton Institute

The overview of the findings from the pre-workshop stakeholder engagement covered the initial insights gained from the 4 themes explored in the interviews: impacts, current plans, future plans and barriers and knowledge gaps. Stakeholders were given an opportunity to rank how strongly they agreed/disagreed with these initial observations (Figure A2.2-A2.5), and to share any comments on these findings. These responses were then integrated in and considered further in the more detailed analysis of the stakeholder interviews presented here (Section 1.2).

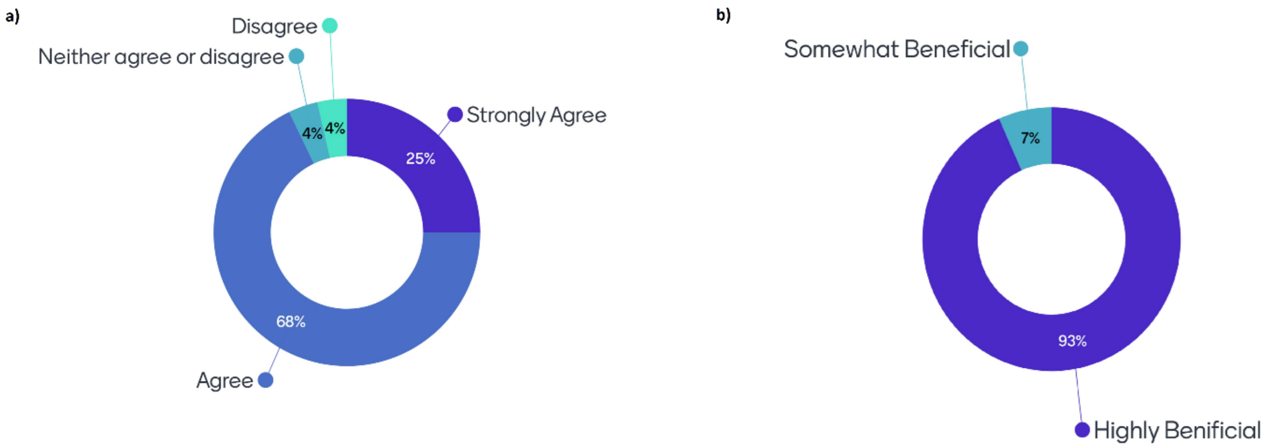


Figure A2.1: Attendees were asked (28 attendees responded): a) How strongly they agreed/disagreed with the statement - The knowledge review has captured the key topics related to water scarcity, with the majority of attendees, 93% (26 attendees), either agreeing/strongly agreeing; and b) Did they think the consideration of water scarcity from both a supply and demand perspective was beneficial, with 93% (26 attendees), believing it to be highly beneficial.

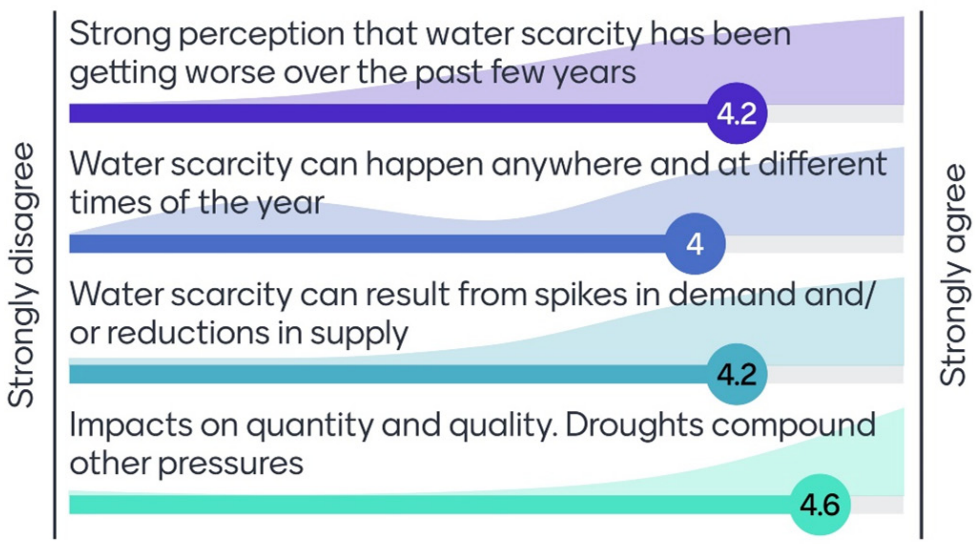


Figure A2.2: Theme 1 – Water scarcity impacts (29 attendees responded). Attendees were asked on a scale of 1-5 how strongly they agreed/disagreed with the 4 key points identified in response to this theme.

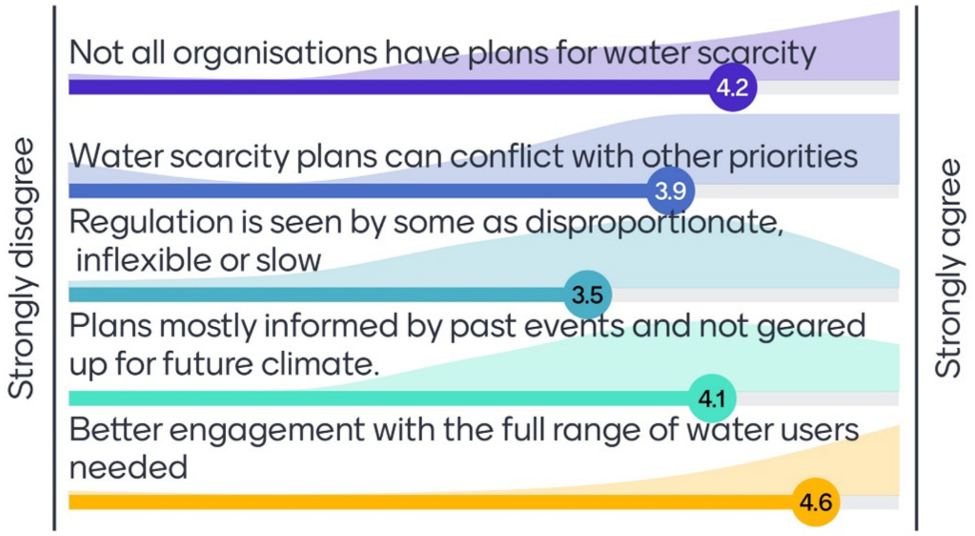
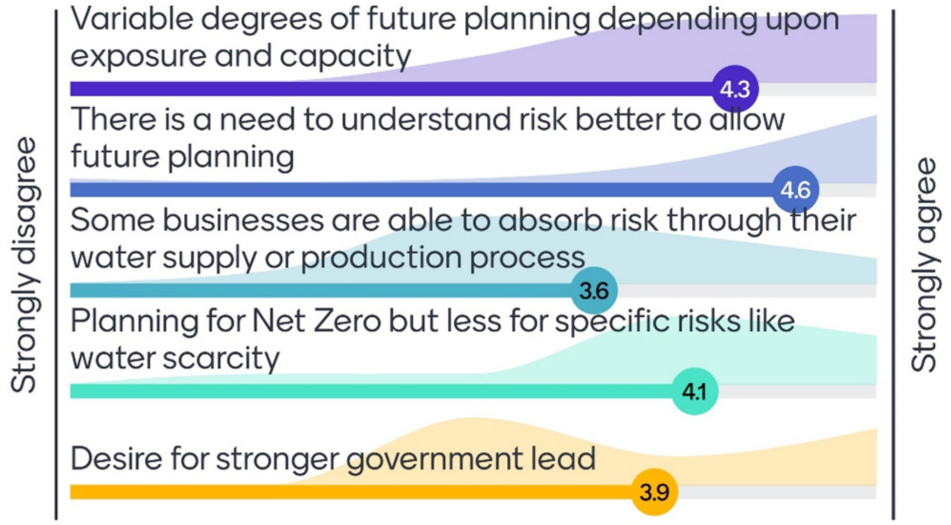


Figure A2.3: Theme 2 – Current water scarcity plans and actions (29 attendees responded). Attendees were asked on a scale of 1-5 how strongly they agreed/disagreed with the 5 key points identified in response to this theme.



FigureA2.4: Theme 3 – Planning for the future (28 attendees responded). Attendees were asked on a scale of 1-5 how strongly they agreed/disagreed with the 5 key points identified in response to this theme.

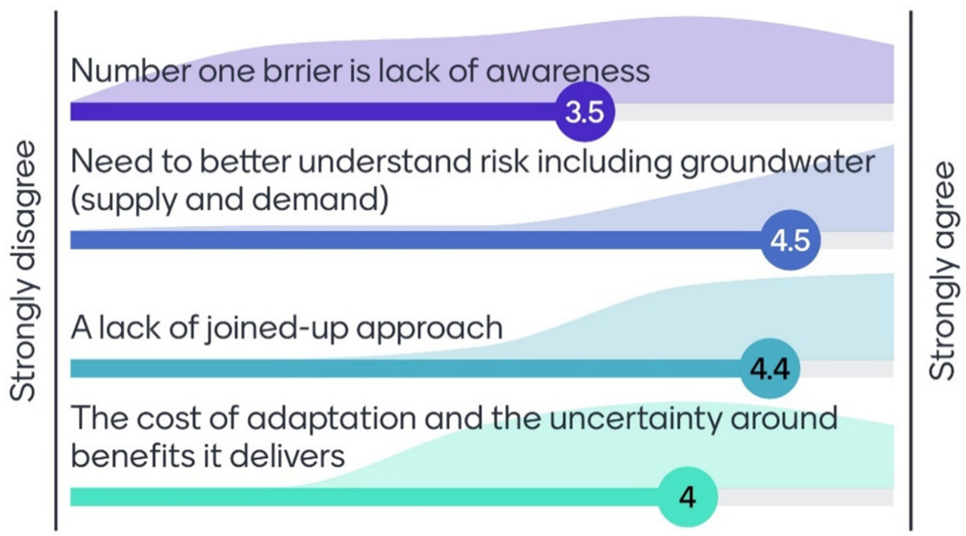


Figure A2.5: Theme 4 – Barriers and knowledge gaps (28 attendees responded). Attendees were asked on a scale of 1-5 how strongly they agreed/disagreed with the 4 key points identified in response to this theme.

Workshop Day 2 – Challenge identification and action development

Day 2 was an in-person full-day workshop, which focused on challenge identification and action development. The attendees were split into mixed organisation breakout groups, with each group facilitated by a project team member, and plenary sessions were used to discuss and collate the breakout group outputs.

2.1.1 Exercise 1 – Challenge Identification

Groups were asked to consider the following statement and discuss what the key challenges and barriers are that currently prevent Scotland achieving this goal:

> *"Scotland is, and will continue to, experience a climate with increasingly frequent and severe droughts. Against this backdrop, a water scarcity resilient Scotland is one in which we are adapting to this change in a way that allows us to continue to sustainably develop the environmental, social, and economic benefits of our water resources."*

Groups were asked to consider different perceptions of the issues related to water scarcity and what is lacking in terms of achieving this long-term goal. Each group reported back 3 challenges during the plenary. The challenges as identified by the groups related very closely to the key issues raised during the stakeholder interviews, and were grouped into 5 overarching challenge areas (Table A2.1):

1. The lack of integration of water into other interconnected policy areas.

   Examples that were discussed by stakeholders, included but were not limited to, that lack of water within the rural policy agenda; consideration of water beyond flooding within the agricultural reform policy; and the importance of water within the NetZero agenda.

2. The lack of a holistic approach to water governance/water resource planning.

   Stakeholders reflected that the siloed approach to water management as a barrier in delivering water scarcity resilience. Stakeholders also noted the need to address both flood and drought risk in an integrated manner.

3. The needs for a stronger evidence base for the impacts of future changes and the effectiveness of different mitigation/adaptation strategies.

   Stakeholders identified that many organisations/businesses do not have a sufficient evidence base to understand the effectiveness, and potential multi-benefits, of water scarcity interventions, and this presents a significant barrier in their implementation. It was also highlighted that organisations/businesses may also not understand the evidence based and future predictions, which underpin why adaptation/mitigation is needed.

4. The needs for appropriate data and systems to use the data to facilitate action.

   Stakeholders noted that the collection of data relevant to water resource management was very limited and not consistent across Scotland. A key data limitation, which was noted by numerous groups, was accurate information on water use. Data sharing and access to data is challenging, meaning that effective use of the data that are gathered is also limited.

5. Lack of awareness and understanding of the issue of water scarcity in Scotland.

   Stakeholders noted a lack of understanding among the general public and different organisations/businesses about the future risks of water scarcity and about the importance of water efficiency. A lack of education about the value of water was seen as central to this. Many felt a major barrier to addressing water scarcity was the perception that Scotland does not have a problem with water availability and that solutions from the past would be sufficient to address future events.

Table A2.1: Challenge Areas – What are the barriers/challenges preventing Scotland from being resilient to water scarcity?

Integration of water into different policy area	Holistic approach to water governance/water resource planning	Evidence base for the impacts of future changes and the effectiveness of different mitigation/adaptation strategies	Appropriate data and systems to use the data to facilitate action	Awareness and understanding of the issues
Water needs to be further up the agenda – need to make more of this narrative – moving beyond NetZero.	There is not a joint approach to flooding and drought – water management needs to consider the whole system and provide multiple benefits.	Uncertainty of historic trends for future planning – better predictions (supply but also demand)	Improved data needed to deliver improved understanding	Communication and public engagement to influence behaviour change; joined up messages, inter-generational memory.
Water needs to be considered within the rural development/ planning agenda.	Is current framework(s) fit for purpose; governance, can we compare and learn from other countries; water resources must be considered holistic, i.e. flooding and scarcity cannot be separated.	Lack of a robust evidence base which is needed to make change. Sectors need to have enough evidence to proceed and take action, but actions should also not be limited by current evidence e.g. groundwater, land use change	Data and information; importance of variability in water use, spatial / temporal patterns; importance of domestic and business consumers and agricultural; patterns of use.	Water usage is increasing, and we don't understand the reasons for change – education and awareness key (across all sectors, public, agriculture, business), how willing are people/originations change.
Moving towards linking different systems; water and energy but also land use, NetZero, infrastructure.	Planning – systems; changing land use and effect on water resources; (water resource planning and many other structures).	Lack of evidence to understand what interventions would work (need joined up approach); or how the success of different interventions would be measured.	Data – climate science; how related to investment decisions e.g. at farm scale; islands of data; no single source or methods of collection	Awareness and communication challenges; lots of information but conscious v unconscious behaviours difficult to address (domestic especially); people don't know how much water they use. Attitudes to value of water need to change, and shared narratives needed.
Tourism is a key water resource demand which is highly variable in space and time and needs to be integrated within this policy area.	Resource planning needs to acknowledge differences in urban and rural contexts: urban, aging infrastructure for future change (population, West > East etc), carbon and infrastructure costs; rural, single sources affecting development potential, spikes in holiday periods	We don't know how much water we have, how much we use, or how much we will have or will need.	Data and information – no point in collecting data without info systems to use for interventions.	Awareness and perception; new issue in Scotland, how to communicate; hydrological cycle; flooding relationship to drought, effect on mitigation options. Carrots and sticks. Individual or collective? How to support collective action; how to take individuals on journey.

2.1.2 Exercise 2 – Action development

Groups were asked to consider two of the challenges identified in exercise 1 and explore the possible actions which would address these and enable the long-term goal of water scarcity resilience to be achieved. In respect of each action, groups were asked to consider:

- The strength of evidence that the action will deliver the desired outcome: strong, moderate, weak.
- The scale of impact the action would result in: local, regional, national.
- Any interdependencies or prerequisites associated with the action.

During the plenary session, each group them reported back on their identified actions and these were discussed and an overarching list of 11 distinct actions developed (Table A2.2). The actions identified covered each of the 5 challenge areas and ranged from more holistic data collection and sharing; to the development of new strategy for water resource management; to considering an enhanced role for different advocacy bodies.

All stakeholders were then asked to independently give a prioritisation to each of the actions: Low, Medium, or High (Figure A2.6). There was strong support for actions tackling integration of water into wider policy areas and for ensuring the value of water is on the policy agenda (> 80%); and stakeholders also strongly supported actions focused on improved monitoring to understand water environment, including water use (>70%). There was less support for action on education (31%), and for actions focused on private water supplies (10%). However, this prioritisation is only indicative. It is important to recognise that the order in which the actions were presented may have influenced the stakeholder's prioritisation and that individual stakeholders noted that where a low prioritisation was given, it was sometimes because they felt the action needed to follow on from other actions (i.e. Education needs to come after water resource governance is addressed). It is also important to note that key stakeholders, for whom the targeted actions related to private water supplies were most directly relevant, were not in attendance on Day 2 of the workshop. This has been reflected upon in the development of the logic model.

There was also discussion about the strength of evidence that the different actions would have the desired effect. Many stakeholders noted the need to make use of international exemplars, from countries already experience significant water scarcity, so that Scotland can learn from their experiences. For example, the lessons learned from the Cape Town 2018 water crisis, and the innovations in water efficient technologies now being explored (e.g. Fourie *et al*., 2021). However, it was also noted that for some actions the evidence base can be mixed, for example the effectiveness of education in delivering meaningful behavioural change was highlighted, as well as how long-term the behavioural change achieved is (e.g. Koop *et al*., 2019; Thompson & Stoutemyer, 1991; van de Wetering *et al*., 2022). However, health focused campaigns have been successful in achieving behavioural change (Worthington *et al*., 2009). It was also reflected that addressing water scarcity challenges will require innovation and therefore some actions which could be pursued, even though a strong evidence base may not exist yet.

Table A2.2: A summary of the unique actions the stakeholders developed to address the challenges currently prevent Scotland from become a water scarcity resilient country (numbers in brackets represent the order in which these actions were discussed in the workshop). Table A2.2 continued to following page.

Challenge Area	Action	Detail	Strength of Evidence	Scale of Impact	Percentage of attendees who stated the action was high priority	Discussion points
Integration of water into different policy area	Valuing water needs to be on the agenda [1]	Effective communication tailored to all water users/ sectors	Moderate – more targeted approach needed at different scales	National	86%	Important to recognise there will be a trade off with other things. A collective approach is essential. Water scarcity needs to be embedded to ensure is remains a priority.
	Promote water related criteria within wider policy and planning frameworks [7]	Absence of water in key policy areas especially Rural, Agricultural Reform, NetZero.	Strong – clear deficit / marginalised	National	83%	Recognised that water, beyond flooding, is not often fully considered in wider policy areas.
Holistic approach to water governance/water resource planning	Develop and implement a national water resource management plan [4]	Linking both supply and demand, infrastructure and behaviours; Improve funding to facilitate the implementation of the national plan	Strong - Exemplars from other countries that this form of water resources management is effective	National	64%	There are existing legislative tools which may be able to provide this, e.g.River Basin Management Plans however they do not currently address water from a resource management angle. Should consider the role of the Hydro Nation Strategy.
	National body for private water and wastewater (advocacy role) [6]	New, or expanded role e.g. for Consumer Scotland	Moderate - exemplar groups/ support mechanisms	National	10%	Local authorities and rural communities need to be engaged on this. It was recognised that this action may have a direct impact on some of the most vulnerable communities.
Evidence base for the impacts of future changes	Ensure planning considers future scenarios of change [11]	Adaptation and mitigation strategies needed to be stress tested against future scenarios of change (both demand and supply)	Strong - Exemplars from other countries where water scarcity is already a significant challenge	National	69%	Need to ensure that any policy that is put in place stands the test of time. Policies need to be flexible enough to accommodate future changes which may not have been predicted yet.

Table A2.2: A summary of the unique actions the stakeholders developed to address the challenges currently prevent Scotland from become a water scarcity resilient country (numbers in brackets represent the order in which these actions were discussed in the workshop). **Table A2.2 continued to following page.**

Challenge Area	Action	Detail	Strength of Evidence	Scale of Impact	Percentage of attendees who stated the action was high priority	Discussion points
Appropriate data and systems to use the data to facilitate action	More effective monitoring of the water environment [3]	Identify the data gaps – what is needed/missing; Develop a system of collation of accurate water usage data	Moderate – provide the evidence base to measure action impacts	Local to National	76%	There is a lot of data already collected, so how can we utilise it better. The transferability of data is often limited as it is siloed to a particular discipline/originations. Data sharing needs to be made easier.
	Improved understanding of water use across Scotland [2]	Modelling/ mapping of water use across Scotland – focused at the regional/local scale.	Moderate – better understanding should enable targeted action	Local to National	69%	Important to recognise there are lots of uncertainties with modelling. There are genuine gaps in understanding – e.g. actual water usage, which need to be addressed.
	Water Scarcity Data Hub [9]	Create a platform so water scarcity relevant data can be shared and used effectively	Strong – good evidence that environmental platforms are successful	Local to National	56%	There are existing platforms which could be used to provide this service (Scottish Environment web; SEPA Water Environment Hub). However, it was recognised that currently data is split across multiple platforms.
Awareness and understanding	Education [10]	Across a range of different educational levels (Schools, curriculum; Universities – innovation; also Scottish Enterprise; local knowledge).	Mixed (see discussion)	Local to National	31%	There is mixed evidence on how successful education is in driving behaviour change in relation to water use.
	Incentivise water usage efficiency [5]	Business as usual will not incentives sustainable use. Design in enhanced efficiency	Strong - Exemplars from other countries where water use is more efficient	Local to National	59%	Tiered approach needed – other actions need to come first
	Wider remit for Scottish Water in relation to Private Water Supplies [8]	Role would be advisory not regulatory	Weak	Regional	10%	It can't be assumed that private water supply users wish Scottish Water involvement. There is a huge diversity of private water supply users across the rural community.

Figure A2.6: Attendees were asked to state what priority level should be associated with each on the initially identified actions: 1) Valuing water needs to be on the agenda; 2) Improved understanding of water use across Scotland; 3) More effective monitoring of the water environment; 4) Develop and implement a national water resource management plan; 6) Incentivise water usage efficiency; 7) Create a national body for private water and wastewater advocacy; 6) Promote water related criteria within wider policy and planning frameworks; 7) Wider remit for Scottish Water; 8) Create a platform so water scarcity relevant data can be shared and used effectively; 9) Education; 10) Ensure planning considers future scenarios of change.

2.1.3 Working better together

To close, the workshop the stakeholders discussed how to work better together to achieve the identified actions. Stakeholders were asked to consider:

1. Who needs to be working together to achieve these actions – Are these new connections or just better more integrated activities?
2. What are the key barriers that limit effective communication/working together?
3. How specifically can organisations work together more effectively?

The discussion recognised that the workshop has been an excellent first step in getting water scarcity to the fore of the agenda for the different organisations and allowing different stakeholders to discuss the topic. It will be important to build on this. The discussion highlighted that there is an existing Water Scarcity Group which consists of representatives from Scottish Water, SEPA, the Scottish Government and NatureScot, however this group is reactive and only meets during periods of scarcity, in an event response/management capacity. Stakeholders also noted that there is a separate "water efficiency stakeholder group", which has a more strategic in purpose, and is jointly chaired by Scottish Government and Scottish Water. It was discussed that a more integrated, proactive approach was needed, and that perhaps a formation of a "Water Resource Group" could provide this role[3].

The stakeholders recognised the need to be working more efficiently. Different organisations have limited capacity and available resources, which is a huge barrier for working together. Partnerships were recognised as important tool for allowing people to work together collaboratively. However, these must be valued and given time to develop. The importance of long-term thinking and solutions was reflected. The role of senior leadership in recognising water scarcity as a priority and engaging and empowering staff to be proactive in this area was seen as critical. Stakeholders recognised that we need the time to have these conversations.

The stakeholders also recognised that some key voices were missing from the room (i.e. private sector), and that if we are to address the challenges posed by water scarcity, we must engage all sectors. The stakeholders also noted that while it is good to see positive work being undertaken in this space, it's important that all the work ties together so we can have collective impact and avoid duplication.

[3] It was noted that there has been a historic Water Resources Group made up of Scottish Water, Forest and Land Scotland, Scottish Forestry, Forest Research and SEPA and this could be reinvigorated.

3 Appendix 3: Workshop FAQ

During both the online and in person elements of the workshop, several questions were put forward by attendees that the project team agreed to provide follow up on. The original questions and the relevant response can be found in the table below.

Table A3.1: Questions related to the Scottish Government water policy update		
No.	**Question**	**Response**
1	Would be great to hear more about the other policy areas that they are connecting to and how these alignments are created and maintained	Other policy areas contributing to the policy development for the water industry (beyond drinking water, water environment, wastewater, and drainage policy): planning policy, climate change adaptation, public health, building standards, agriculture, forestry, land use. Mainly linkages have been made via internal government policy teams and via working groups with a range of external stakeholders. Regular engagement takes place with these groups.
2	Would be good to know how rural areas across Scotland and their specific challenges are being considered in the policy update? I've noticed that water is not included in the rural delivery plan.	It hasn't been considered in that work. However, the concept of water resource planning (if it goes ahead following consultation and further policy development) would very much factor in the water needs, as well as pressures, of rural areas.
3	We're seeing more energy efficient homes, but there doesn't seem to be much done on water efficiency (in homes and businesses) - e.g. drinking water used to flush toilets. How can we reduce water use?	Water use in Scotland is higher than most other EU countries. It's very much a point that the policy development focussing on water efficiency has considered. A suite of options will be required to reduce demand. Behaviour change and awareness sits at the top but a key challenge is the mindset that Scotland is a water abundant country. Which it is. It's just not evenly spread. The consultation asks for views on efficiency.
4	It was mentioned that the government will be considering introducing water efficiency measures as one of the policy options. Could you say more about this e.g. What types of measures?	Several options have been explored and as mentioned above, a suite of options will be required to improve water efficiency. Nothing has been decided yet but some of the options on the table are a water efficiency strategy, targets, water efficiency designed into building regulations, water efficient appliances, behaviour change, meters.
5	Will there be any focus in the upcoming events and consultations on the impact of seasonal population changes (e.g. holiday visitors) to areas in Scotland on water supplies and scarcity?	The consultation and associated engagement events are focusing on the strategic policy principles that will drive the direction of where we want the water industry to go in the next 50 or so years in the face of climate change. A key aspect of this will be on water resource planning. The idea here that we need to get into a place where we know nationally how much water we have and how much we use, so we can better plan for current and future changes/demand pressures. This would factor in seasonal pressures, water scarcity etc. You won't see this topic specifically mentioned in the consultation, but there is an awareness of it. Particularly so within private water supply policy.
6	How much does someone get charged for raw water abstraction. Is it a licence cost or a cost by volume?	Details of the CAR licence charging scheme can be found here.
7	Since COVID our demand for domestic public supply remains 5% to 10% higher and we see impacts far more suddenly. Need to account for this in planning	Agreed and it is being considered.
8	Headroom calculation methodology reports are not available on the Scottish Water website. Are such calculations part of abstraction justification?	The drinking water policy team in SG don't carry this work out. For the public water supply, Scottish Water will be responsible for this and for licensed abstractors, SEPA would be responsible. I can't say however, if either use this methodology.
9	When will the public consultation on WS be happening. Is this different to the flood resilience consultation?	Now live. Link here. Yes, it's different to the flood resilience work. However, flooding plays a part of this work, particularly in the drainage Section.
10	Has groundwater been considered in any policy discussions? Thought it can also experience drought it responds slower and can be utilised as a more resilient supply	This would be factored into water resource planning if it goes ahead.

Table A3.2: Questions related to the SEPA regulatory framework		
No.	**Question**	**Response**
11	Scarcity thresholds are calculated for relatively large catchment scales, but abstractions by some distillers/agric users can be at smaller scales, where timing is different. Does SEPA consider this?	SEPA use a combination of different data set water scarcity thresholds: soil moisture, river flow and rainfall. These are reported at a hydrometric area level when water scarcity is normal to moderate. When water scarcity reaches significant scarcity, it is reported at a higher resolution relating to one of the 82 DRAT (Drought Risk Assessment Tool) sites, which are deemed to be indicative of conditions in those specific catchments.
12	How do licences take account of the type of agriculture e.g. if a farmer switches to new crops, does the licence adjust overall amount and timing of abstractions? How often are licences reviewed?	The amount licensed and used should reflect a reasonable volume of water to carry out that activity so SEPA can calculate volumes based on crop type. This is more common for new activities whereas the River Basin Management Planning (RBMP) process would drive effort for existing activities. Irrigators will rotate crops and are not required to notify SEPA when doing so unless additional water is required. We are looking at efficiency and considering options to better understand water use through monitoring. This will help to ensure the volumes are only the amount required. Licence reviews are done through the RBMP process. Licences in catchments requiring improvement measures (I.e. less than good status) would be reviewed in line with basin plan cycles.
13	Any info plans for hydrogen production	Where a proposal for hydrogen is directly from the water environment, SEPA would assess such proposals against environmental standards to keep cumulative abstraction within a sustainable limit. If the activity is using public water supply, then this would also have to be within the environmental standards coupled with the domestic and non-domestic supplies from that source.
14	We need to discuss headroom. I believe it is a statutory requirement down south for headroom calculation reports every five years from suppliers. Is that the case in Scotland?	This is not currently a statutory requirement in Scotland.

Table A3.3: Questions related to the Knowledge Review		
No.	**Question**	**Response**
15	Will the knowledge review be available afterwards?	Yes. The story map (Gosling et al., 2023) will remain live and a more detailed version will be available in the final project report.
16	Regarding changes to demand, what about future use in cities or growing rural communities - implications for new reservoirs/ water being moved between catchments (e.g. Severn to Thames down south)?	The water supply demand balance work that Scottish Water undertake considers the movement of demand and determines the options to maintain future supplies. This could be focussed on reducing the demand side or connecting areas where there are surplus resources or creating new sources.
17	Regarding demand, manufacturing seems to be missing (including distilling, and other aspects of agriculture e.g. livestock waterings, washing potatoes etc. Maybe circular economy is a missing policy area.	We hope to be able to include all major water demands in Scotland within the knowledge review. A separate project is looking at this and its findings should be able to inform this project. There is also a separate CREW project which will be looking specifically at Distilleries and Agriculture.
18	How will Scottish agriculture evolve in a drying and warming climate. There are opportunities surely through crop changes, water storage, farming at higher altitude etc to mitigate	Climate change will be one of a number of factors that will influence future changes in agriculture. Some examples of adaptation can be found here. Other factors will include the Scotland's land use strategy, international dimensions and the nature of farm payments, details of which are considered within the recently published Agriculture and Rural Communities Bill.
19	Are we looking at lessons from other countries who have been dealing with water scarcity more regularly (and for a long time)?	Yes, the project is looking at examples from other countries e.g. France, Denmark and the Danube region and these will inform the project's recommendations.
20	Any view of tourism past 2019. My head says it will have increased since COVID further but not sure	Yes, good question. Data are available for 2021 and 2022 but not 2020. International visitor numbers were down in 2021 (and presumably 2020) due the pandemic but as you suspected, the numbers for 2022 show a continuation of the previous rising trend reaching nearly 30 million visitor nights. The knowledge review will be amended to include these data.
21	Inclusion of a breakdown of water use (to help inform where we can cut back) would be beneficial	This is being investigated by a separate hydro nation chair research project. If available in time, the results will be used by this project
22	Is there a potential to include the link of water scarcity to health implications?	Although health implications were beyond the remit of this project, further investigation may form part of this project's recommendations.
23	You've highlighted some key gaps in knowledge during the talk through. Any in particular you/ others would highlight as a particular barrier to better planning/response?	There is generally a lack of information around future demand from sectors other than public water supply.
24	The Drought/Water Scarcity definitions are unusual. In DRR literature normally all one concept with cascading effects Meteorologic->Hydrologic->Agri->Socio-econ	We have used the definitions of water scarcity and drought that are laid out in the European Commission's guidance for implementing the Water Framework Directive. This underpins the Scottish legislation and regulations that set out how water abstractions are licensed.
25	Is the Water Scarcity Plan more of a drought plan (mainly considering meteorological , hydrological and soil moisture)? Are licensed abstractions/ forecasts monitored to inform decision-making?	The National Water Scarcity Plan sets out actions for water users at all levels of drought severity. This includes the expectation of water saving measures under normal conditions to help address the risk of a long-term imbalance between supply and demand. As Scottish policy develops, the Scottish Government and its delivery partners aim to expand upon these more proactive measures, including making use of the findings of this project. There is a requirement on most licensed abstractors to submit data on their actual daily water use and this information is used to better understand the nature of water scarcity in Scotland. During droughts, SEPA makes use of weather and river flow monitoring and forecasts to inform the setting of the severity levels identified within the plan and the decisions made based upon those levels. Additionally, SEPA liaises directly with abstractors to check their current and upcoming water needs to inform decision making. Abstractions within a catchment also influence when the Significant scarcity level is reached so have a direct impact on reductions and/or suspensions.

Table A3.3: Questions related to the Knowledge Review		
No.	**Question**	**Response**
26	The future of Hydrogen or any other change in industry. Consider people's changing water use which means our starting position is higher than it was in 2019	A point that has been raised by a number of stakeholders is around the lack of national water resource planning. The project will reflect this viewpoint which, if such planning were to be introduced, would require a method for understanding and accounting for future water demand from any sector.
27	Implications of low env flows needs to be considered more e.g., higher water temp, lower oxygen, lack of pollution dilution, biodiversity impacts including loss of species. England are ahead of us in regard.	Yes. The knowledge review presented on the day was a headline summary of the social, environmental, and economic demands for water. A greater level of detail around environmental requirements for water including water quality will be available in the project report and will inform the project recommendations.
28	Would be nice to have more examples of environmental impacts and more of an environmental focus as well as a human impacts focus	See response 27
29	The impact of biodiversity/ecosystem services?	See response 27
30	Reflection to Richard's slide on future plans. Can we find a way to wrap the water scarcity benefits/plans in to Net Zero plans. Organisations need to know what this means.	The project has been looking at the interactions between policy areas e.g. Net Zero. The project recommendations also will include considerations of the governance of water scarcity management and how this system of governance will interact with those of other policy areas.
31	Have you spoken to representatives of the public (e.g. Consumer Scotland) on this (e.g. PWS, swimming in rivers/lochs, costs of changing behaviours, levels of awareness etc).	Consumer Scotland is represented on the project steering group and have been interviewed as a stakeholder as has a local authority with a large number of private water supplies.
32	We'd also be keen to know of knowledge out there on how communities respond to water scarcity events.	The final report will provide information on the current knowledge related to community responses/actions during water scarcity and will look to highlight knowledge gaps in this area.
33	The lack of snow cover was not mentioned. Does this not represent an enormous loss of storage	Typically in Scotland, snow lies for around 26 days per year. However for some upland catchments, snow can significantly influence seasonal flow regimes. The EFlaG river flow and groundwater projections data highlighted within this study includes a snowmelt component and, as such, the influence of climate change on snow has been taken into account.

Workshop attendees feedback on the stakeholder interview summary

In addition to these specific questions there was a range of comments around what delegates felt were surprising results from the stakeholder interviews or aspects they felt were missing. These are very helpful, and the project team will reflect on these when developing the project recommendations.

Some comments highlighted the need for wider views across all water users. A small number of further interviews have been planned to widen this view and the final project report will detail which organisations/sectors have been involved. Furthermore, this project is being undertaken in parallel with other research projects, one of which is a CREW project looking at the impact of water scarcity on the agriculture and distilling sectors.

Some of the issues identified, particularly around national and catchment water resource planning and alignment with other policies, are beyond the scope of this project to address in detail but may form part of the Scottish Government’s policy development around water management that is currently underway.

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