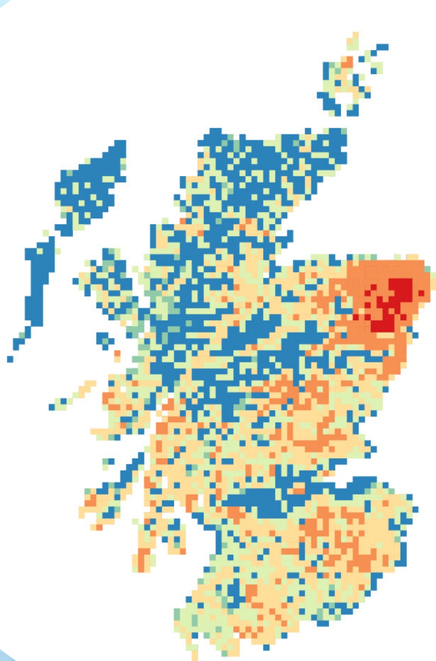
CENTRE OF EXPERTISE FOR WATERS

Private Water Supplies and Climate Change

The likely impacts of climate change (amount, frequency and distribution of precipitation), and the resilience of private water supplies

Policy Brief



Background:

The aim of this study was to better understand the likely impacts of climate change (amount, frequency, and distribution of precipitation) on Private Water Supplies (PWS) in Scotland. In particular, the consequences on PWS *resilience* to water shortages in order to assess changes in *vulnerability* due to reduced quantity of water as a result of climate change.

Climate change is affecting Scotland's weather patterns, which in turn impacts the quantity, distribution, and frequency of precipitation. The policy drivers are that: (i) PWS must meet the requirements for Drinking Water Quality in the Drinking Water Regulations (The Water Intended for Human Consumption (Private Supplies) (Scotland) Regulations 2017); and (ii) sufficient water quantity is a basic condition for adequate living standards in line with the Sustainable Development Goal 6 (SDG: Access to water and sanitation for all). Supplies are classified into regulated (Type A) and exempt (Type B) supplies: this report is a general assessment covering PWS types (and their respective sizes) and collection technologies from different sources. Regulated supplies are typically those serving more than 50 people, more than $10m^3$ or those that supply commercial or public premises. There are some 2500 regulated and 20,000 exempt supplies in Scotland.

Introduction

Scotland has abundant water resources as a result of its mostly temperate and oceanic climate, but with a highly variable spatial and temporal distribution of precipitation. The west is generally wetter whilst the east is dryer, giving a distinct west to east gradient due to the 'rain shadow' influence of the western and northern uplands. Annual and decadal variability in precipitation can be large. Drought can be an issue with very low river and spring flows and low reservoir and loch levels known to occur in both west and east Scotland in connection with periods of prolonged (i.e. lasting for one season or longer) dry weather. The 2015-2021 River Basin Management Plan (RBMP) report compiled by the Scottish Environment Protection Agency (SEPA) points to a greater risk of water flows being worse than the good status required by the Water Framework Directive ("*Directive* 2000/60/EC) in rivers used for irrigating cropland but only during dry weather. It is essential to address resilience to drought given the latest climate projections for the UK (UKCP18) indicating increasingly variable weather, including: altered spatial and temporal precipitation patterns and variable amounts across Scotland (West becoming increasingly wetter, East becoming drier); higher probability of drier and warmer summers; and increased rates of loss of surface water through greater evapotranspiration (from plants and ground surfaces) and evaporation from water bodies.

The 2018 drought was marked by its severe impacts on decentralised rural water supplies, with unprecedented numbers of requests for support. These PWS are the responsibility of their owners and users rather than Scottish Water. The Drinking Water Quality Regulator (DWQR) reported that in summer to autumn 2018 many PWS across the country ran dry and at least 500 of them requested emergency assistance from their respective Local Authorities. The Scottish Government (SG) provided additional funding (c.£475K) to Local Authorities (LA) and to Scottish Water (SW) to enable emergency assistance to be provided free of charge in the form of water bottles and water in tankers (DWQR 2019; SG 2018).

The extent of emergency assistance requested by PWS users during 2018 raised awareness about their vulnerability in the face of future climate projections and highlighted the need to improve their resilience to drought. PWS numbers vary from year to year but generally serve approximately 4% of the resident population in Scotland and potentially many thousands of tourists, primarily in rural areas. In 2018, there were 21,980 PWS and the largest population relying on PWS reaching approximately 30,000 and 40,000 people in Aberdeenshire and Highland, respectively. PWS use a variety of sources such as boreholes, wells, springs, river-intakes, lochs or rainfall and may serve a single house, rural communities up to 5000 people, schools, hospitals and other public, holiday and business premises. The Private Water Supply (Scotland) Regulations 2017 (the PWS Regulations), which transpose the requirements of the Drinking Water Directive (DWD) (Directive 98/83/EC) as amended to national law, put a duty on LA to monitor and carry out risk assessment in PWS serving more than 50 people, or public or commercial premises. However, the PWS Regulations address PWS vulnerability to pollution and public health risks and not to drought.

Definitions of Resilience and vulnerability

Resilience: we define resilience as the ability of a drinking water supply system to undergo change in the quantity of water resources and maintain a reliable service to meet their users' needs, i.e. supply sufficient amount of safe and affordable tap water.

Vulnerability: we adopt the definition whereby vulnerability refers to 'the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard". In this context a lower water supply vulnerability is associated with higher protection capacity against the risk of a decline in water quantity.

Research questions and conclusions

What are the main influencing factors on PWS vulnerability?

The key interacting factors controlling the vulnerability of an individual PWS include:

- Meteorological-climate drivers, such as rainfall or snowpack deficit and temperature anomalies;
- Catchment characteristics such as geology, topography, soil types, land cover;
- Catchment hydrological processes, such as evapotranspiration, soil moisture, groundwater recharge and groundwater-surface water interactions;
- Human activities, such as land and water management and water use (e.g. rates of water abstraction), and the location of the PWS within the catchment;
- The source of PWS, with rainwater harvesting, springs shallow wells and rivers in catchments with a more quickly responding groundwater system, being more vulnerable to a precipitation deficit than rivers in slowly responding catchments and boreholes from aquifers receiving recharge from extensive catchment areas and sustained from confined deep aquifers;
- Future levels of PWS vulnerability will likely be a combination of changes in the climate that affect water quantity availability and interactions of the specific catchment scale water use. Across Scotland this will be spatially and temporally variable due to precipitation and temperature differences affecting overall water balance.

What are the likely impacts of future changes in the amount, frequency and distribution of precipitation and the resilience of private water supplies (PWS)?

- The analysis indicates there is a high probability that climate change will result in drier and warmer summers that will consequently increase water deficits and the vulnerability of PWS, particularly those more reliant on surface water;
- Summers similar to, or drier and warmer than 2018, are projected to occur more frequently, indicating an increased probability of requests for support from PWS users.

What can be deducted from climate change projections regarding changes in precipitation?

- The timing of when and rates at which precipitation enters the hydrological system is likely to change;
- There is an increased probability of warm dry summers, interspersed with more intense rainfall events.
- Seasonality shifts have occurred and are projected to continue changing, altering the timing of when groundwater is recharged;
- It is not just an issue of precipitation, as increasing temperatures lead to great rates of water loss from evaporation.

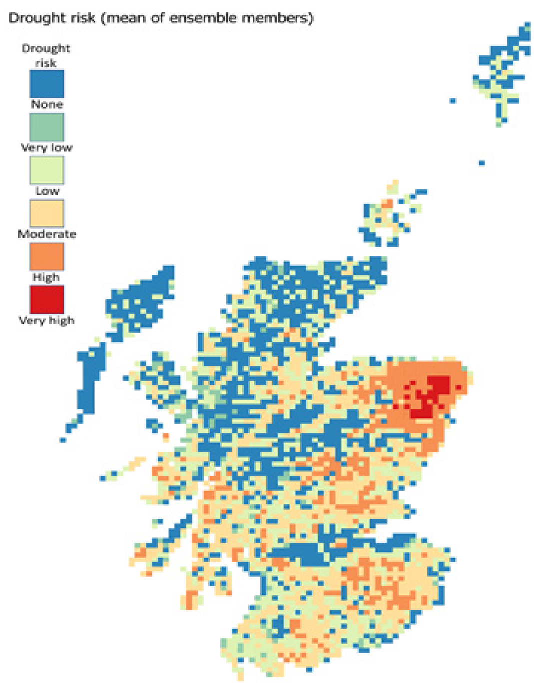
How will different regions in Scotland be affected? How will it affect regions where PWS predominate?

- Geographic distribution of precipitation will likely change, with the west becoming wetter and the east drier, with a general increase in the probability of more intense precipitation events.
- The north-east of Scotland is estimated to experience the largest increase in water shortages, where there is also the highest density of PWS.

Limitations: These overview conclusions should be interpreted within the context of the key findings from the literature review and future modelling projection estimates and details on caveats and uncertainties about future modelling, as provided in the main report.

Figure: Meteorological Drought Risk Indicator, mean of 12 climate model simulations.

Combination of the number of years in the period 2020-2050 that the UKCP18 projected annual precipitation (mean of 12 ensemble members) falls below the 20th percentile of the actual observed precipitation between 1990-2016 in relation to the density of Private Water Supplies.The risk classes shown in Figure 1 are the sum



of the number of years (0 - 31) in the future projections (2020 – 2050) where the annual total rainfall falls below the 20th percentile threshold of the observed annual total precipitation, multiplied by the number of private water supplies in the same 5km cell. The values were then classified into 6 drought risk classes.

Recommendations:

1. Risk assessment of PWS for water quality issues can be extended to include climate-change related issues.
2. Policy prescription on fit-for-purpose technologies for collection and treatment of water is a feasible way to help build resilience in decentralised, small rural supplies.
3. Improve meteorological drought risk indicators and monitoring of water availability and shortage early warning mechanisms by developing catchment scale meteorological linked to hydrological drought risk indicators and apply to localised contexts to improve early warning systems.
4. Assess potential of bedrock *aquifers* across *Scotland* to sustain various levels of borehole water supply and improve PWS resilience to drought (e.g. using Bedrock Productivity map by British Geological Survey as a guide).
5. Provide risk awareness and water conservation advice to PWS users.
6. Develop household water storage capabilities as back-up support to non-drinking water uses during drought. This may be more suitable for non-drinking water use.
7. Identify the potential for cost effective connection to mains water supply by using spatial risk indicator mapping.
8. Integrate policies and associated research for improving catchment storage potential with those focussed on nature-based solutions for improved ecosystem resilience (e.g. water retention in soils, Natural Flood Management). These measures to improve soil and groundwater water retention for agricultural and ecosystem management purposes may also help PWS resilience.
9. Account for changes in water demand in view of climate change.
10. Assess impacts of meteorological and hydrological drought on reservoirs.
11. Review and assess the benefits of centralised management on water supply resilience to climate change in rural areas to inform and enable the use of lower-risk source water services.

Find out more

The full report (104 pages) containing a detailed analysis on which this summary is based, including the sections listed below. It can be accessed at www.crew.ac.uk/publications

Phase 1: Literature review of drought and its implications for PWS

- Climate change and quantity of water resources in Scotland and internationally.
- Drought: definition and types.
- Hydrological drought generation and drought propagation.
- Hydrological drought monitoring indices and early warning systems.
- Climate change and small rural water supplies.
- Knowledge gaps.
- Evidence-based practical implications.

Phase 2: Climate and climate change analysis and risk mapping

- How unusual was the weather in 2018?
- Climate Projection Summary
- Probabilistic Climate Projections
- Projected changes in dry year frequency
- Assessing changes in precipitation seasonality
- Meteorological Drought Risk Indicator maps
- Precipitation volume
- Additional Indicator maps of change (Agrometeorological Indicators)
- Practical implications

Publication details

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Please reference this policy brief as follows: **M. Rivington, I. Akoumianaki and M. Coull (2020). Private Water Supplies and Climate Change: Policy Brief. CRW2018_05. Scotland's Centre of Expertise for Waters (CREW).**

Appendix: Summary of Findings

Key Findings – Literature review:

1. A meteorological drought (below-normal precipitation) can propagate through the hydrological system and, if prolonged, lead to a hydrological drought, i.e. below-normal water availability in rivers, streams, reservoirs, lakes, or the groundwater table. This concept of the progressive development of a drought is sometimes known as drought propagation. Hydrological droughts are directly associated with socio-economic impacts including drinking water shortages. In Scotland, very low river and spring flows and low reservoir and loch levels have occurred during the past century in both West and East Scotland in connection with periods of prolonged dry weather. Generally, the impact of meteorological drought on water sources serving small rural water supplies is controlled by catchment water storage levels prior to onset of dry weather and depends on the type of water source.
2. In addition to meteorological-climatic drivers, catchment properties (e.g. land cover, topography, soil type, bedrock geology) and human activities (e.g. abstraction, land and water management and water use) influence the impacts of a hydrological drought event on small supplies.
3. The key drivers of a hydrological drought are:
   i. Climate-atmospheric drivers such as precipitation deficit and temperature anomalies, which are key to shaping the distribution of drought duration in natural and human-influenced catchments.
   ii. Hydrological drivers in natural catchments such as evapotranspiration, soil moisture and water storage (e.g. in the soil and aquifers), and runoffs which are influenced by catchment response to rainfall ("flashiness").
   iii. Human drivers include surface water and groundwater abstraction, urbanisation, damming and deforestation. In short timescales, the onset and duration of a hydrological drought depends on water demand and water management. In longer timescales the threshold below which a hydrological drought occurs is mainly influenced by groundwater depletion and anthropogenic land use change. A human-induced drought has a lower threshold below which a hydrological drought occurs than a climate-induced drought.
4. Hydrological drought events are described by their frequency, severity, duration and deficit (i.e. deviation from normal flows and water table levels for a given area and season). Generally:
   i. In cold climates, hydrological drought deficit is governed by annual precipitation and winter precipitation, which is controlled by temperature.
   ii. River drought duration is primarily controlled by seasonal water storage (e.g. snow pack and glaciers). River drought deficit is mainly controlled by water storage in soil and aquifer.
   iii. Increased annual precipitation increases soil moisture and subsequently evapotranspiration (when temperatures are sufficiently high), which may or may not influence groundwater recharge. Increased annual temperature increases evapotranspiration rates and reduces recharge in winter. Increased winter temperature reduces the extent of ground frost and shifts the snow melt from spring toward winter, allowing more water to infiltrate into the ground, resulting in increased groundwater recharge.
5. Generation and propagation of different hydrological drought typologies is controlled by meteorological drivers and catchment processes, such as groundwater storage. Hydrological typology distinguishes drought generating mechanisms as (their key driver in parentheses): Classical rainfall deficit drought (precipitation deficit in any season); Rain-to-snow season drought (precipitation deficit continuing into snow season); Cold snow season drought (low temperature in snow season leading to no recharge); Warm snow season drought (high temperature in snow season leading to no

recharge); Snowmelt drought and Glacier-melt drought (in winter, in very high latitudes, leading to no recharge); and Composite droughts (multiyear droughts in catchments slowly responding to rain). The classical rainfall deficit drought is the most commonly occurring, but types such as rain-to-snow-season droughts and warm snow season droughts can have more severe impacts.

6. A wide range of indicators, standardised indices and thresholds exist to define a hydrological drought and support early warning systems. Indices are typically computed numerical representations of drought severity, assessed using indicator data such as precipitation, snowpack, streamflow, groundwater or well level, reservoir storage, and modelled data. Ideally, they have both monitoring and forecasting components to prompt action (via "below-normal" threshold triggers) within a drought risk management plan, as a means of reducing potential impacts. Examples of standardised hydrological indices are the Standardized Streamflow Index (SSI), which is used and reported by SEPA, and Standardised Water-Level Index, which is used for assessing risk from groundwater drought. The baseflow (i.e. groundwater contribution to river flow) index (BFI) can be a good proxy for the combination of multiple catchment characteristics indicative of catchment storage.

7. Few studies detail vulnerability to meteorological and hydrological drought of small rural supplies in developed countries by source and water treatment technology. Sources sustained by precipitation (e.g. household rainwater harvesting and some springs) and immediate aquifer recharge from rainwater (e.g. protected springs and protected shallow wells) are more vulnerable to precipitation deficit and variability than boreholes. However, boreholes and deep wells from unconfined and relatively shallow aquifers are sensitive to precipitation variability unless in cases where an aquifer receives recharge from an extensive catchment area. Rivers are vulnerable to a prolonged precipitation deficit. Reservoirs are vulnerable to the variability of rainfall, which outweighs the positive effect of an increase in total annual precipitation.

8. Major knowledge gaps are related to research questions on the following issues: drivers of drought; human influences on the prevention, exacerbation or management of hydrological drought; collecting data on the impacts of hydrological drought; modelling drought propagation, severity and recovery; and identifying "normal" in a constantly changing world.

9. The practical implications of this evidence can be summarised as:

    i. Risk assessment of PWS for water quality issues can be extended to include climate change related issues; the World Health Organisation (WHO) has already provided an extended conceptual flow of activities addressing climate change risk in water safety plan risk assessment.

    ii. Few studies account for changes in water demand in view of climate change in Scotland; therefore, data on catchment storage will be key towards management of water resources for PWS resilience.

    iii. Policy prescription on fit-for-purpose technologies for collection from source and treatment of water is widely recognised as a feasible way to help build resilience in decentralised, small rural supplies. This approach can be tailored to local conditions and tied into other risk management approaches (e.g. water quality risks), such as the specified technologies' approach to health-based targets described in the WHO's Guidelines for Drinking Water Quality. For example, a change of source (e.g. from spring to borehole) can be a sensible course of action in areas where bedrock aquifers have the potential to sustain borehole water supply, and when vulnerability to drought and contamination co-occur for a given PWS or supply zone.

    iv. Centralised management is key in developing water supply resilience to climate change. This is because the technical, human, and financial resources are usually sufficient to permit the integration of climate issues within management plans and the expertise and ability to identify alternative sources to produce lower-risk source water services.

Key Findings - Future projections:

1. Climate change will result in alterations to the precipitation input to Scotland's hydrological system, with different spatial distributions and seasonality shifts giving reduced rainfall in the east and increase in the west. There is an increasing probability of experiencing drier years in the future. Warmer temperatures also imply increased rates of evaporation loss.

2. There will likely be an increased risk of meteorological drought which may lead to hydrological drought and impact on PWS with an increase in the number of drier years (low total annual precipitation) occurring more frequently with water shortages due to large water precipitation deficits.

3. Using risk mapping, approximately half of the PWS are estimated to be within areas of High or Very High-risk categories[1] between 2020 and 2050.

    i. The geographical distribution of PWS in Scotlands' rural landscape places those supplies at an increasing risk of experienceing more years in the future, when the total annual precipitation is less than the 20th percentile of the observed period.

    ii. The risk mapping does not differentiate between PWS types; however springs and shallow wells will be relatively more vulnerable than boreholes.

4. The level of meteorological drought risk is spatially variable:

    i. The north-east of Scotland may have the greatest exposure to risk of precipitation deficit due to projected changes in precipitation and high concentration of PWS.

    ii. PWS in large areas of upland Scotland including the southern west coast and upland central and south Scotland may also experience increased water deficit.

    iii. Although some areas are estimated to be at lower risk of experiencing more dry years, the risk of experiencing severe drought in some years remains.

5. Analysis of 2018 data indicates that there was a climatic contributor to the large number of requests for support for PWS. For north-east Scotland there were areas that were consistently drier than average. The chance of exceeding 2018 temperatures (joint hottest summer on record) are estimated to become 50% more likely to occur by 2050 than in the past. This implies a larger evapotranspiration amount risking reduced groundwater recharge. The policy implications are for the need for adaptation to reduced water availability.

6. Rainfall seasonality may have changed in the past, with projections indicating further seasonal shifts that may alter the timing at which groundwater recharge occurs.

7. Total annual precipitation volume for the whole land area of Scotland using the UKCP18 data, is estimated to decrease (but is spatially highly variable, see 4 above). This, combined with projected higher temperatures and associated increased evapotranspiration and evaporation and reduced winter snow cover indicate risks of a reduction in the amount of water entering groundwater storage in many parts of the country in some years.

    I. For the whole UK there is an overall increased drying trend in the future, but increased intensity of heavy summer rainfall events.

8. There will likely be increased variation in the climate leading to more frequent extreme weather events such as droughts and floods.

1. The table below provides greater detail about the risk register used, as also shown on the map on page 3.

• None: dry year count x PWS number = 0 • Very Low: dry year count x PWS number = 1-5 • Low: dry year count x PWS number = 6-25	• Moderate: dry year count x PWS number = 26-100 • High: dry year count x PWS number = 101-500 • Very High: dry year count x PWS number = >500

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