Hurstwood reservoir, spring 2010. ©United Utilities

Drought: Understanding and reducing vulnerability through monitoring and early warning systems

Report of the DrIVER workshop, 17 March 2015, Wallingford, UK

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Suggested Citation:

Collins, K., Hannaford, J., Haines, S., Bachmair, S., Crossman, N., Stephens, L., Svoboda, M. 2015. Drought: understanding and reducing vulnerability through monitoring and early warning systems. Report of the DrIVER workshop, 17 March 2015, Wallingford, UK. DrIVER Project Report.

Acknowledgements

We would like to express our sincere thanks to all the workshop participants, who shared their knowledge and experiences relating to drought and monitoring systems, and their organizations for enabling their participation. We would also like to thank the wider team from CEH for their contribution to the organisation of the day, in particular George Wright and Lucy Barker.

The work presented in this report was developed under the DrIVER project, and was funded by the Natural Environment Research Council and Economic and Social Sciences Research Council. NERC Grant Number NE/L010038/1. Contributions were also made by the Historic Droughts project (NE/L01016X/1) and IMPETUS (NE/L010488/1).

Drought: Understanding and reducing vulnerability through monitoring and early warning systems

1. Introduction

This document reports on the workshop held on 17th March with representatives of various organisations with an interest in drought and monitoring and early warning systems (M&EWs).

The workshop was convened by UK members of the DRIVER research project, funded by the Belmont Forum. The workshop is the first of two workshops planned in the UK. The first workshop aimed to explore existing views and perspectives on droughts and M&EWs. The second workshop, to be held in 2016, is expected to provide an opportunity for development of interactive 'strategy games'.

Several other projects on drought have also recently been funded by the UK Research Councils (RCUK). Researchers from two of these projects (Historic Droughts and IMPETUS) have been collaborating with the DRIVER team to maximise the cross-project learning and limit demands on stakeholder time. A protocol has been drawn up between the projects to ensure confidentiality on sharing and use of data from this workshop and future events between projects.

2. Workshop Aims

The aims of the workshop were developed in collaboration with key sponsors of the DRIVER project and also other RCUK projects and were as follows:

1. Introduce RCUK drought projects
2. Introduce DrIVER and early highlights
3. Engage with stakeholders' experiences, understandings and needs in relation to droughts
4. Identify M&EWs future needs
5. Identify scope of future DrIVER and RCUK research on drought.

The aims were used to inform the design of the workshop.

3. Workshop Design

The workshop was based on a commitment to social learning – that is, learning which arises from interaction between participants. This co-inquiry was to enable participants to contribute their experiences and ideas and concerns in relation to drought and aspects of monitoring and early warning systems as appropriate. In this sense, the researchers were also participants in the co-inquiry – contributing their experiences and ideas, but also learning from the other participants.

4. Organisers and Participants

The workshop was initiated by the DRIVER project (http://www.drought.uni-freiburg.de/) funded by the Belmont Forum (https://igfagcr.org/), bringing together researchers from the Centre for Ecology and Hydrology (UK), Open University (UK), University of Freiburg (Germany), National Drought Mitigation Center (USA) and CSIRO (Australia). All of the DRIVER partners were represented at the workshop. The aim of DrIVER is to share experiences in M&EW across three continents in order to develop improved M&EW systems.

The DRIVER project is collaborating with other RCUK drought projects to help maximise the potential of our combined research. Specifically, the workshop was co-organised with the following projects, with attendees at the workshop from each of the following projects:

- IMPETUS (Improving predictions of drought for user decision-making) – aims to improve monthly to decadal forecasts of UK drought and water scarcity to support user decision making.

- Historic Droughts – an interdisciplinary project which aims to develop a systems-based understanding of the drivers and impacts of drought, and their interactions, through study of historical droughts in the UK from the late 19th Century to present.

- OMPORS (Oxford Martin Programme on Resource Stewardship) project 'The Usability of Forecasts' – an interdisciplinary project, funded by the Oxford Martin School, which brings together social and physical science to address the usability of weather and climate predictions for the management of natural hazards and resources.

Consistent with the workshop aims, potential participants among the stakeholder community were identified through existing networks from current and previous research and recommendations from project partners and advisors.

A mix of researchers, policy-makers and practitioners from key stakeholder groups were represented at the workshop (see Appendix 1).

5. Workshop Method and Agenda

Consistent with a commitment to co-inquiry, the workshop method comprised an introduction to DRIVER and other RCUK drought research projects, and a series of three interactive working sessions interspersed with presentations from expert researchers involved in the DrIVER and RCUK projects.

Participants were seated at five tables of approximately 8 participants, with each consisting of a mix of participants from different sectors and a researcher 'host' from either DrIVER or IMPETUS. Each table worked together during the day, reporting back to the others during the plenary sessions.

The agenda is included in Appendix 2.

The interactive sessions were designed to actively engage participants in an open exploration of drought issues using the systemic technique of conversation maps. Conversation maps have been used by Open University researchers as a systemic device to enable diverse stakeholders to explore their understandings and views about a central theme. Conversation maps comprise two parts: a conversation 'trigger' and participants' responses to

the trigger. Each participant writes their response to the trigger; other responses from participants on the same theme are linked together with a line as the conversation progresses. Each participant uses a different coloured pen. The process continues until all of the participants' responses have been discussed and recorded on the conversation map in the time available.

In Session 1, the conversation trigger was 'How do we know we are in a drought?' and in Session 2, the trigger was 'What should a M&EW system of the future look like?'.

The presentations between each interactive session were designed to provide expert research input into the conversations as part of the co-inquiry. This helped raise new ideas and insights about different aspects of the topic area. Participants were encouraged to critically engage with the presentations based on issues and themes emerging in their conversations. The key themes emerging from the conversations maps were then captured in two plenary sessions.

The final session of the day explored the actions needed relating to the themes emerging from the conversation maps.

It was assumed that the participants had at least some knowledge and experiences of the issues associated with drought, but no prior knowledge or experiences in using systems techniques. Thus, a brief explanation of the technique was given before each task in the working sessions. Researchers from DRIVER acted as the main facilitators throughout the workshop, with researchers from the other RCUK projects acting as table facilitators. The discussions were captured in a number of ways. The conversation maps form a portable record of the debate for participants to use during the day. Key insights and issues were recorded on post-its and then used to identify emerging topic and thematic areas. Researchers also acted as note-takers, during both the interactive sessions and the plenaries to complement the development of themes. The facilitators also used a large mind map to record the final plenary discussion.

The views expressed represent those of the workshop participants based on their knowledge and experiences of drought.

6. Results and Discussion

Interactive Session 1 Conversation maps - How do we know when we are in drought?

Working together in small groups, the workshop participants created five conversation maps (one per group) depicting the main topics of their conversation and the relationships between them. The central trigger – how do we know when we are in drought? – was deliberately designed to allow for multiple perspectives to be explored. The trigger only refers to M&EW implicitly, in a very general way; no particular M&EW 'system' is pre-supposed and the question opens up wider discussion of definition and perception of drought.

The aim of this conversation map was to capture the different perspectives on drought and knowing about drought, to communicate it to others on their table and develop insights. Figure 1 is an example of one of the conversation maps, but all the conversation maps from this session can be found in Appendix 3.

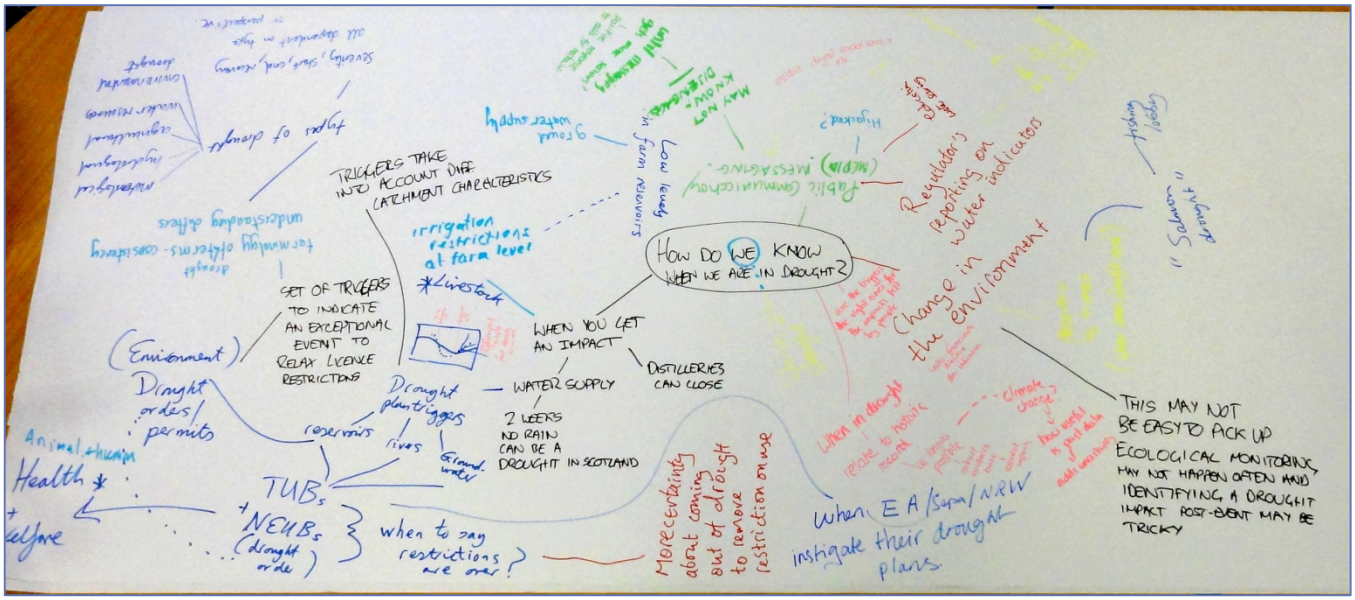


Figure 1 – Example of a Conversation Map: How do we know when we are in drought?

The conversation maps in Session 1 revealed many different facets relating to drought. Each group was asked to identify 5 themes arising from their map that they wished to share with the rest of the meeting. Each group wrote these on Post-its, located on their map. These were collated in a subsequent plenary session

Plenary Session 1 Emerging themes - How do we know when we are in drought?

Towards the end of Session 1, the participants were asked to identify themes emerging from their conversations in the context of drought. In a facilitated plenary discussion, the themes from each group in turn were noted and clustered into a collectively agreed set of emerging themes. Overlaps and similarities were identified. The aim was to develop a set of insights relating to the conversation map trigger and work towards a shared appreciation of the multiple understandings of drought.

Once all the Post-its had been clustered, several 'meta-themes' were assigned in plenary with the agreement of the meeting. An example of the clustered Post-its and meta-theme arising from the discussion is shown in Figure 2.

In Plenary Session 1, 7 main themes emerged as shown in Table 1.

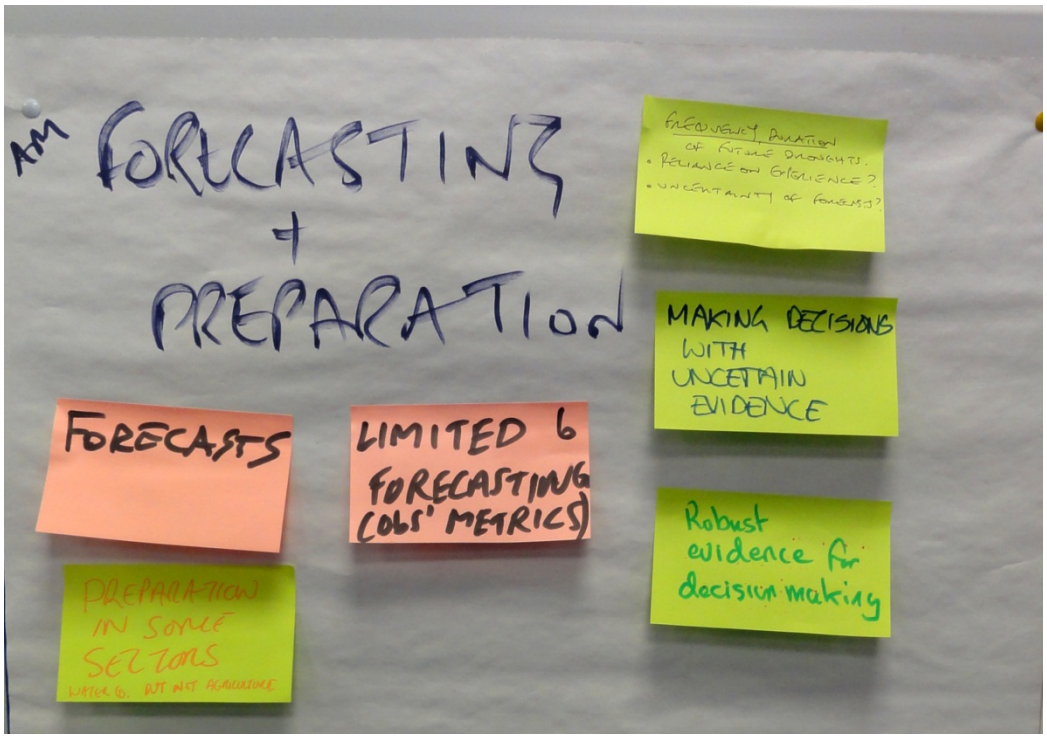


Figure 2 – Example of emerging theme and Post-its from Plenary Session 1

Table 1 – Post-its and emerging themes from Plenary 1

Post it	Post it	Post it	Post it	Post it	Post it	Emerging Theme
Frequency and duration of future droughts. Reliance on evidence? Uncertainty of forecasts?	Forecasts	Preparation in some sectors – water but not agriculture	Making decisions with uncertain evidence	Robust evidence for decision-making	Limited forecasting (obs' metrics)	Forecasting and Preparation
Differences regionally: water systems, re-use; cost, savings…	Type Environmental; public water supply / agriculture	Catchment characteristics are important in WR zone				Types of Drought
Monitoring	Triggers	Supply and use triggers may be different	Monitoring impacts, rainfall (different in different sectors)	Consensus of interested parties based on range of indicators		Indicators ->uncertainty and risk
Impacts on public health are relevant for many agencies	Risk -> impacts: contingent on circumstances (threshold depends on … political, situational etc. and hydrological)	Hindsight determines impacts	Restrictions on water use: - Educating and information before this - Calls for restraint / conservators	Change in Environment: EA triggers? Is it linked?		Impacts

Post it	Post it	Post it	Post it	Post it	Post it	Emerging Theme
Different resilience to droughts within sectors	Planning	Investment	Supply chain resilience / planning			Resilience
Political declaration / response	Politics and communication	Regulations (legal requirement for drought orders; abstractions restrictions; exceptional shortage of rainfall)				Politics (governance)

The themes as represented in Table 1 are a simplified representation of drought from the participants' perspectives and a simplification of complex discussions with several themes cutting across discussions. However, the main comments relating to the themes were noted and summarised below in Table 2.

Table 2 – Summary of comments and discussions in Plenary 1

Theme	Comments in plenary discussion
Types Of Droughts	• Different geographies give rise to differential resilience. For example, catchment characteristics are really important: in Scotland droughts can be 2 weeks; in SE England droughts are longer (years). • Regional differences are not just in the climate and physical landscape characteristics but in the different supply systems (link to resilience point below) and different types of impacts (different costs in parts of southeast England compared to less populated areas) • What are the societal costs and consequences for different return period events? For given event severity, will get different impacts for different sectors.
Indicators > uncertainty and risk	• Droughts are diverse: how do we know what type of drought we are talking about? When we go into a drought is it likely to be a short drought or a long multi-year drought? Is it primarily going to impact agriculture, the environment and so on? This all has a bearing as indicators for monitoring need to be able to help us make this call *during* drought as events evolve. Currently, indicators not well geared up to this. • Is it possible to create a consensus about using indicators? Drought is a contestable idea. It is not helpful when everyone is starting from different points. • Monitoring indicators are already a key part of drought plans – but what exactly to monitor? Who decides we are in a drought on the basis of what indicators? EA/Defra or more widely?
Forecasting and Preparation	• What we communicate as drought is (part of?) preparation => forecasting => instigating drought plan. What is drought and what is preparation? • Planning in the water sector has a 25-year horizon, but there is no 25 year plan for farmers! Farmers often feel left to their own devices and having to respond to impacts that are already happening. Drought is seen by some as a slow-onset event, but for farmers it can become a problem overnight.

Theme	Comments in plenary discussion
	• What is the commercial utility of longer term forecasts? Gap between user needs and reality of forecast skill. "We need a five year forecast" – but how reliable will such long-range forecasts be? • What role or implications for regulation. Is the licensing system inflexible? • There are limits to how much experience can help you – we need to get used to working under uncertainty as the 'past is not reliable' (in a non-stationary world) and 'forecasts are not reliable' (given current skill levels). How to make robust decisions under uncertainty? • Considerations of accountability under uncertainty – who is responsible/blamed for the results of declarations and decisions?
Impacts	• Public health impacts of drought cross many sectors, for example, agriculture and electricity generation. What are the health impacts on farmers, how do people feel when they lose access to utilities? • For a given event, impacts vary for different sectors e.g. agriculture, water supply sector etc. The link between indicator and impacts is not always clear. • Agriculture often feels the presence of drought first in problems with crops. How does this differ to others in other sectors and regulators? • Impacts are often used to define drought but this is normally done in hindsight, rather than impacts being actively monitored • Thresholds might be more useful? But they depend on risk, impacts and circumstances (e.g. timings and events- as was the case during the 2012 Olympics when drought was a concern). Politics really is a key factor in managing droughts. • Environmental impacts are important and recognized by people. Environment Agency (and other organisations') drought plans are mitigating environmental impacts, but are certain impacts more visible for the public to recognize drought (e.g. fish rescues)? If the EA and others are doing their job and drought impacts are mitigated then the drought events might not be visible. • There is an expectation of a short-term impact of 'drought' as an 'event'. It is defined as an exception, i.e. not the norm (rather than being interpreted as trend or step change in climate). How (and who) defines what is 'normal'? • There is the crucial difficulty of separating natural vs anthropogenic; drought vs water scarcity. What is the effect of 'drought' itself and what is the effect of management/anthropogenic exacerbation?
Public Communication & Education	• 'We know we are in drought because we see it on the TV'. Agencies don't just rely on quantitative indicators but on media and social media – it's not just about the declaration based on indicators and impacts, but on media discourse. • Some participants saw a need for more co-ordination and consistency in media coverage. Media hype can be unhelpful: there should be more/better education. • The word 'drought' itself was noted as sensitive – there are repercussions for commercial sectors, e.g. agriculture where retailers might turn to external and other suppliers if they are told that a drought is expected in certain areas or uncertainty of supply. • Drought is a physical phenomenon and also political. Do impacts drive political will and declaration of drought? This returns to the above point about the political constitution of drought as a state of exception (see under 'impacts' and under 'politics (governance)'. • Effective communication between stakeholders is critical; perception and co-ordination (consistency of messaging). It might be useful to consider how to communicate 'preparation in case of drought' to avoid hype/panic. Should we be talking about 'drought plans' or more holistically about 'management of water'?

Theme	Comments in plenary discussion
	• For the public, "once there are restrictions there is a drought". i.e. to some, Temporary Use Bans (TUBs, i.e. hosepipe bans) equates to drought. But is that too late? Could more education and different ways of communicating lead to more acceptance of preventative/advance measures? • It's not just about hard data – but visibility (e.g. reservoir levels in parts of south Wales that are widely visible and become seen as a prime indicator by the media. Role of perceptions is important in drought.
Politics (Governance)	• Who monitors and who declares drought, and when? Legal concerns are evident: what does 'exceptional deficiency of rainfall' mean? This is quite a vague conception which has impacts on observations and indicators. • What pressures/inputs are influential? Can e.g. the NFU call on government/companies to respond? • Does it matter how visible the impacts are?
Resilience	• Who feels the pressure of rain (or lack of)? For the public, sometimes a lack of rain is seen as a positive… • Who is going to invest in different strategies: when and how might a farmer decide to build her own reservoir? Tackling these issues needs to involve supply chains and businesses, not just individual irrigators.

Presentations 1 International perspectives on droughts and M&EW

Following Plenary 1, DRIVER researchers gave two presentations on aspects of droughts as follows:

- USA experiences (Mark Svoboda, National Drought Mitigation Center, USA)
- Australia experiences (Neville Crossman, CSIRO, Australia).

The aim of the presentations was to showcase experiences elsewhere on drought and to help participants in the co-inquiry by sharing examples, raising ideas and insights from the point of view of the DrIVER researchers presenting.

The presentations can all be downloaded at:
https://www.drought.uni-freiburg.de/Publications/PresentationsUKworkshop

Neville Crossman presented on issues of drought and drought policy in Australia. He demonstrated the high variability in Australian climate, in particular the highly spatially and temporally variable nature of rainfall. In recent years Australia has gone through a number of water management reforms to make Australia more resilient to drought. Water has been recognised as an asset and is now traded through markets (in the Murray Darling Basin). A cap on extractions has been implemented by law to introduce a scarcity value and to ensure the environment receives a share of water. The 1999-2010 Millennium Drought hit south-eastern Australia, with the lowest inflows on record. There were major ecosystem impacts, exacerbated by over-extraction for irrigation. Water reform and water markets allowed irrigators to trade water at high prices, saving many irrigators from financial ruin. Water trade provide options for irrigators during drought:

- Valuable water licenses motivated efficiency and/or other behaviours
- Sell permanent water licenses – high price; retire from irrigation
- Sell temporary water – income for supplementary feed; other farm costs
- Buy water – keep alive permanent plantings.

While the Millennium Drought was broken by 2 major floods (2011 and 2012), the past 2 years have seen a return to drought conditions in a number of parts of south-east Australia. The current drought policy in Australia provides Farm Household Assistance (delivered through welfare agencies) and concessional loans packages, but only to farmers who take a risk management approach to their farm business by demonstrating diversification strategies.

Mark Svoboda presented on drought monitoring activities taking place at the National Drought Mitigation Center (NDMC) with regards to drought early warning in the context of drought risk management planning. A suite of tools were introduced that address monitoring and planning at all scales, from local to national. The U.S. Drought Monitor (USDM) (http://droughtmonitor.unl.edu) (Fig. 3) was launched in 1999 and serves as the United States' "state-of-the-science" for monitoring drought severity and spatial extent. This composite indicator (first of its kind drought hybrid) blends dozens of objective, scientific indicators along with drought impacts and feedback with over 360 local experts across the 50 states and Puerto Rico. In addition to becoming the "go-to" source for the media and public, it has major national policy ramifications and is used to trigger several state and federal response efforts via the Farm Bill, Internal Revenue Service, National Weather Service and several others.

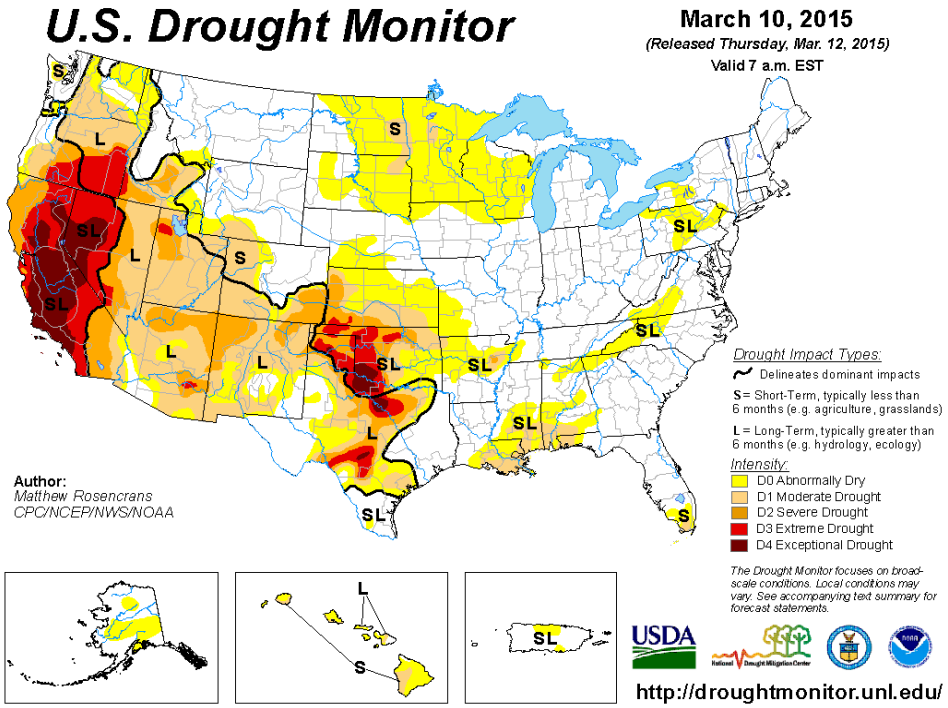


Figure 3 – Screenshot of US Drought Monitor

In addition, the history and goals of the U.S. National Integrated Drought Information System (NIDIS) (http://drought.gov) was discussed with an emphasis placed on the development of "useful", value-added information for decision makers in the United States. The monitoring and collection of key drought indicators along with forecasts are needed in a timely fashion and in a form that is usable and meets the variable needs of various regions and states (Fig. 4).

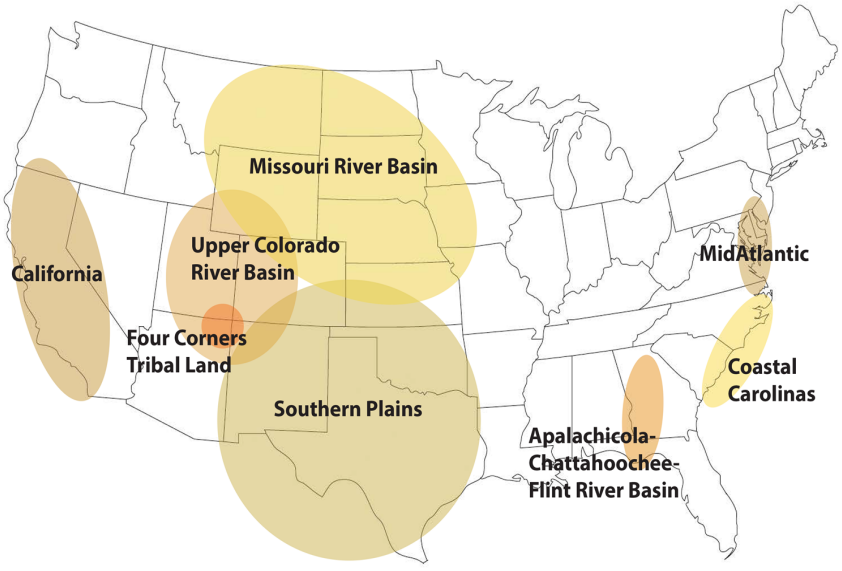


Figure 4 – NIDIS key drought indicators and forecasts

Other tools presented included the Drought Impact Reporter (DIR) (http://droughtreporter.unled) and the Drought Risk Atlas (DRA) (http://droughtatlas.unl.edu). Establishing a consistent and sustainable baseline of impact monitoring and collection is a real challenge. Understanding how we are impacted by droughts helps to identify our risk with the goal being to reduce such risk during the onset of a drought or during future events. Impact data can also be used to "ground truth" indices and models as well as remotely sensed products. The DIR database, developed and housed at the NDMC (beginning in 2005) has captured nearly 30,000 reports and over 20,000 impacts to date. The DRA was launched in 2014 and contains just over 3,000 high quality, long-term stations. Five drought indices were calculated from these stations with a goal of answering questions with regards to historical drought frequency/return periods, duration, trends, magnitude and spatial extent.

In summary, monitoring is one of the most foundational pillars of risk management planning as this activity helps inform and trigger decision making. As such, several key points were made:

- Just as there is no single definition of drought, there is no single indicator/index that does it all for all sectors and users;
- Impact collection must be an integral part of any DEWIS as all droughts are "local";
- Decision support tool development must include the users up front in the process;
- Dissemination is needed through a variety of mediums and educational materials in order to reach a variety of audiences.

The Q & A following the presentations raised some further points about how political and regulatory systems work in different national contexts, for example discussions of legislation for 'critical human need' in Australia, the recent introduction of groundwater regulations in California, the implications of growing populations, the roles and interactions of local indicators, local powers to declare droughts (e.g. via US state governors), and fiscal resources to respond. The relationship between policy and science was discussed (in terms of the aim to put science before policy rather than vice versa); it was also suggested that perhaps there should be a 'water monitor' for managed systems (vs a drought monitor for unmanaged systems). The Australian example also provoked discussion of markets: if farmers sell all their water rights the associated infrastructure (state assets) will be obsolete/stranded. Currently the price is low and the market is operating more freely – there is less

anxiety about drought. Historical connections and separations of water and land in terms of rights and markets also appear to be important.

Interactive Session 2 Conversation maps: What should monitoring and early warning in the UK look like in future?

Having explored the more general aspects of drought in the first conversation maps and plenary and noted some of the issues in the presentations, the second interactive session used the conversation map technique to elicit thinking about M&EWs in particular and potential future demands and drivers for M&EW. This central trigger – **What should monitoring and early warning in the UK look like in future?** – was deliberately designed to allow a more focussed discussion on M&EWs.

Figure 5 is an example of one of the Conversation Maps, but all the conversation maps from this session can be found in Appendix 4.

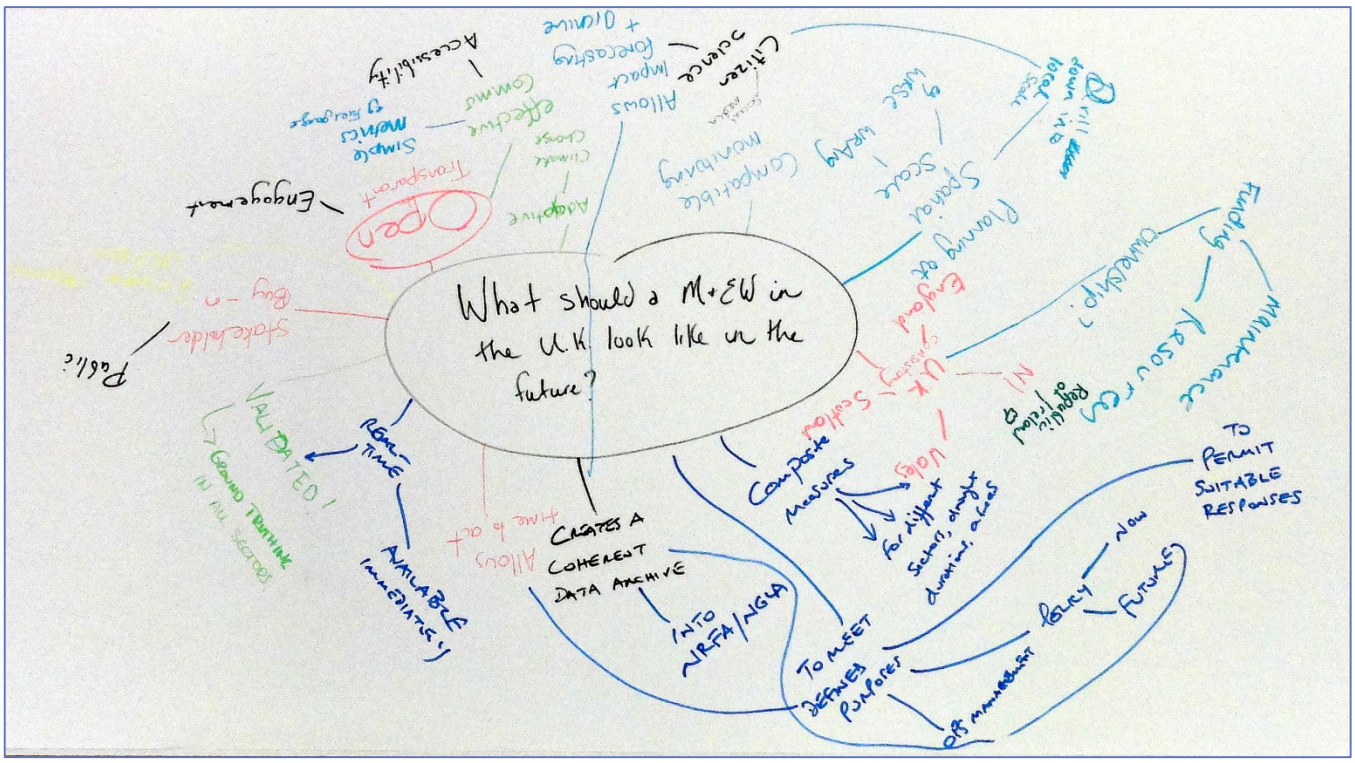


Figure 5 – Example of a Conversation Map: What should a M&EW system in the UK look like in the future?

As with the previous conversation mapping, towards the end of this session, each table was asked to identify up to 5 key points emerging from their conversation map. These were written on Post-its and then discussed in the plenary.

Plenary Session 2 Emerging themes – What should a M&EW system in the UK look like in the future?

The Post-its developed by the tables and assigned to an existing or new emerging theme are shown in Table 3.

Table 3 – Post-its and themes from Plenary 2

Existing and Emerging Theme	Post it	Post it	Post it	Post it	Post it	Post it	Post it	Post it	Post it
Forecasting and Preparation	Weather forecasts > catchment parameters in context of recent history	Data – need data to deliver M&EW	Business – tool for forecasting licensing restrictions	Agriculture plans 6-8 months ahead when ordering feed, preparations, contracts etc. Would be good to know if we are going to have a drought!	Should reflect what has worked well elsewhere*	Accountability for risk and uncertainty*			
Types of Drought	What kind of drought are we heading into - > using several indicators to give us information on the type of drought we are noticing (duration, severity etc.)	Type of drought: • Rainfall • Groundwater • Whisky!							
Indicators > uncertainty and risk	Uncertainty - Better understanding leading to reduction in uncertainty	More robust (spatial/ temporal/ accurate) forecasts	Non-stationarity – you won't be able to use the past to predict the future	Better monitoring – cheaper technology and better spatial resolution	Should reflect what has worked well elsewhere*	Accountability for risk and uncertainty*	More sophisticated health monitoring systems	Recovery triggers (more robust)	Tailored composite measures, to meet defined purposes and to trigger right actions: - policy (strategic) - action / responses (strategic)

Existing and Emerging Theme	Post it	Post it	Post it	Post it	Post it	Post it	Post it	Post it	Post it
Impacts	Include vulnerable locations / communities in risk registers	A layered map you can drill into	Identification of impacts (different sectors) on UK catchment scales	Relevance to water users (impacts)					
Resilience	Capturing response adaptation of different sectors to drought indicators – ability to manage								
Politics (governance)	Allow for spatial scale. UK wide buy-in? Who owns it? Resources/ finance? Need a local level for water users	Co-ordinated public private / government part? Devolved administratio ns							
Stakeholder Buy-in**	Institutional Response Capacity / Demand side	Should provide the 'experience' Guidance Framework Stakeholder buy-in							

* These two Post-its were placed across 'Forecasting and Preparation' and 'Indicators > uncertainty and risk' themes

** The stakeholder buy-in theme was identified as being important during the plenary.

Comments during the plenary discussion raised a number of points concerning M&EW systems in the future. These are summarised below in Table 4, according to the main theme for convenience. However, participants noted overlaps and blurring of boundaries between the themes, and the following table should be read as a 'whole' in order to understand the collective concerns.

Table 4 – Comments on the M&EW systems in the future raised in Plenary 2

Theme	Comments in plenary discussion
Types Of Droughts	• It is important to determine what kind of drought is being warned for: are we talking just about rainfall? Or has the drought become a groundwater situation? It also depends on location. In Scotland we can think of 'salmon droughts' and 'whisky droughts' (e.g. summer 2012) based on how different droughts impact these sectors in different ways: to what extent can the information be tailored to potential users?
Indicators> uncertainty and risk	• Needs to be a focus on reducing uncertainty and how to better handle uncertainty. Uncertainty in forecasts clearly is a major constraint; but also links to communications, with the prime example being the issue of 'forecast bust', i.e. when things go very wrong, e.g. seasonal forecasts of the 'BBQ summer' of 2009 (a notoriously wet summer in the event) • Can increasing availability of cheap monitoring devices be exploited to feed into indicators? • Real-time information is needed which is open access too. Join up all these tools and have for example e.g. real time reservoir levels. • It would be helpful to have graduated systems to monitor the changes as a drought approaches, also need for exploring recovery triggers: when does the drought finish and what happens then? How do we know we are coming out of a drought? 2012 showed the importance of this, and the issues around messaging. Termination criteria are needed. • Need some sort of composite indicator; relevant for both short-term responses/actions; and also long-term policy. This may require linking short term drought plans with long term water resource planning • Generic versus targeted communications; generic messages for all compared to targeted bespoke responses for particular sectors • Indicators need to be linked to impacts. Can we have the same hydrological measure, but that in some way is calibrated to link with impacts in different sectors? • Can we establish indicators relating to health surveillance? • Use indicators that have worked well elsewhere and been linked to impacts – don't reinvent the wheel • How far ahead do we want to look? Irrigators planning 6months ahead; actions for this spring planned last autumn! • A system should be able to give an indication of whether we are in a short term event or a long one; what is the likelihood that it will end, or carry on and if so how long will it last?

Theme	Comments in plenary discussion
Forecasting and Preparation	• There is a need for more robust and accurate spatial and temporal forecasting that is run through hydrological models (It was noted by researchers that this is already being attempted by the Hydrological Outlook) • Weather forecasting and monitoring – needs to be linked up to provide tools to farmers e.g. when are licensing restrictions likely. Being able to forecast when a drought order would come in would be helpful (what would be the implications of this?) • Provide web-based information on droughts including forecasts • Forecasting and cultural change: education needed on what forecasting is and the attendant uncertainties. Also knowledge of the water cycle (lack of knowledge of where water comes from and the cycle of water). • Who is accountable for 'wrong' information? • Themes of uncertainty, forecasting and communication cut across this discussion and those of the first session.
Impacts (Vulnerabilities)	• Hydrological and meteorological characterisation of drought is all well and good but we lack that knowledge of sensitivity to impacts. Observed impacts are key to understanding baseline vulnerability • Mapping of vulnerable locations is required e.g. our reliance on electricity and infrastructure • Public Health is also a key area of impact that needs to be improved. • Spatial scale; local is important too, as well as regional and national M&EW; we need the ability to go to the local scale in assessing vulnerability (as with floods!) Compatibility across spatial and timescales required • Vulnerability should be layered with other factors to create risk maps that one could 'drill into' for more detailed information: a hazard map with vulnerability – to help us understand the hazard
Public Communication & Education	• Education needs to incorporate cultural aspects of communication for example in reference to the impact of hot weather – there is an assumption for many that this is a 'good' thing rather than a potential problem. There needs to be more understanding of the hydrological cycle communicated, rather than just 'what a scorcher!' • Educational interpretation is also required – this is not just about putting information out there
Politics (Governance)	• Governance issues raised included questions about who would 'own' such a system (i.e. of monitoring and early warning info). Who pays for it? • What is the institutional capacity of the user to incorporate all of this information; can a user respond? • A system that covered all the things listed above would require co-ordination of many different systems: public/private, devolved administrations: lots of political work needed.

Theme	Comments in plenary discussion
	• 'Can we have it now?' was asked in relation to the question of feasibility. How far in advance is the information needed? Farmers' decisions on crops etc. needed to be made 6 months in advance of the potential drought state, owing to how the contracts are set up. • Questions were raised around co-ordination; what is public and what is private. How to links all these things together and ensure we have consistency?
Resilience	• Possibility of using historical analogues is more difficult given different contexts and uncertainty under climate change – non-stationarity can mean problems for using historical data for future planning. • How can we be resilient to future climates? How can we 'capture' adaptation? Some sectors may be more able to respond.
Stakeholder buy-in	• Potential use of social media for reporting impacts (as part of citizen science?) in real-time. • A successful system would have to have 'stakeholder buy-in' – this would rely on effective communications. An example from the US uses social media for alerts and for citizen science (getting information as well as giving).

Presentations 2: M&EW in the UK: What's on the horizon?

Following Plenary 2, researchers gave three presentations on different aspects of drought and developments in M&EW systems as follows:

- Current and future developments in UK national M&EW (Jamie Hannaford, Centre for Ecology and Hydrology)
- From indicators to impacts: early findings from the DrIVER project (Sophie Bachmair, U. Freiburg)
- Future developments in drought forecasting from the IMPETUS project (Liz Stephens, U. Reading).

As before, both presenters and audience were asked to consider the presentations in the lights of discussions so far.

Jamie Hannaford presented an overview of current systems for M&EW and potential future avenues in development at CEH. He first reviewed the current national-scale systems (the Hydrological Summaries and Hydrological Outlooks), also acknowledging other tools such as the EA's water situation report. He noted however that these are not drought-focused and none use drought indicators such as the Standardized Precipitation Index (SPI). He then introduced the UK Drought Portal being developed by CEH. This is a tool for visualising maps and time series of the SPI for the UK, which was demonstrated during the lunchtime at the workshop. At present this is a data exploration tool, but he argued that this kind of web mapping environment could form the basis of a higher-resolution M&EW system in future. The Drought Portal is due for release in late spring, just featuring the SPI. By the end of the year it will also have other drought indicators applied to different variables (evapotranspiration, river flows) but also based on the SPI concept. It is hoped that, if data uptake can be streamlined, it could be serving monthly updates – a big step towards a M&EW system – perhaps by early

2016. Jamie then went on to say that this could be joined up with further developments, e.g. the COSMOS soil moisture observations, earth observation data. However, the big question is: how useful is this for end-users? What would users like to see in a portal? He invited participants to comment on the portal after release, and hoped there could be dialogue on future evolution of the portal through this DrIVER stakeholder forum.

Sophie Bachmair presented results from the early phase of the DrIVER project looking at the feasibility of evaluating commonly used drought indicators with drought impacts. For this purpose text-based information on drought impacts was extracted from the US Drought Impact Reporter (US DIR) and the European Drought Impact report Inventory (EDII). The linkage between drought indicators and impacts was assessed via correlation analysis and extraction of indicator values concurrent with past impact onset. An important finding was that different regions and sectors/drought affected systems show different "best" indicators and thresholds for impact occurrence. Text-based impact data thus has strong potential for "ground truthing" drought indicators.

Liz Stephens presented an overview of the IMPETUS (Improving Predictions of Drought for User Decision Making) project, led by Len Shaffrey at the University of Reading, which kicked off in late 2014. IMPETUS is a project that aims to improve the forecasting of UK drought on monthly to decadal timescales. Liz described how the first work package of the project is designed to assess stakeholder needs and co-produce decision-relevant drought metrics, therefore feeding into the later work packages. Work Packages 2-4 cover the evaluation of meteorological forecasts, evaluation of land surface and hydrological models and development of water demand forecasts respectively. The outcomes from these three work packages will feed into Work Package 5 on combining meteorological, land surface, hydrological and water demand forecasts into decision-relevant drought forecasts; the example image shown was a map of the change in probability of hosepipe ban implementation relative to a baseline. The IMPETUS project team are interested in hearing from any stakeholders interested in drought forecasting, they would like input on how the science from the project should be reported, both in terms of the format of reports and the drought metrics that are of interest to different user groups. More broadly, Liz and Sophie Haines are interested in hearing responses to the question: what needs to change in order for drought forecasts to be useable?

Plenary Session 3 Actions

The final session of the workshop was an open plenary on actions needed to progress some of the issues and concerns raised during the preceding sessions, discussions and activities. The discussion was recorded on a mind map by one of the facilitators and is shown in Figure 6.

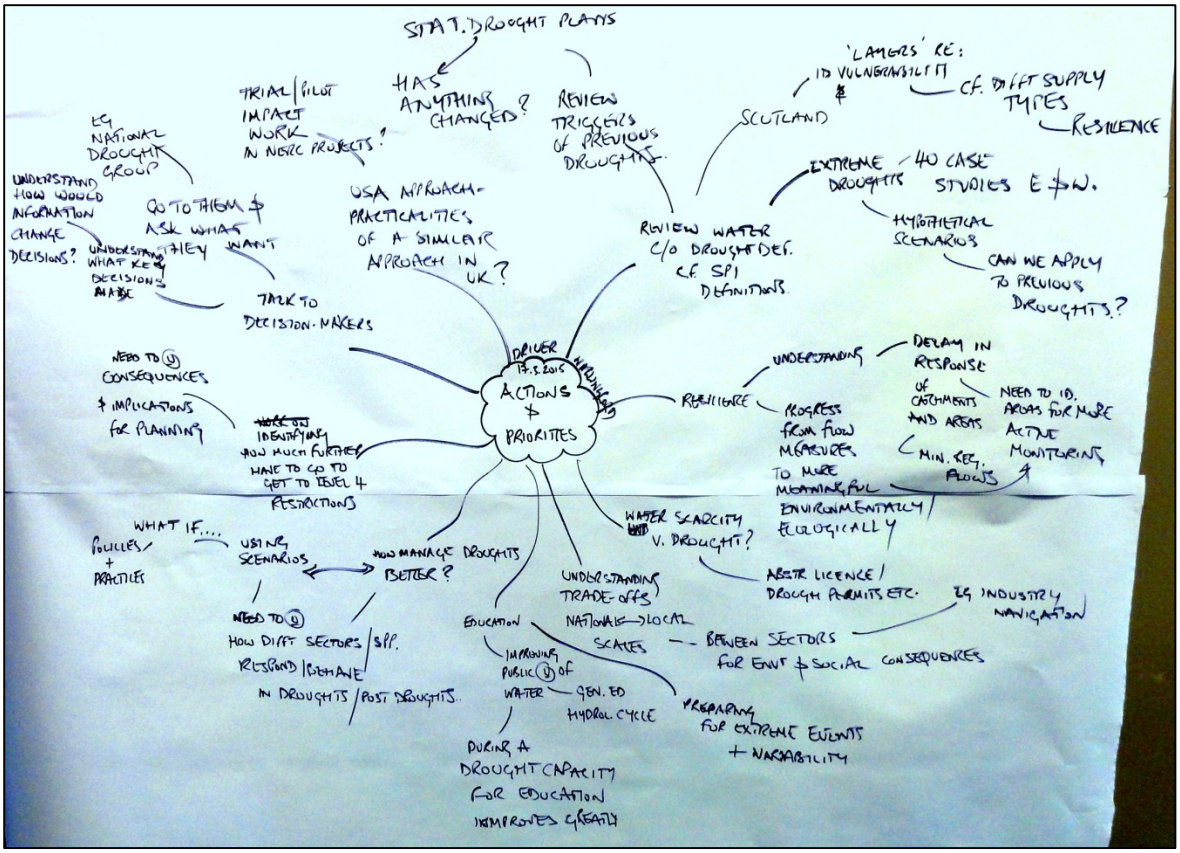


Figure 6 – Actions and priorities for M&EW systems

A number of key points emerged during this discussion and are summarised as follows:

- Drought Plans
  - A priority action could be to review water company drought plans in the context of proposed new indicators (e.g. SPI): can these be related to existing triggers/thresholds? Has anything changed based on / as a result of previous drought events? How are triggers for levels of service/return periods reviewed?
  - In Scotland for example, there are layers of vulnerability. Can these be compared to different supply types and some sense of resilience?

- Resilience:
  - A key question to ask could be: what leads to resilience? The EA/Defra/UKWIR project 'Extreme droughts' (ref: Ledbetter et al. 2015?) is looking into this with a review of 40 water supply systems in England and Wales. But can this also inform M&EW in that it can identify factors that increase resilience or cause vulnerability: can M&EWs be tuned to accommodate these differences?
  - Scenarios – can these be used to test systems (building on the past EA/Defra long droughts work, 2009/10; Watts et al. 2012) How resilient are environments? Identify areas that need more active monitoring (in some areas and catchments there may be delayed responses).
  - Progress from flow measures to measures that are more meaningful environmentally/ecologically. The UK is very advanced on ecological measures, but not all linked up with drought.

- Water Scarcity / Drought
    - What are the impacts of abstraction reform? To what extent is scarcity due to drought vs over-extraction? More information is needed to understand the impact of mitigation measures on drought development.

- Trade-offs
    - Need to increase understanding of trade-offs at national through to local scales and between sectors for environmental and social consequences. What are acceptable trade-offs between industry and navigation sectors?

- Education
    - Need to improve public understanding of water and general education about the hydrological cycle. During a drought capacity for education improves greatly! Here there is a link with the RCUK project 'DRY' (drought and you) which is looking at communication/education, and also Historic Droughts, particularly the work being undertaken by linguists at Lancaster and Exeter who are looking at media communication of drought, and behavioural responses respectively.
    - Education also important for preparing for extreme events and variability.

- Managing droughts
    - How can we manage droughts better? Use 'What-if' scenarios to explore policies and practices. Scenarios as a tool for investigating "what-ifs" in management; especially for fairly extreme scenarios that test to the limits. Need to understand how different sectors and species respond / behave in droughts and post-droughts.
    - Can we use scenarios to work through to 'end game?' One way of doing this might be strategy games/simulations; this links into conversations about education and communication
    - Explore forecasting abilities, trigger understandings of how we might do things differently (e.g. in terms of adaptation and management), with a view to changing policies (e.g. examining different policy/management scenarios as well as drought scenarios). There may be different trigger points depending on drought intensity.

- Restrictions
    - Need to identify how much further (and likelihood) to go until we get to Level 4 restrictions (in water company Drought Plans). What are the consequences and implications for planning (link to strategy games)? What are the worst case scenarios (Level 4!); and how to avoid them? Need to understand consequences and implications for planning.
    - How much worse than history does it have to be, and what has changed? How to go beyond reliance on the historical record? Work is being done on this at the EA about the potential for merging drought and water management plans, and changing the requirement to plan on the historical record (also cf. the RCUK project MARIUS advocating a risk-based approach to drought management: http://www.mariusdroughtproject.org/).
    - What are the consequences of 1 in 200/300/400 year droughts: where is there a 'step-up' in impacts? For London, the step up at (current) level 4 has huge cost implications.

- Decision-makers and decision-making
    - Talk to decision-makers and understand what decisions are being made and how information would change this. The point was made that sometimes more information can lead to bad decisions!
    - Who owns the systems? Who are the decision-makers? Technical people? Cabinet office? National drought group? What role for the Natural Hazards Partnership? To find out what information will influence decision making, we need to find out what decisions are being made and which ones are

flexible, by asking people what they do and how information could change this ('what could you do if..?'), rather than what information they want.

- Learning from others
    - What can we learn from the USA? What are practicalities of a similar approach in the UK? Can we trial / pilot impact work in the NERC projects?

The workshop ended at 1600.

7. Concluding Points

The workshop was designed as a co-inquiry into aspects of drought and M&EWs involving researchers, policy-makers and practitioners. Overall, feedback from participants suggests the workshop was successful in meeting its aims.

The workshop content suggests different ways of thinking and acting are required about drought and M&EWs in particular. The discussions and presentations also suggest the complexity of droughts requires a more systemic understanding of drought policy, processes and practices in order to determine the role of M&EWs and how these can be improved by linking indicators and impacts. In particular, the DRIVER research team noted the following key points.

- Be aware of different contexts and the ways droughts are experienced in different sectors at different times. This includes the well-known spatial and temporal variability in the hydro-climatic drought hazard (e.g. short vs multi-annual droughts; regional contrasts between north-west and the English Lowlands. But also 'Types of droughts': recognising not just the classic 'meteorological-hydrological-agricultural' distinction but also their different manifestation in different sectors (including whisky droughts and salmon droughts!)
- Following on from this, recognise and assess the societal costs and consequences for different types of events and different 'severities' (in terms of duration, intensity, Return Period, etc.) thus the different impacts for a given event severity will lead to different impacts for different sectors. Can we refine existing hydrological measures to allow calibration of impacts in different sectors?
- Identify factors that increase resilience or cause vulnerability in different contexts (both in different sectors and different geographies) and tune M&EWs to accommodate these differences.
- Recognise that Impacts are often used to define drought but usually in hindsight rather than impacts being actively monitored; a key area where perhaps the UK can learn from other countries (e.g. in the US where impact monitoring is an integral part of M&EW)
- Understand decision-making requirements and processes, and the capacities to respond to M&EW information, again from a range of different contexts. (Contrasting for example water resources, with statutory drought planning and long timescale impacts, with agriculture where impacts can happen early and rapidly, and there is no formal drought plan).
- Acknowledge the overlap in stakeholder discussions of M&EW and forecasting: both are relevant to decision-making and preparation for drought/water management and may not always be thought of as separate processes, types of information.
- Appreciate that decisions are being made in a complex environment where there is high uncertainty in forecasts, but similarly big uncertainties in using the historic record as a basis for planning in a changing world.

- Develop indicators which are meaningful environmentally/ecologically to improve the links to drought
- Understand the impact of mitigation measures on drought development
- Develop scenarios to understand how different sectors and species respond / behave in droughts and post-droughts
- Understand the key role of definitions, perception, communication, education in drought management and early warning; M&EW systems do not operate in a vacuum where only the hydro-climatic state is important.
- Following this, can improved M&EW systems help enable consistent messaging and communication regarding the complex phenomenon that is drought?
- In addition recognize the political and governance aspects too; this is not just in relation to drought definitions or declaration, but even fundamental issues of ownership and governance of M&EW systems

These conclusions, and the rich background discussions that led to them and summarised in this report, will be a key source for planning the next DRIVER workshop in 2016 and other events convened by RCUK drought research projects.

8. Appendices

Appendix 1 – Participant List

Attendee	Organisation
Jamie Hannaford	Centre for Ecology and Hydrology
Mike Acreman	Centre for Ecology and Hydrology
Kevin Collins	Open University
Mark Svoboda	University of Nebraska - Lincoln
Kerstin Stahl	University of Freiburg
Sophie Bachmair	University of Freiburg
Erik Tijdeman	University of Freiburg
Cody Knutson	University of Nebraska - Lincoln
Neville Crossman	CSIRO
Nicole Wall	University of Nebraska - Lincoln
Liz Stephens	University of Reading
Steve Rayner	University of Oxford
Sophie Haines	University of Oxford
Ian Overton	CSIRO
Steven Wade	Met Office
John Bloomfield	British Geological Survey
Mark Smith	United Utilities
David Mould	Canal River Trust
Barry Bendall	Rivers Trusts
Paul Hammett	National Farmers' Union
Paul Merchant	UK Water Industry Research/South-West Water

Attendee	Organisation
Colin Fenn	World Wide Fund for Nature
Mike Keil	Severn Trent
Ken MacDonald	Severn Trent
Nick Walters	Anglian Water
Stamatia Evangelidou	Anglian Water
Natasha Wyse	Environment Agency
Richard Davis	Environment Agency
Victoria Williams	Environment Agency
Stuart Sampson	Environment Agency
Sarah Mukerjee	Water UK
Ken Meger	Department for Environment, Food and Rural Affairs
Adrian Brooks	Department for Environment, Food and Rural Affairs
Richard Gosling	Scottish Environment Protection Agency
Karen Gibbs	Consumer Council for Water
Steve Tuck	Thames Water
Miranda Foster	Yorkshire Water
Melvyn Kay	UK Irrigation Association
Giulia Branzi	Water Services Regulation Authority
Mike Storey	Agriculture and Horticulture Development Board
Debbie McConnell	Agriculture and Horticulture Development Board
Katie Fawcett	Natural Resources Wales
Tracey Dunford	Natural Resources Wales

Attendee	Organisation
Carla Stanke	Public Health England
Ugo Gasperino	RWE Npower

Appendix 2 – Agenda

Drought: Understanding and reducing vulnerability through monitoring and early warning systems

AGENDA

Tuesday 17th March 2015, 10:00 – 16:15
Centre for Hydrology and Ecology, Benson Lane, Crowmarsh Gifford, Oxfordshire OX10 8BB

Time	Session
09:30-10:00	**Coffee and Registration**
10:00-10:10	**Welcome, Aims of the day & Housekeeping**
10:10-10:30	**Mapping the landscape of current drought research: introduction to DrIVER and the Research Council drought projects**
10:30-11:30	**Interactive Session 1: current understanding of droughts, their impacts, and Monitoring and Early Warning (M&EW) practices** *Coffee available from 11.00 during this session*
11:30-12:00	**Plenary 1: Key points and reportage**
12:00-12:45	**Presentations 1 + Q&A: International perspectives on droughts and M&EW from the DrIVER team.** 1. USA experiences (Mark Svoboda, National Drought Mitigation Center, USA) 2. Australia experiences (Neville Crossman, CSIRO, Australia)
12:45-13:30	***Lunch Break***
13:30-14:15	**Interactive Session 2: gaps in current M&EW approaches, future needs and policy drivers**
14:15-14:45	**Plenary 2: Key points and reportage**
14:45-15:00	***Coffee***
15:00-15:30	**Presentations 2: M&EW in the UK - what's on the horizon?** 1. Future developments in UK national M&EW (Jamie Hannaford, Centre for Ecology and Hydrology)

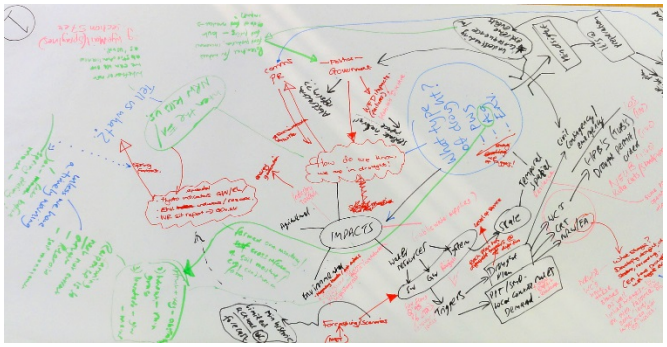
2. From indicators to impacts: early findings from the DrIVER project (Kerstin Stahl/Sophie Bachmair, U. Freiburg)
3. Future developments in drought forecasting from the IMPETUS project (Liz Stephens, U. Reading)

15:30:1600 **Plenary 3: Developing decision-relevant M&EW information for stakeholders in the UK**

16:00-16:15 **Round up, next steps, and close**

Appendix 3 – Interactive Session 1 Conversation Maps *How do we know when we are in drought?*

Table 1



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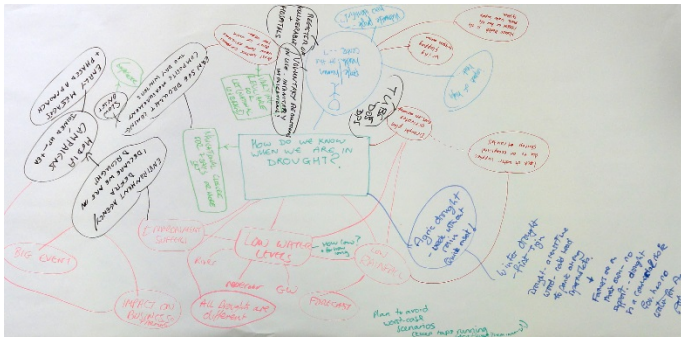

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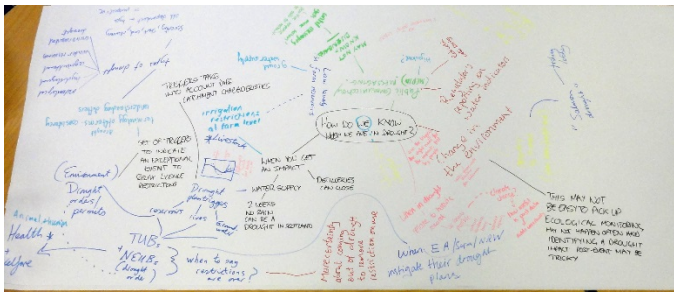
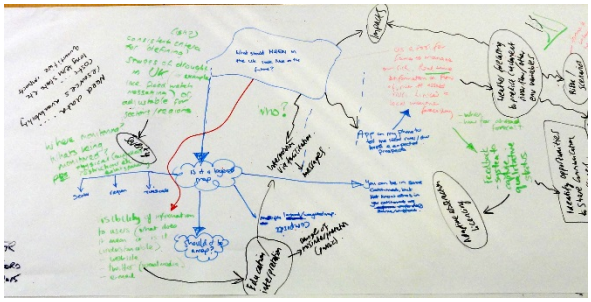


Appendix 4 – Interactive Session 2 Conversation Maps *What should a M&EW of the future look like?*

Table 1



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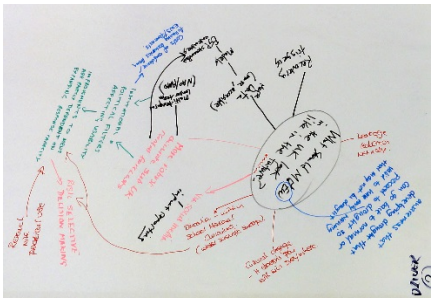

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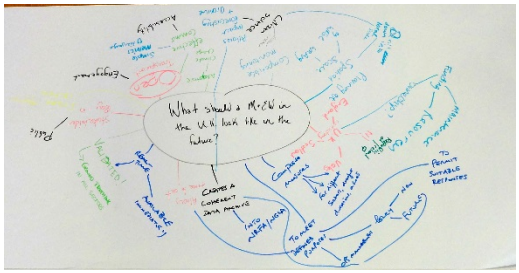

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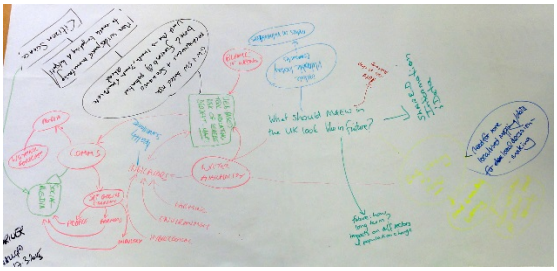

Table 5