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Enhancing drought monitoring and early warning for the UK through stakeholder co-enquiries

Authors: Jamie Hannaford¹,² *, Kevin Collins³, Sophie Haines⁴, Lucy J Barker¹

2. Irish Climate Analysis and Research UnitS (ICARUS), Department of Geography, Maynooth University, Kildare, Ireland
3. Applied Systems Thinking in Practice, School of Engineering and Innovation, The Open University, Milton Keynes, Bedfordshire, UK.
4. Institute for Science, Innovation and Society, Oxford University, Oxford, Oxfordshire, UK

*Corresponding author

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Abstract

Drought is widely written about as a complex, multi-faceted phenomenon, with complexity arising not just from biophysical drivers, but also human understanding and experiences of drought and its impacts. This has led to a proliferation of different drought definitions and indicators, creating a challenge for the design of drought monitoring and early warning (MEW) systems, which are a key component of drought preparedness. Here, we report on social learning workshops conducted in the UK aimed at improving the design and operation of drought MEW systems, as part of a wider international project including parallel events in the USA and Australia. We highlight key themes for MEW design and use: ‘types’ of droughts; indicators and impacts; uncertainty; capacity and decision-making; communications; and governance. We shed light on the complexity of drought through the multiple framings of the problem by different actors, and how this influences their needs for MEW. Our findings suggest that MEW systems need to embrace this complexity and strive for consistent messaging while also tailoring information for a wide range of audiences in terms of the drought characteristics, temporal and spatial scales, and impacts that are important for their particular decision-making processes. We end with recommendations to facilitate this approach.

1. Introduction

Drought hazards are an intrinsic feature of the climate regime of a given location, but the impacts on society and the environment can be mitigated through drought management frameworks. These rely on monitoring and early warning (MEW) systems to track the onset/decay of drought conditions and to quantify drought severity, thus enabling appropriate and timely management actions. Existing MEW systems operate at a range of scales, from catchments and regions through to national and continental scales (e.g. Pulwarty and Sivakumar 2014). MEW systems typically involve the use of drought indicators and indices (WMO and GWP 2016) to monitor the status of rainfall, river flows, groundwater levels and other hydrometeorological variables, relative to historical precedents. Some MEW systems also include forecasting of these indicators over timescales of days to seasons, and beyond. In designing MEW systems, a key consideration is which indicators to use to characterise drought hazard. Drought indicators have proliferated in recent decades. While
distinctions between certain ‘types’ of drought may be readily drawn (e.g. meteorological compared to agricultural), this proliferation is partly due to the absence of a universal definition of drought. However, this may be a meaningless endeavour (Lloyd-Hughes 2014) given the many different sectors impacted and their different definitions, framings and perceptions of drought (e.g. Smathkin and Schipper 2008; Kohl and Knox, 2016).

Bachmair et al. (2016a) surveyed over 40 MEW systems from around the world. They reported an emphasis on hydrometeorological indicators, and generally less consideration of impacts on society or the environment. Recently, there has been a growing effort to validate hydrometeorological indicators using impact information (Bachmair et al. 2016b; Stagge et al. 2015). However, there is little consensus in the literature on what this means for choosing indicators, their translation to impacts and the implications for MEW systems. There is, we argue, also a key role for stakeholders and user input in designing MEW systems. To address this gap, the ‘Drought Impacts: Vulnerability thresholds in monitoring and Early-warning Research (DrIVER)’ project explored MEW systems and drought impacts on three continents (Europe, North America and Australia), combining quantitative analysis of indicators and impacts with learning from stakeholder co-enquiries (Collins et al. 2016). Fundamentally, DrIVER aims to bring these two strands together to make recommendations for enhancing existing and future MEW systems.

In this paper, we report on such an approach applied in the UK, a DrIVER case study country with well-developed drought management systems, but with a very complex interplay of actors involved in drought decision-making and a multi-tiered arrangement of established, operational MEW systems and emerging MEW products. Our findings are based primarily on a stakeholder co-inquiry developed over the course of two workshops and supported by ongoing work on the development and testing of new hydrometeorological indicator and impact datasets, the relationships between them, and prototype MEW tools. We bring this to bear to address the following research questions:

- How do framings of drought and drought management influence MEW practices and needs for a broad range of stakeholders?
- How should the above be used to improve current MEW systems or design new systems to meet multiple user requirements?
This paper is structured as follows. Firstly, we describe the UK context, setting out the current drought management framework and MEW systems. Secondly, we outline the methodology and workshop design. Thirdly, we present outcomes in terms of six key themes. We conclude by setting the findings in the context of MEW design and making recommendations for future development of multi-stakeholder MEW systems.

2. The UK Context: drought management and current MEW systems

The UK is a wet country as a whole, but has experienced a number of major drought episodes in recent years (e.g. Parry et al. 2013). Parts of south-east England are relatively water scarce and vulnerable to multiyear droughts (Folland et al. 2015). Drought is recognised as a key issue (e.g. in the Cabinet Office Risk Register; Cabinet Office 2017), particularly given projections of increased drought severity in future (Watts et al. 2015), although arguably droughts are not part of public consciousness compared to other hazards. Perhaps partly for this reason, there is no UK-wide drought-focused MEW system comparable with, say, the US Drought Monitor. However, the UK has a dense, high-quality hydrometeorological observation network and a number of intersecting MEW efforts (introduced below).

The UK has a very long-established framework for long-term water resources and drought planning and various other governance arrangements including implementation of EU legislation, and there are many key actors and processes involved in drought management (e.g. Robins et al. 2017; Lange and Cook 2015). In England, the Environment Agency (EA) is responsible for managing impacts of drought on people and the environment. The EA produces voluntary Drought Plans, which set out how it will operate and communicate during a drought and what actions will be taken to ensure the environment is protected. Similar arrangements exist in the other countries of the UK (e.g. SEPA 2016) which, for brevity, are not expanded upon here.

In an international context, one of the interesting features of UK water management is the mixed ownership of water utilities. In England, privately owned water utilities have a statutory obligation to produce water resources management plans (WRMPs), setting out long-term strategic investment, and drought plans (DPs), setting out what actions they will take during a drought, typically with reference to various triggers (e.g. reservoir levels) at which a number
of actions can be taken (e.g. communications campaign, temporary use bans, pressure reduction). As an example, Figure 1 shows a reservoir control curve, triggers and a summary of actions. Statute requires that water companies consult the EA (Section 39 B (7) (a) WIA 1991) and Ofwat, the economic regulator (Section 39 B (7) (b) WIA 1991), before they prepare their statutory Drought Plans and Water Resource Management Plans (Sections 37 A (8) (a) and (b) WIA 1991). Parallel planning frameworks exist in Scotland, Wales and Northern Ireland, although water company ownership differs.

[Insert Fig 1 around here]

In addition to these ‘regulatory’ stakeholders, there are a wide range of statutory and non-statutory organisations involved in drought risk management. While agriculture is not as significant a proportion of the UK economy as in some other western societies (e.g. in southern Europe, the US or Australia; see World Bank (2017)) it is a major water user, accounting for some 20% of freshwater abstraction in England and Wales (ONS 2015). Irrigation has major economic benefits and is of particular importance in the drier east of England (Rey et al. 2016). Similarly, the energy sector demand in 2011 for water (for cooling and hydropower) in England and Wales paralleled domestic water consumption (Byers et al. 2014) and together these account for almost 60% of freshwater abstraction while manufacturing accounts for 11% (ONS 2015). These sectors alone cover many thousands of organisations, businesses and stakeholders, each with particular concerns, needs and views about water management and drought preparedness.

The main operational MEW carried out under legal duty is by the EA, Scottish Environment Protection Agency (SEPA), Natural Resources Wales (NRW) and the ‘Department for Infrastructure – Rivers’ in Northern Ireland. Each monitors river flows, groundwater and other variables at key locations through regular reports (e.g. Water Situation Reports, WSRs: www.gov.uk/government/collections/water-situation-reports-for-England). While similar in aim, the reports diverge in their methodology and formats and are not all publicly available. The National Hydrological Monitoring Programme (NHMP: www.nrfc..ceh.ac.uk/nhmp), operated by the Centre for Ecology & Hydrology and British Geological Survey, has provided an accessible, independent monthly UK ‘Hydrological Summary’ since 1988. These organisations have also produced the ‘Hydrological Outlook UK’ (Prudhomme et al. 2017), a monthly operational hydrological seasonal forecasting service, since 2013. In common with
other countries impacts are not systematically collated (Bachmair et al. 2016a), or at least
published, in routine MEW updates via WSRs or the NHMP. The EA do collate impacts
information via incident management processes, and these are referred to in internal
documentation and shared with partners, but not necessarily made publicly available.

While the examples above are the main large-scale UK MEW activities, MEW is also
undertaken on a range of finer scales by a very wide range of stakeholders. Hydrometric data,
including water supply-focused indicators such as reservoir levels and other triggers, are
gathered by water companies and shared in dialogue with regulators, they are not always
publicly available. MEW information is also gathered at the local scale by a wide range of
actors (e.g. farmers monitoring soil moisture; rivers trusts and interest groups monitoring
river levels on a reach scale), and these parties will, naturally, often keenly observe and record
drought impacts that have a direct bearing on their livelihoods and interests. However, these
informal efforts are not co-ordinated or collated centrally.

In summary, there are formal MEW systems which underpin dialogue between key statutory
stakeholders and a wide range of other MEW efforts, but these are not currently well
integrated.

UK drought MEW efforts focus on rainfall, river flows and other hydrological variables.
Generally the focus of the NHMP and WSRs is on absolute values of these variables, or simple,
rank-based methods like percentiles. With the notable exception of Scotland (Gosling 2014),
there are few operational uses of the dedicated drought indicators which are widely used
internationally (e.g. WMO and GWP 2016), such as the Standardized Precipitation Index (SPI).
Recently, several DrIVER studies have explored the use of the SPI and similar indicators in the
UK (see Barker et al. 2016 and Svensson et al. 2017) and these have now formed the basis of
a novel MEW system, the UK Drought Portal (Figure 2; www.eip.ceh.ac.uk/droughts). From
June 2017, monthly updates of the SPI have enabled current conditions to be explored in a
dynamic mapping and time series visualisation environment, offering more scope for user-
deﬁned information than the static online documents currently available via WSRs or the
NHMP. The addition of more indicators to the Portal (representing river flows and
groundwater) is currently in development.

[Insert Fig 2 Around here]
Major changes to water management legislation and practice in the UK are underway (Robins et al. 2017). These include changes to DPs to align them with WRMPs, and adopting stochastic methods to respond to the objective of resilience set out in Section 22 of the 2014 Water Act (Water Act, 2014), and address EA drought planning guidance that strongly encourages water supply companies to plan for droughts worse than those in their historical records (Environment Agency 2015). Other areas of uncertainty include abstraction reform, which has the potential to open up water markets and trading (Wentworth and Mayaud 2017), and legislative changes associated with Brexit (Robins et al. 2017). Thus, drought agendas and practices in the UK are changing at a rapid pace, with limited clarity on indicators and the role of MEW systems in policy and decision-making. Bearing this in mind, and given the diverse interpretations and experiences of drought, DrIVER researchers sought to engage with a range of stakeholders to identify crucial concerns and opportunities for improving UK MEW.

3. Methodology

Our starting point was recognising the messiness (Ackoff 1974) and complexity of drought as an idea and situation that arises from ongoing scientific uncertainty, interdependency and multiple perspectives of diverse stakeholders (Collins and Ison 2009; Lange et al. 2017). On the basis that no single group can proclaim the nature of the problem and its solution, DrIVER researchers in all three case study areas (North Carolina, Adelaide and the UK; see Collins et al. (2016)) were committed to a social learning process alongside other stakeholders. In brief, social learning can be characterised by one or more of the following elements: convergence of goals, criteria and knowledge about the nature of the situation; the co-creation of knowledge, which provides insight into the causes of, and the means required to transform or progress a situation; and concerted action whereby different activities collectively contribute to situation improvement (SLIM 2004). Consistent with social learning, situation improvement is always contextual and defined by those involved in the situation (see Wallis et al. (2013); Foster et al. (2016)). This provides the imperative for the wider involvement of stakeholders in social learning to recognise and work with multiple framings and contexts of drought and MEW, to help develop more systemic and integrated policy and actions.
Conceived as a social learning co-inquiry into drought MEW, the design of the UK research was centred on two UK stakeholder workshops, organised to run in series with one Australian and two US workshops. Collins et al. (2016) describe in more detail the interplay between the international workshops and make comparisons between the outcomes from the three different continental settings. This model enabled researchers from different country teams to participate, ensuring cross-fertilization of ideas regarding event design and content, and to gain key critical insights into European, US and Australian MEW experiences and how these might differ according to environmental/technological factors and also legal/political cultures (Jasanoff 2005).

For efficiency and to minimise stakeholder fatigue, the two UK workshops were co-organised in partnership with other UK drought research projects funded under the UK Drought and Water Scarcity (DWS) Programme, including IMPETUS and Historic Droughts (see acknowledgments in this paper, and for further information see links at the DWS Programme website: http://aboutdrought.info/).

The first workshop (WK1) was attended by over 40 delegates from a range of sectors and professions, including water supply companies, regulators, environmental NGOs, agriculture related organisations, power generation companies, public health agencies and consumer bodies (see Collins et al. 2015). Invited stakeholders were selected and invited building on partnerships being developed through the DrIVER and related droughts projects.

WK1 explored participants’ framings, expectations and needs relating to drought, indicators and MEW systems by combining open discussion in mixed (i.e. mixed professions/sectors) groups of stakeholders, scientific presentations from international partners, and plenary sessions. Using conversation maps (Figure 3), after McKenzie (2005), participants were asked specific, but open questions such as, ‘How do we know we are in a drought?’ designed to trigger discussion from diverse viewpoints rather than presuppose particular MEW expectations and experiences. A second key question – ‘What should the MEW of the future look like?’ – moved the discussion towards actions. The plenary sessions between the conversation mapping activities were facilitated by project researchers and involved reporting the key discussion points by stakeholders followed by collective agreement of ‘meta-themes’, issues and actions (see Collins et al. 2015). The social learning design enabled flow between group work, sifting and categorisation, scientific presentations and plenary discussion; culminating in suggestions for an action plan.
While the social learning design remained consistent, the methods of UK workshop 2 (WK2) were adapted in response to the findings of WK1. A key development was the iteration through a ‘worked example’ of the 2010-2012 drought – a recent event in institutional memory (see Parry et al. 2013). This progressed the specific question of WK1, ‘What should the MEW of the future look like?’ by using the UK Drought Portal as an example of a novel MEW system. The session involved using a mock-up (Figure 4) of a possible future version of the UK Drought Portal to explore potential benefits, garner specific feedback and design input to explore the ‘art of the possible’. Current and planned MEW innovations that could realistically be added to the portal in future were used at key points throughout the event, including: high spatial resolution information; consistent rainfall/river flow/groundwater indicators; use of historical ‘benchmarks’; example forecasts (using real hindcasts from IMPETUS); use of observed impact information (real impacts taken from the European Drought Impact report Inventory (EDII), Stahl et al. (2016)). Key questions for this activity were: ‘What decisions would this new information support?’ and, ‘What would you do differently?’ Subsequent sessions focussed on linking indicators in future MEWs with the types of impacts experienced in various sectors. As with WK1, the event was well attended (with over 30 delegates) but with a deliberately selected group of related sectors: public water supply, agriculture related organisations, and the environment (principally regulators from the EA). This focus enabled further development of mutual understanding and social learning among core project stakeholders, and consideration of how their concerns might interact or diverge during drought events. Unlike WK1, delegates were seated in sector-based groups for all activities, to more closely simulate decision-making discussions and clarify divergences between sector orientations.

4. Results: emerging themes

This section discusses key insights emerging from WK1 and WK2 according to six high-level themes identified by participants. Although the themes are presented separately in the following sub-sections, the boundaries were less distinct in the workshop discussions.
4.1 TYPES OF DROUGHTS

Our results show different actors have different concerns and divergent definitions of the ‘same’ drought event. While keen to avoid endless definitional problems, and recognising conventional distinctions between ‘meteorological’, ‘hydrological’ and ‘agricultural’ droughts, participants in both workshops also wanted MEW systems to accommodate the complexity and multi-faceted nature of droughts and impacts as experienced from their different contexts, at different times. Thus, ‘whisky droughts’ and ‘salmon droughts’ in Scotland, and ‘navigational droughts’ (as defined by the Canal and River Trust) framed stakeholders’ thinking about the properties of droughts likely to impact their operations and thus future MEW design.

Furthermore, WK1 participants highlighted spatial and temporal variability in the occurrence of the hydro-meteorological drought hazard, e.g. short versus multi-annual droughts; and regional contrasts between north-west and south-east England – both of which require regional ‘tailoring’ of MEW information. The WK2 water supply sector participants affirmed this distinction between north-west England, where medium to long range forecasting is potentially useful in the context of rapidly-responding catchments (see also Lopez and Haines 2017) and the south-east where situation monitoring is more useful due to the slow evolution of multi-annual droughts (e.g. Folland et al. 2015).

WK1 and WK2 participants also noted the difference in resilience (spatial and temporal) of water supply systems arising, for example, from different degrees of connectedness and conjunctive use of sources. These factors influence resilience to different types of drought events (Anderton et al. 2015) as some areas will be more vulnerable than others, even within the ‘same’ meteorological drought. WK2 agriculture participants noted also the geographical variation in ‘types’ of agricultural drought stress: for example, types of cropping, (e.g. rain-fed or irrigated) and location in the country (Rey et al. 2016; 2017). The latter distinction reflects water supply/demand balances, the type of drought and impacts depending very much on existing vulnerability and water availability. This explains variations around the country but also through time; Rey et al. (2017) found significant improvements in resilience
to drought over time in eastern England as farmers have adapted and become less vulnerable
to a given deficit.

4.2 INDICATORS AND IMPACTS

The proliferation of indicators in the academic literature was matched by a similarly wide
range of indicators used by participants to ‘know when we are in a drought’. A key concern
across both workshops was the extent to which indicators relate to reality. Although a MEW
system may show very severe (drought) conditions in terms of rainfall, there may not be
drought impacts ‘on the ground’. In WK2, the upper panel on Figure 4 was challenged because
it showed a severe drought in some western areas (based on rainfall and river flows) which
did not agree with local knowledge in terms of impacts experienced. Similar contradictions
between MEW information and ‘on the ground’ perceptions have been reported in the US
(Kohl and Knox, 2016).

In parallel to the differentiation in ‘type’ of droughts experienced across different sectors,
impacts are not linear or uniform in onset, distribution, scale and severity, or predictability.
Farmers could experience impacts ‘overnight’ at planting time, whereas water utilities would
only become concerned over a monthly or seasonal time scale. Participants in WK1 expressed
a need for future MEW systems to recognise and assess the societal and economic costs and
consequences for different ‘types’ of drought events and different ‘severities’ of impacts
(quantified in terms of duration, intensity, return period etc.) arising from variations in
vulnerability. Thus, a given event severity will give rise to different impacts for different
sectors across different spatial and temporal scales according to particular configurations of
social and bio-physical systems. This has been further demonstrated through quantitative
work on indicator-impact relationships for the UK (Bachmair et al. 2016b).

Participants noted that while impacts are often used to define drought, in the UK this is usually
undertaken in hindsight rather than actively monitored and reported publicly. In England,
during drought events the EA monitors and reports impacts internally within weekly ‘Drought
Management Briefings’, but these are not necessarily systematic nor made public as an aid to
decision-making for external stakeholders. Other stakeholders like water companies and
farmers are, clearly, acutely aware of impacts and track them for their own purposes.
Both workshop discussions suggested a need for dynamic impact monitoring in an open and transparent way as, for example, undertaken with the US Drought Impact Reporter (DIR: www.droughtreporter.unl.edu/map/), which was discussed at both workshops as an example of a system for capturing impacts in near-real-time and feeding them into MEW. Currently, the DIR predominantly based on media reports, which often lag the emergence of impacts. Thus, while the DIR holds some promise for dynamic impact monitoring, there are comparatively fewer submissions made by observers and it is not fully incorporated into operational monitoring, although significant progress is being made in this direction (pers comm, Kelly Smith, National Drought Mitigation Centre; see also Lackstrom et al. 2017).

As if all this were not enough, both workshops raised a fundamental question: ‘What are impacts and what are indicators?’ Researchers have differentiated these on the basis of biophysical indicators and tangible (normally negative) social and environmental impacts (e.g. Stahl et al. 2016). This distinction is the basis of the growing trend towards using impacts to ‘ground-truth’ MEW indicators (e.g. Bachmair et al. 2016a, b). However, workshop participants found the distinctions very fuzzy and struggled with determining absolute impacts or indicators (especially in the WK2 exercise of mapping indicators onto specific impacts). For example, for water supply stakeholders their drought ‘impact’ is on supply e.g. in terms of reservoir stocks, which could be considered an indicator by consumers. This reveals the relative nature of impacts and indicators depending on a stakeholder’s ‘position’ in a drought event and their particular framings, concerns and responsibilities. The WK2 water supply participants extended this further by noting the interconnectedness of sectors and impacts. Water supply management actions, such as Drought Orders, can exacerbate environmental impacts and may have knock-on impacts on agriculture, recreation and commercial sectors, which can lead to tensions. This was also reaffirmed by the ‘environmental’ (regulatory) stakeholders who recognised their official remit of decision-making is focussed on impacts in rivers, reservoirs and irrigation, but the impacts of their decisions may be broader, e.g. mental health impacts on the farming community.

While it was nearly universally agreed that determining impacts on the environment is crucial for drought management, it was accepted that the evidence base for ecological impacts is relatively limited, in part because of incomplete understanding of the links between hydrological states and ecological impacts over time, particularly the nature and extent of
ecosystem recovery from drought stress (e.g. Dollar et al. 2013). Workshop participants underscored the importance of ecologically meaningful indicators, and moreover requested an indicator of ecosystem recovery time.

Finally, participants in both workshops highlighted that there is a whole host of ‘untapped’ impact variables, some of which are not yet included in centralised MEW systems, and some of which are not monitored at all. For example, in the UK, regulators routinely conduct a wide range of monitoring activities (e.g. water quality, temperature, biological status) which are relevant for drought early warning, and in England have been used to support a national Drought Surveillance Network (Dollar et al. 2013). Citizen science initiatives offer significant potential to fill gaps, e.g. to record drying of headwaters; currently, these are underexploited in the UK for drought, notwithstanding progress in other areas like water quality (e.g. www.catchmentbasedapproach.org/resources/volunteer-monitoring). Other key sources included Earth Observation (e.g. to track vegetation health; Bachmair et al. 2018), which is a cornerstone of continental scale systems such as the European Drought Observatory, but is not yet built into public UK MEW systems. Agriculture attendees in WK2 stressed that technologically sophisticated, fine-scale monitoring is already undertaken at the farm level, which could be assimilated into a larger-scale MEW system. This could be particularly advantageous for monitoring variables which are currently not well covered by in-situ monitoring networks, e.g. soil moisture, but could also include information of on-farm impacts.

4.3 CAPACITY AND DECISION-MAKING
While keen to improve MEW systems, participants signalled a need for learning about decision-making requirements, and understanding the capacities of stakeholders to respond to MEW information in a range of contexts. Discussions highlighted distinct contrasts, for example between water supply and agriculture. A phrase highlighted in both workshops from the water supply participants was: ‘It’s all about the Drought Plans!’ These legally-required DPs are well resourced, embedded, and clearly set out what water companies will do and when, based on specific triggers. In contrast, there is no WRMP or DP for agriculture – ‘farmers have to just get on with it’. Although good lines of communication exist between
farmers and other sectors (Rey et al. 2017), the agricultural stakeholders in WK1 noted they sometimes feel ‘left to their own devices and have to respond to impacts that are already happening’. Participants observed that water supply sector planning has a 25-year horizon, and while many agricultural businesses engage in long-term planning this is not formalised or statutory (although water companies do consider agricultural abstractions in supply/demand balances in WRMPs and there are increasing efforts to bring agricultural stakeholders into the planning process, e.g. Water Resources East, www.waterresourceeast.com/).

To this end, more dynamic, high resolution MEW tools like the UK Drought Portal were considered useful innovations in delivering local scale information over and above current systems. Even so, within agriculture, major differences were noted in capacities and decision-making processes between different users. In discussing how users would interpret the UK Drought Portal, or other MEW products, alongside many other factors under consideration, it was widely agreed in WK2 that for the agricultural community especially, interpretation and operationalisation by trusted intermediaries would be needed for information to be understood and acted upon. Such intermediaries may include organisations such as the National Farmers Union (NFU), who already collate a range of weather-related services for farmers (www.nfuonline.com/cross-sector/environment/weather/), the Agriculture and Horticulture Development Board (AHDB), and in certain catchments, abstractor groups (see Rey et al. (2017) for discussion on the role played by the latter in communicating with regulators and other stakeholders around drought status).

4.4 UNCERTAINTY: PAST AND FUTURE

This theme recurred throughout: stakeholders all wanted more certainty, but appreciated that decisions are made in complex situations where there is uncertainty/lack of confidence in forecasts (Lopez and Haines 2017) and also significant and increasing uncertainties in using the historical record as a basis for planning in a climate-changing world (e.g. Watts et al. 2015).

Even so, historical benchmarks (or comparisons) were highlighted as useful aspects of any MEW – for stress-testing drought plans (e.g. Watts et al. 2012) and ‘ground-truthing’ indicators against observed impacts. However, some participants also questioned the use of historical droughts: WK2 water supply participants noted the significant changes in supply
systems and therefore resilience, such that a given rainfall accumulation/river flow would not translate into the same historical impacts or severity (see also Bachmair et al. 2016b). Water companies now plan for events more severe than those in the historical record, using a range of simulation approaches to extrapolate beyond past observations (e.g. Anderton et al. 2015; WaterUK 2016). Participants considered how such complexity could be brought into large-scale, national MEW frameworks. Although there were no easy answers, it was noted that highlighting risk could be useful at least for communications and could parallel flood terminology e.g. identifying the ‘reasonable worse case’.

While interpreting past droughts was the source of much uncertainty, forecasting future droughts proved an equally rich topic for discussion at both workshops, especially around the operational utility of seasonal forecasts. Despite advances in skill (e.g. Scaife et al. 2014) and improved accessibility of hydrological forecasts (Prudhomme et al. 2018), it was generally agreed that forecasts are still not readily useable for decision-making by water companies. Water company attendees said they generally use forecasts ‘qualitatively’, for context, rather than as ‘evidence’ to trigger actions.

All workshop participants desired more accurate and less uncertain MEW systems/products and forecasts. Environmental regulators wanted improved confidence in forecasts of drought development, duration and termination. Farmers were satisfied with short-term weekly forecasting, but noted crop decisions are made on conditions of the previous year and months in advance of the potential drought state, owing to contracts arrangements and markets, with limited consideration of the drought outlook for the following year. While seasonal forecasting offers considerable potential in this sector, better MEW and forecasting could influence cropping decisions (e.g. type, location and timing) to reduce risks of drought, inherent uncertainties in forecasting at the seasonal scale and beyond remain a major constraint.

4.5 COMMUNICATION

Participants in WK1 highlighted the key roles of definitions, perceptions, communication processes, and education needs in drought management: MEW systems do not operate in a vacuum where only the hydro-climatic state is important. Following this, participants wanted improved MEW systems to help enable consistent messaging regarding the complexities of
drought. Problems of communication were typified by the 2012 drought continuing during significant summer rainfall and flooding (Parry et al. 2013), but despite the challenges, it was generally felt that communication in that drought-to-flood event was successful.

While WK2 participants noted that new tools such as the UK Drought Portal are useful visually and allow historical and regional comparisons for internal and external communications in a more standardised way, communication is closely linked to trust, which can be a barrier to uptake of new systems and indicators. Issues of trust permeated other discussions around communication: water companies in WK2 also referred to ‘credibility’ in terms of having to be seen to act on issues, such as leakage, to maintain the trust of other stakeholders and the public when issuing drought permits.

The two workshops also made it clear that there is no universal, neutral language of communication which meets everyone’s needs. The word ‘drought’ itself was noted in both workshops as sensitive; there may be very real financial repercussions for commercial sectors, e.g. agriculture where retailers might turn to other suppliers if a drought is expected in certain areas, creating loss of income and uncertainty of supply. An important – but not the only – aspect of this is communicating the skill/confidence of drought forecasts to users.

Finally, visibility of drought impacts was highlighted as a key issue in communications. Environmental impacts are important and recognized by the general public. Workshop participants suggested that if regulatory and water company DPs are successful in mitigating environmental impacts, the expected impacts of drought may not arise or be visible. This suggests that MEW systems based on evidential impacts may not offer a ‘true’ picture of a drought event if the impacts are mitigated or hidden before they can be recorded and communicated, with implications for garnering public support.

4.6 GOVERNANCE

This theme emerged from a complex set of discussions in both workshops. Linked to drought definitions, it became apparent that ‘declaring’ a drought was politically and organisationally sensitive for many reasons including reputation, commercial interests, media interest and public perception and responses. This led to the recognition of fundamental questions about the ownership and governance of MEW systems such as: ‘Who is technically and legally...
responsible for declaring a drought (over) given the differentiation in drought impacts in
different sectors?’ In turn, this prompted questions on ‘ownership’ of drought and MEW
systems, with wide-ranging implications for responsibilities and collective, coordinated
responses. For example, ‘Who is responsible if a drought is ‘declared’ incorrectly?’ and, ‘Who
funds and owns the MEW and who carries the responsibility of interpreting data?’ While there
was no consensus on answers to these questions, participants did note that governance
considerations are a key part of drought preparation and the design of MEWs, especially
where MEW outcomes could potentially be contradictory. Participants in WK2 felt that ‘new’
MEW systems like the UK Drought Portal could be useful as an additional source of evidence
in the governance of drought such as applying for Drought Orders. However, it was recognised
that multiplicity of data and indicators could prove problematic as it opens up the possibility
of challenge based on alternative sources.

This led to further discussion about the nature of drought declaration. While in other
countries drought declaration is formal (e.g. Botterill and Hayes 2012), in the UK, declaring a
drought is informal and more for communication purposes; it does not have any statutory
basis (although authorisation by the Secretary of State of an application for a drought order
under Section 73 of the Water Resources Act 1991 is a de facto drought declaration). An
analogy was drawn with floods which are also not declared as such, but are much more visible.
The relative intangibility of drought, combined with the potentially contentious management
decisions such as abstraction licenses and resource allocation, make drought declaration
particularly politically ‘loaded’. Furthermore, some locations are vulnerable to water shortage
even without drought conditions: water availability (taking account of demand) is the crux,
and needs to be set in the context of abstraction licensing, which participants noted was
challenging enough already (‘How much of the shortfall is due to ‘natural’ drought versus
human use?’ See Van Loon et al. (2016)), even before considering the potential complexities
of future abstraction reform.

5. Discussion and Recommendations
Returning to the aims of this study, the thematic sections above have highlighted the
complexity of drought as an idea, its management, and the implications of this complexity for
MEW design and optimisation. The different framings of potential users lead to divergent
views on what MEW systems are for, how to interact with them, how they should be
operated/governed and by whom, and how they should link with existing regulatory systems.
There were key differences between ‘sectors’ in terms of drought definitions, drought
impacts, institutional capacity and engagement with drought. A notable example is the
comparison between water supply, which has 25-year WRMPs and where impacts can be
slowly evolving, and agriculture, where there is no statutory requirement for long-term
planning for drought, which is just one of many shocks faced by farmers and where impacts
can happen very rapidly.

Similarly, organisations such as water companies and regulators have existing plans
specifically for drought. This means that MEW systems face a barrier to uptake, namely that
any indicators must be translated into the context of existing DPs. This was noted in both
workshops: any ‘novel’ indicators being proposed (e.g. the SPI used by the UK Drought Portal)
need to be related to local scale triggers and impacts. More broadly, this speaks to the divide
between large-scale, centralised regional to national MEW systems (e.g. WSRs, Hydrological
Summaries, UK Drought Portal) and local, operational MEW and drought management carried
out by a wide range of actors (water companies, farmers, etc.). This highlights a ‘translation
imperative’ between centralised MEW systems and local operational needs, which has been
highlighted elsewhere in the literature. MEW indicators can be used to set triggers for action
(e.g. Steinemann et al. 2015; Botterill and Hayes 2012). However, in most large-scale, public
facing MEW systems, outputs are ‘awareness’ indicators for a wide range of stakeholders
rather than triggers for specific sectors. These awareness indicators set the wider context for
stakeholders’ own ‘private’ operational triggers (e.g. reservoir trigger levels). The translation
imperative highlights a need for better understanding of the (dis)connections between
information and decisions, and especially the social and institutional factors influencing the
usability of warnings, forecasts and other information products that are intended to inform
preparedness (e.g. Rayner et al. 2005; Kohl and Knox 2016).

For MEW design, the problem of different definitions/framings/decision-making processes is
arguably insurmountable; the old adage “one cannot please all of the people, all of the time”
holds some sway. National/regional MEW systems need to provide information for a range of
potential users, and rely on ‘translation’ activities and the use of intermediaries (e.g. in linking
to water company DPs or working with farmers, respectively). Who undertakes and owns these translation activities, and how the consistency of messaging is maintained remain important questions. The diversity in MEW users’ requirements underscores a clear need to maintain MEW systems with multiple indicators tailored to particular sectors. Conversely, both workshops highlighted the political need for government ministers and other policymakers to have a simple, single answer to questions such as, ‘How severe is the drought?’ This tension between single ‘composite’ indicators and multiple, tailored indicators has precedent (WMO and GWP 2016; Bachmair et al. 2016a). Composite indicators are widely used internationally, and typically blend a wide range of hydrometeorological indicators into a single indicator, using a range of both quantitative (typically, multivariate statistical approaches e.g. see the review Hao and Singh, 2015) and qualitative techniques to achieve the blending. The most notable example is the US Drought Monitor with categories running from D0 ‘abnormally dry’ to D4 ‘Drought-exceptional’, variants of which are used around the world.

For the UK, from Mawdsley et al. (1993) onwards, and as also discussed in Lloyd-Hughes (2014), there has generally been a tendency to avoid sweeping definitions of drought severity within a single, over-arching indicator in the UK in favour of a more nuanced multi-indicator approach (Mawdsley’s ‘basket of indicators’). A composite indicator is employed by the EA (2017), based not on a single definition of drought, but three broad types (environmental, agricultural and water supply) and a simple, traffic light concept of drought status (normal, developing drought, severe drought, recovering). While this reflects the complex and multi-faceted nature of drought, it also leads to a certain fuzziness – it is not transparent in the outputs what indicators or triggers are used to lead to such status. Similar debates can be recognised in the international literature (e.g. Botterill and Hayes 2012).

As evident in the workshop discussions, droughts and their impacts are diverse and dynamic. Even if a key difficulty of distinguishing indicators from impacts could be resolved, indicators for monitoring need to accommodate and represent this diversity as a drought develops. But current indicators are inadequate in this respect, and skilful seasonal forecasting is in its infancy, at least in practical terms. While all sectors identified the central role of impacts, it is clear that, as with international experience, impacts are not currently a central part of MEW...
systems at a broad scale, and systematic impact data collation is lacking. A further complicating factor is that there is not a one-way path from ‘indicator’, such as rainfall, through to ‘impact’ on society – this chain depends on definitions of what constitutes an indicator or an impact, the mediating role of terrestrial and aquatic ecosystems, and a complex chain of feedbacks. Increasingly, drought is seen from a systems perspective, with humans playing a key role as agents in mitigating or exacerbating a hydrological drought to the extent that a reframing of drought as a socio-hydrological system is underway (e.g. Van Loon et al. 2016; Lange et al. 2017).

Our findings lead us to question whether it is desirable, or even possible, to create a consensus about using indicators: despite very real privations, drought is by its very nature a contestable idea. While it may not seem helpful for everyone to be starting from different points, it is inevitable that multiple framings of drought and its impacts exist and are dependent on the interests and values of the ‘observer’. Our findings in this regard chime with other international research, e.g. the ‘multiple ways of knowing drought’ of Kohl and Knox (2016). Furthermore, as many workshop participants from across sectors made clear, drought is but one of many factors shaping decisions that involve water resources. The degree of flexibility in a MEW system and the extent to which it can include local/sector knowledge is a key design consideration and one which we suggest will be important in determining use and trust in any MEW. Where indicators do not agree, user communities need to rely on discontinuities being communicated openly by trusted sources and intermediaries and incorporating this into, rather than driving, decision-making. A flexible approach that accounts for context differentiation offers a better basis for drought management than a deterministic and singular over-reliance on MEW data and outputs.

We end by synthesising our findings to make the following recommendations for the design of large-scale, multi-stakeholder, multi-sectoral MEW systems in the UK, including consideration of how they interact with extant, finer-scale localised MEW. While we have grounded these recommendations in concrete actions relevant to the UK, we suggest the key principles are of relevance to MEW systems in other international settings.

- A combination of the ‘basket of indicators’ approach, to cater for a wide community of users, alongside some simple composite indicators to provide high-level drought
status for government, policymakers the media and general public. The ‘basket of
indicators’ already exists in current systems, e.g. the Hydrological Summary and WSRs.
Composite indicators are used by the EA, but there is a disconnect between the
‘basket’ approach and the high-level messages. We recommend investigation of
quantitative, multivariate composite indicators such as those used in the US Drought
Monitor and increasingly adopted elsewhere in the world.

- The above combination implies a modular system, with a core based on simple
hydrometeorological indicators that are meaningful for all users, with options to
provide add-on modules/apps with consistent, sector-relevant indicators (for
agriculture, water companies, energy sector, etc.). Technologies like the UK Drought
Portal could prove to be beneficial as the core of this modular system, allowing
seamless, interactive multi-scale visualisation of and access to an agreed set of
indicators. Add-on modules may reside elsewhere but should be integrated or linked.
These must be co-developed by researchers and users; and while the indicators can
be different, consistency and comparability of presentation are crucial.

- The need to accommodate capacity and decision-making needs of users: some users
want technical information (SPI, severities, probabilities); some require high-level
information (answering questions such as, ‘Is the drought getting worse in my
catchment?’). Systems like the UK Drought Portal are well adapted for the former. The
latter may need different modes of presentation (e.g. podcasts, webinars) through
trusted sector-dependent intermediaries – e.g. the NFU or abstractor groups, Rivers
Trusts, catchment partnerships – with capacity-building opportunities.

- Using historical information as benchmarks: such standards are widely understood,
but MEW systems should recognise both non-stationarity and the expectation for
larger events by chance; further work is needed to incorporate information from the
stochastic approaches being used in WRMPs/DPs for planning for droughts beyond
the historical record. Current research on expanding our historical understanding of
hydrological drought through reconstructed streamflow datasets (Smith et al. 2018)
and extensive ensembles of synthetic hydrometeorological data (Giulod et al. 2018)
provide opportunities for improving the historical analogues, and ‘what-if’ or
‘reasonable worst case’ scenarios that may feature in future MEW systems.
Integrating forecasting into MEW: while currently-available weather and hydrological forecasts may not command sufficient confidence among most potential users to provide a basis for high-stakes decision-making, they may be incorporated alongside other sources to inform decision processes, and to facilitate discussions among forecasters, decision-makers and regulators about information needs and risk perceptions. Research is already underway within IMPETUS to explore how to improve forecast performance, relevance and usability given recent advances in hydrological forecasting skill, particularly in some regions/seasons, and forecast accessibility (notably through the Hydrological Outlook UK, see Prudhomme et al. (2017) and references therein)

MEW systems must recognise users are dealing with hydrological variability in the round, from drought to floods, along with a whole host of other stressors.

An impact-focused approach: bringing impacts into public MEW systems where possible. This entails synthesising existing information from routine monitoring (e.g. water quality) and using novel approaches (e.g. citizen science) for variables that are not yet monitored, and highlights a need for informatics solutions to integrate and synthesise information. The DIR and the EDII could provide models, noting however that neither of these are yet fully used operationally; this represents an important avenue for research in the UK and internationally.

Addressing the gap in ecosystem health: there is a particular need for improved understanding of ecological status and recovery, and ecosystem response to droughts, and to bring this understanding into MEW systems. England benefits from a nascent Drought Surveillance Network which provides a way forwards, but there remains a need to better understand the link between hydrological and ecological drought status.

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REFERENCES


Figure 1 Reservoir control curve and trigger levels for Grafham Water, Cambridgeshire, UK. Note that the data and actions presented may change in the future (after Anglian Water, 2014).
Figure 2: The UK Drought Portal showing interactive mapping and time series visualisation functionality. The indicator shown is the 3-month SPI (SPI3), showing the severity of meteorological drought conditions across the UK in summer 2018. The user-defined time series shown is for the catchment (the Thames) selected in south-east England.
Fig 3: Example of two ‘Conversation Maps’ from WK1, used to record participatory break-out group work. Participants thread together conversations from the central ‘trigger’ (each pen colour represents a different participant). The key five points from each group were summarised at the end and reported back in plenary.
Figure 4: Mock-up of a possible future integrated monitoring portal, showing two elements for the 2010-2012 drought. The top panel shows the six month SPI (SPI-6) for Great Britain overlain with the one month Standardized Streamflow Index (SSI-1) and the Standardized Groundwater Index (SGI). It also includes time series plots of these indicators (with historical benchmark events for comparison) and an example drought impact report from the European Drought Impact report Inventory (EDII). The bottom panel shows SPI-3 for East Anglia overlain with the SSI and SGI and shows plots for two SSI series and an SGI series. It also includes a winter (December-February) SPI forecast for
East Anglia (based on real hindcasts) shown in green using the upper/lower bounds and median of the ensemble forecast.