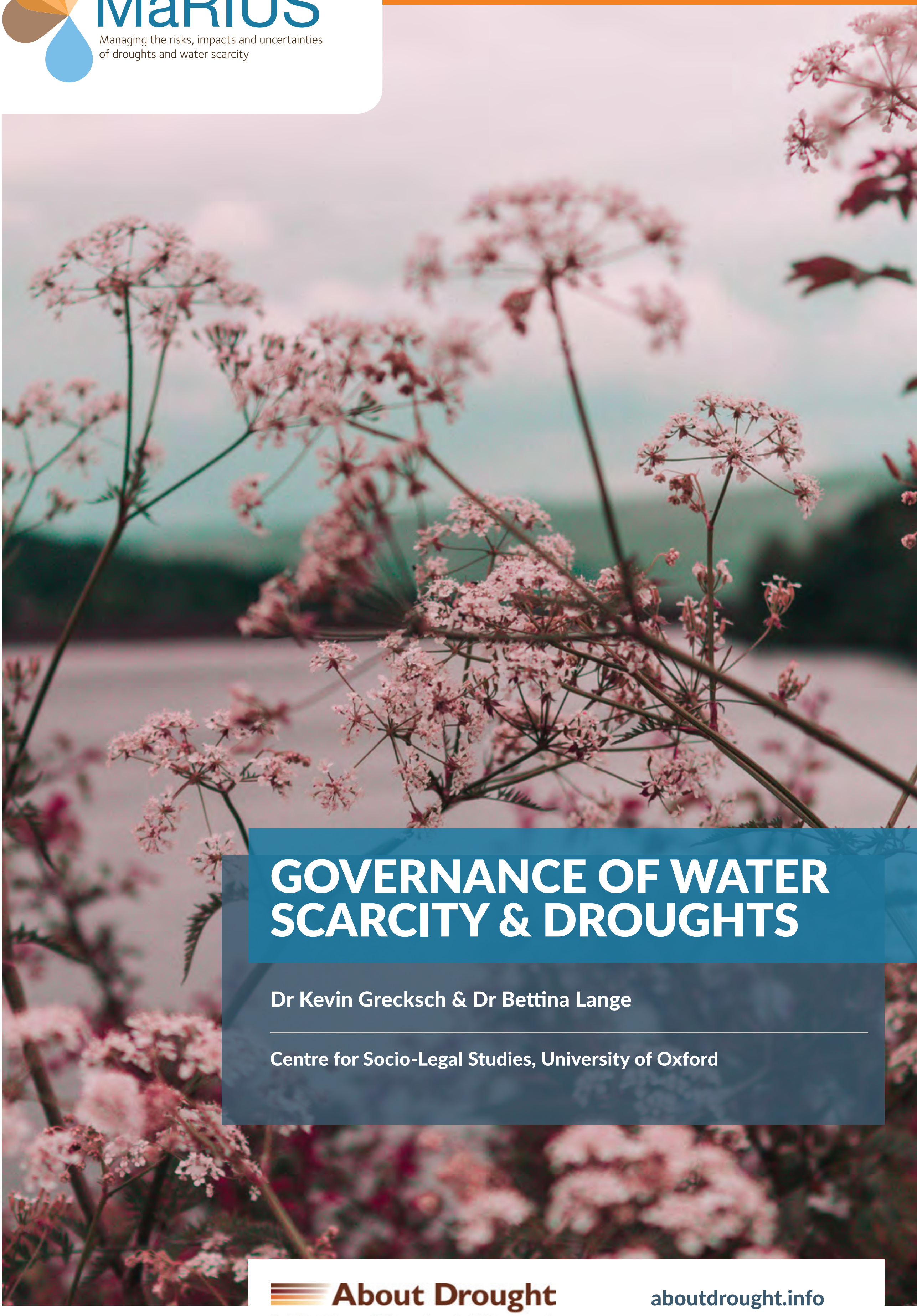
MaRIUS
Managing the risks, impacts and uncertainties of droughts and water scarcity



GOVERNANCE OF WATER SCARCITY & DROUGHTS

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About Drought
Maximising the impact of UK research on drought & water scarcity

aboutdrought.info

About MaRIUS

Following the 2011–2012 UK drought experience, the MaRIUS project received NERC funding to explore how best to manage future droughts. Managing the Risks, Impacts and Uncertainties of drought and water Scarcity (MaRIUS) introduces a risk-based approach to drought and water scarcity in order to inform management decisions and prepare households.

MaRIUS is funded by the Natural Environment Research Council, and undertaken by a project team spanning the University of Oxford [NE/L010364/1], University of Bristol [NE/L010399/1], Cranfield University [NE/L010186/1], the Met. Office, and the Centre for Ecology and Hydrology [NE/L010208/1].

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www.mariusdroughtproject.org

Cover photo of Ladybower Reservoir, Hope Valley by Ryan Booth via Unsplash

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Abbreviations

CAMS	Catchment Abstraction Management Strategies
CCW	Consumer Council for Water
DWI	Drinking Water Inspectorate
EA	Environment Agency
EAR	Environmental Assessment Report
EFI	Environmental Flow Indicator
EIA	Environmental Impact Assessment
EU	European Union
Defra	Department for Environment, Food & Rural Affairs
DP	Drought Planning
NRW	Natural Resources Wales
HRA	Habitats Regulation Assessment
Ofwat	Office of Water Services – The Water Services Regulation Authority
RAM	Resource Assessment and Management Framework
RSA	Restoring Sustainable Abstraction
RSPB	Royal Society for the Protection of Birds
SEA	Strategic Environmental Assessments
SSSI	Site of Special Scientific Interest
TUB	Temporary Use Ban
UK	United Kingdom
UKWIR	United Kingdom Water Industry Research
WFD	Water Framework Directive
WRMP	Water Resources Management Plan

Note on interview citation

Interviews are quoted in a standardised format. For example, “DP1.WC2” stands for Drought Planning case study interview, Water Company 2. “CON” stands for consultant, “REG” for regulator, “ABS” for abstractor (group), “OTH” for other. “HIS” for the Historic Drought case study and “RSA” for the Restoring Sustainable Abstraction case study.

Executive summary

This report sets out key findings, and the methodology in which they are grounded, for the A2 task of the NERC funded MaRIUS project. Our main research question explored how environmental science knowledges inform the use of regulatory tools for managing drought and water scarcity in England and Wales. Our findings are based mainly on an analysis of 50 qualitative semi-structured interviews with water resource managers working in regulatory agencies, water companies, consultancies, farming and industry.

The report highlights, firstly, that a broad range of regulatory tools and environmental science knowledges – beyond those referred to by the legal framework – are in practice relied upon by water resource managers. We, secondly, present a typology which summarises key characteristics of these regulatory tools and associated environmental science knowledges. This shows variation around key features, such as whether regulatory tools are standard or exceptional measures, whether they involve a large infrastructure solution or provide an ‘on the spot’ response, and whether they are more or less contested. In relation to environmental science knowledges the typology points to variation around the degree of professionalisation of drought knowledge, whether the knowledge simply renders drought visible or provides analytical tools for understanding the causes of drought, as well as whether the knowledge is internal or external to water companies.

The report, thirdly, identifies key policy issues arising from regulating drought with reference to environmental science knowledge. These are the value of more hydroecological data for drought management which enable to identify in an integrated, though complex way interactions between the state of water bodies and wildlife habitats. The interviews also suggest scope for greater consideration of local expert knowledges of catchments and their response to drought.

For more integrated and systematic drought governance various statutory and voluntary drought and water resource planning processes need to be more aligned. Our research also points to the value of flexibility in the choice of drought regulatory tools, coupled with greater clarification of what droughts need to be planned for. Finally, and fourthly, the report illustrates how highly contested environmental science knowledges can inform the mobilisation of regulatory tools with reference to the example of a review of agricultural abstraction licences at the Catfield Fen wetland nature reserve.

1 Introduction

The purpose of work task A2 within the MaRIUS project (www.mariusdroughtproject.org) is to generate a critical account of the governance space for preventing and managing drought and water scarcity in the UK. This matters also in light of the fact that **Drought is a recurring feature of UK climate** (Marsh, Cole, & Wilby, 2007). The last drought event occurred between 2010 and 2012 (Met Office, 2013), before that droughts occurred in 2004-2006 (Met Office, 2016) and 2003 (Met Office, 2012). Other major drought events took place in 1995/1996 and 1976 (Marsh *et al*., 2007). The UK Climate Change Risk Assessment 2017 attributes a 'medium magnitude now' but a 'high magnitude in future' to the 'risk of water shortages in the public water supply, and for agriculture, energy generation and industry, with impacts on freshwater ecology' (Committee on Climate Change Risk Assessment, 2016, p. 36). The overall assessment is that more action is needed in tackling the risk of water scarcity and drought (*ibid*.). The extent to which water shortages will occur in the future in the context of a changing climate depends also on the way in which water resources are governed, including with reference to scientific knowledge about water availability.

A first key objective of the A2 MaRIUS research is therefore to identify the main environmental science knowledges that inform the use of regulatory tools in relation to drought and water scarcity management, in particular in England and Wales. Second, and related to this, the research seeks to explore how a specific range of environmental science knowledges shape relationships of power between key institutional actors in the drought governance space. Addressing this question thus helps to understand how the governance space in relation to drought and water scarcity is configured, and enables to draw some tentative conclusions about key lines of influence between various actors in this governance space.

The data on which this report is based is a set of 50 qualitative semi-structured interviews with regulators, staff working in water companies, consultancies as well as individual abstractors and abstractor groups, located mainly in England and Wales. The data were collected for three exploratory case studies – one addressing drought planning, another discussing the Restoring Sustainable Abstraction (RSA) process and a third, about the use of regulatory tools during specific historic drought episodes, in particular the 2010–2012 and 2003–2004 droughts in the UK. The drought planning case study examined the use of environmental science knowledges during the drafting phase of drought plans, while the RSA case study analysed how environmental science knowledges inform decisions by regulatory agencies to modify or revoke abstraction licences. The third case study examined the use of environmental science knowledges for mobilising specific regulatory tools during particular historic drought episodes. Hence, the three case studies examine the link between environmental science knowledge and regulatory tools in different contexts. Taken together they enable to understand key facets of the governance of drought and water scarcity: the revision of abstraction licences is a forward looking regulatory tool that can increase the amount of water left in the environment, and thus increase water available for buffering water shortages during drought. The revision of abstraction licences can also promote a 'fairer' distribution of water in catchments thus enhancing abstractors' support for specific water allocations, which can become highly contested during actual drought. In contrast to this, drought planning, is more directly focused on what stakeholders understand drought to be about: i.e. it involves the identification of triggers and thresholds for what is considered as a drought scenario for a particular water company. Most importantly drought planning involves to set out operational actions, such as water supply restrictions, which can be put in place by water companies during a specific drought episode. While conventionally understood as operational plans, our analysis of the drafting of the now five yearly drought plans also opened up a window onto the more strategic thinking of water companies in England and Wales about drought governance. This included an understanding of what environmental science knowledges they mobilise in order to use particular regulatory options for reducing the socio-economic and environmental impacts of a drought.

Our working definition of environmental science knowledges considers these to be specific types of expertise that identify causes, incidences and impacts of drought and water scarcity. They include a whole range of knowledges that characterise the state of the natural environment from a science perspective and that are deployed in practice by water companies, regulators or consultants when a proposal is made for a particular regulatory tool to be deployed, for example a drought order, or when that regulatory tool is actually applied in practice. Examples are data on the availability of water in reservoirs, the building of hydrological models of surface and groundwater flows, also for gauging potential environmental impacts of drought and water scarcity.

There is variation in the environmental science knowledges mobilised in regulatory decision-taking about drought. For instance, there is variation in the degree to which these knowledges are clearly *defined* with reference to particular methodologies and there is variation in the degree to which they are *required* to be used when regulatory decisions are taken. Some environmental science knowledges, such as Strategic Environmental Assessments (SEA), Habitats Regulation Assessments (HRA) or Water Framework Directive (WFD) assessments are required by law and further defined by legal provisions. Other environmental science knowledges are developed by water companies and regulatory agencies themselves, sometimes in an *ad hoc* way, in order to support internal decision-making, being less directly required or defined by law.

We use the term 'regulatory tool' to refer to measures that are deployed by either a water company or a state regulator, such as the Environment Agency for England (EA) or Natural Resources Wales (NRW) in order to prevent the occurrence of water scarcity or alleviate drought conditions during a drought. Examples are Temporary Use Bans (TUBs), drought permits and drought orders. Water companies can implement Temporary Use Bans that restrict watering your garden or washing your private motor vehicle, under their own powers. These restrictions are temporary measures that are intended to reduce the demand for water and are usually one of the first steps a water company will take to protect its supplies during a drought. The water company does not require regulatory approval to restrict these uses of water but must provide public notice of its intention to impose TUBs during a specified period of time and must allow for representations to be made before the restriction comes into force. Another regulatory tool that water companies can deploy are drought permits. These are authorised by the EA and enable a water company to increase the supply of water abstracted from the natural environment. A drought order on the other hand, issued by the Secretary of State heading Defra or the Welsh Minister, can increase abstraction from the environment by water companies in order to meet statutory duties for public water supply. It can also restrict demand from commercial water users or limit abstraction by a water company, other abstractors or the EA.

The next section introduces the research questions and hypotheses. The results section presents, first of all a typology of environmental science knowledges and key regulatory tools derived from the case studies. This is followed by a presentation of key findings about linkages between environmental science knowledges and regulatory tools. After that, we highlight key knowledge gaps identified through the analysis and we discuss the results of the analysis. The penultimate section presents a 'critical' case study that illustrates in rich and rounded detail links between environmental science knowledges and regulatory tools in the governance of water scarcity. The report closes with conclusions and policy recommendations.

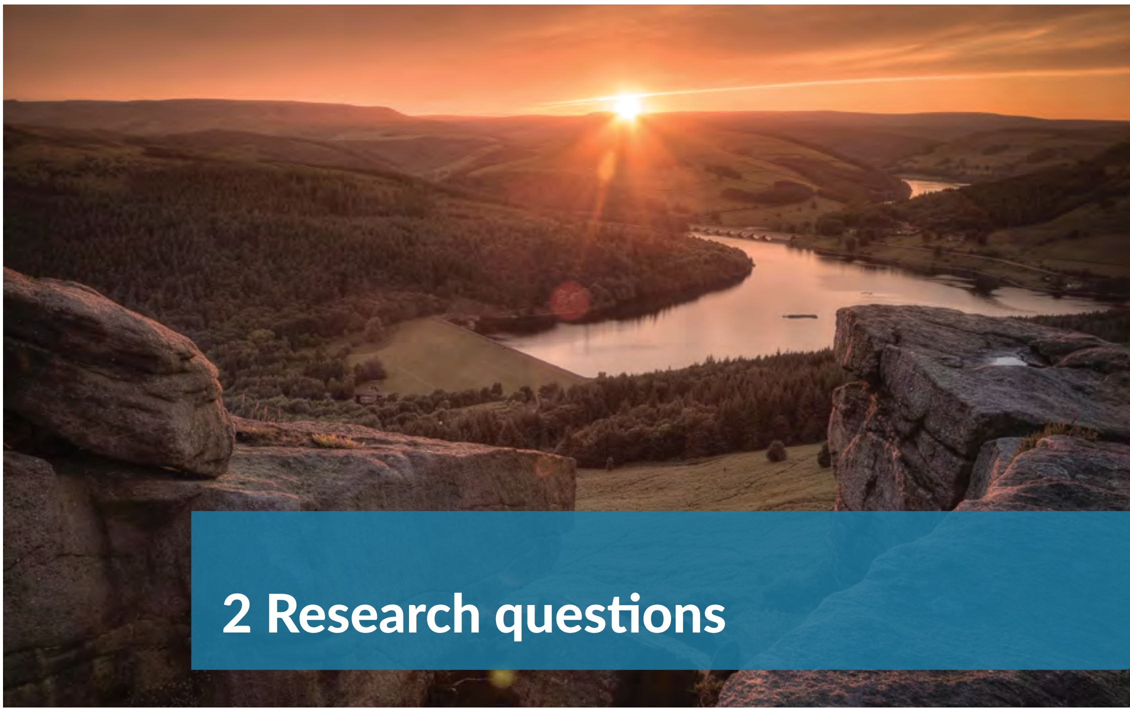

Photo of Ladybower Reservoir, Hope Valley by Rob Bates via Unsplash

2 Research questions

In order to address the key objectives of the research – identifying the main environmental science knowledges that inform the use of regulatory tools in relation to drought and water scarcity management and exploring how a specific range of environmental science knowledges linked to regulatory tools, shape relationships of power between the main institutional actors in the drought governance space – we formulated the following research questions.

Overarching research questions

1. What key environmental science knowledges are gathered and relied upon when regulatory tools are applied for preventing and managing drought and water scarcity in England and Wales?
2. How do environmental science knowledges inform the use of key regulatory tools for preventing and managing drought and water scarcity in England and Wales?
3. How does the mobilisation of environmental science knowledges and linked regulatory tools shape relationships of power between main actors in the governance space of regulating drought and water scarcity in England and Wales?

3 Hypotheses

H1: Monitoring is considered as a key regulatory tool for preventing drought and water scarcity.

Knowledge practices are not just used instrumentally, in the sense that they inform the application of specific regulatory tools, but simply the compilation of knowledges about water resources is considered to be a 'regulatory tool' in its own right.

Monitoring of various water bodies is shared by water companies and regulatory agencies. While the former focus in particular on water available through reservoir storage, the Environment Agency monitors groundwater levels and river flows. Our interview data suggests that water companies understand monitoring as 'quasi' regulation that is fundamental to their capacity to supply water services.

H2: How responsibilities for generating environmental science knowledges are allocated shapes relationships of power between the key organisational actors in the governance space for drought and water scarcity

Shared monitoring responsibilities shift the balance of power from regulatory bodies to water companies and consultancies. The latter provide environmental science knowledge in case water companies lack the necessary in-house capacity to generate it. In order, however, for drought plans or drought permits/orders to be approved water companies have to provide the necessary data to support their applications, and the way they make a case in these for those regulatory tools. This, though by some water companies described as 'ticking boxes', retains power for regulatory agencies to scrutinise drought management by water companies.

Consultants can play an influential role in these relationships of power shaped also by access to data, in light of the fact that the EA sometimes employs consultancies to generate environmental science data.

H3: 'Local knowledge' is potentially significant in regulatory decision-making

Besides the abstract and formal natural science knowledge generated by key organisational stakeholders – water companies, regulatory agencies and consultancies – local, including *expert* knowledge can also be important. Local knowledge is knowledge generated and provided – on the basis of personal interests and observations – by local people, e.g. inhabitants of a catchment. Local expert knowledge is knowledge generated and provided by semi-professional and professional bodies, such as local environmental non-governmental organisations or angling clubs. Local expert knowledge also includes knowledge generated by experts who in their capacity as professionals working either for a regulatory body or water company have accumulated extensive *local* knowledge, e.g. about a catchment or a certain stretch of a river.

4 Research design

Having set out the research questions and inductively generated hypotheses this section introduces the three case studies and the primary original data collected for this research.

4.1 A brief introduction to the three case studies

In order to answer the key research questions we draw on three linked exploratory case studies. They are exploratory because few academic or grey literature studies have been so far conducted in relation to drought planning, Restoring Sustainable Abstraction (RSA) and the use of drought orders and drought permits during the droughts of 2010–2012 (Met Office, 2013) and 2003–2004 (Met Office, 2012). These are also critical case studies because they cover areas of regulatory activity that are central to preventing and managing water scarcity and drought in the UK.

The first case study – Drought Planning (DP) – examined how statutory water company drought plans are drafted, in particular how environmental science knowledges inform the drafting of these drought plans, and the choice of regulatory tools for dealing with drought, i.e. drought management options in these plans.

The second case study – Restoring Sustainable Abstraction (RSA) – analysed how environmental science knowledges inform decisions by the environmental regulator (EA, NRW) to modify or revoke abstraction licences and how this, in turn, can reduce the risk of water scarcity arising during times of low rainfall.

The third case study – historic use of drought orders and permits (HIS) – analysed how environmental science knowledges have been used in the recent past during the specific drought episodes of 2003-6, and 2010-12 in water companies', EAs' and regulators' decisions to apply for and grant drought orders and drought permits.

The three case studies are linked because the effects of the regulatory tools they focus on are synergistic. Decisions taken during the Restoring Sustainable Abstraction (RSA) program have an impact on how much water is abstracted in which catchments. This, in turn, has an effect on whether it is likely that during a specific historic drought episode a TUB, drought order or drought permit needs to be put in place. Experience with specific historic droughts has also informed where through the RSA program the EA has pinpointed efforts to reduce water abstraction in particular catchments. Decisions taken during the RSA programme can then also further influence whether water companies have to make provisions through their Drought Plans for using, TUBs, drought orders and permits during drought.

4.2 Data sources and analysis

The research generated a new data set of 50 semi-structured interviews with key actors in the drought governance space – water companies, regulators (Defra, EA, Natural England), environmental consultancies as well as abstractor groups and individual abstractors reflecting in particular farmers' perspectives also in light of the fact that their abstractions are linked to food security and that farmers hold the greatest number of abstraction licences in the UK. All together, twenty water companies, eight representatives from Defra, EA and Natural England, one representative from Scottish Natural Heritage, four different consultants, four abstractors including a representative from the National Farmers Union, an abstractor group, an individual farmer and a representative from a soft drinks producer, plus a representative from a law firm who specialises in water regulation, were interviewed. Some interviewees were interviewed twice or three times with regard to the different case studies as introduced above. The interview guidelines covered themes in relation to the research questions and hypotheses stated above, and were adapted to the different stakeholder groups in order to make them more relevant to the specific interview partner.

The Drought Planning interviews covered questions with regard to how water companies use environmental science data and knowledge in drought planning. Hence, the interviews asked about the process of drought planning, how the different drought management options are chosen, as well as about relationships between water companies and regulatory bodies and consultancies.

The Historic Drought interviews were concerned with the use of drought orders and permits during a past drought event, the use of environmental science data (and reports produced from that data) in making an application for a drought order or drought permit and the role of environmental science data (and reports produced from that data) in informing relationships with other organisations involved in drought management. Hence, the interviews also elicited information about how water companies liaised with regulatory bodies during these processes.

The Restoring Sustainable Abstraction interviews covered the process of an RSA investigation and what it entails. This relates to the environmental science data used in these investigations, Review of Consent processes as well as the relationship among the key stakeholders such as the EA and water companies. Other sources of data were extracts of public policy documents and legal provisions.

This qualitative data was analysed using thematic coding in the software program NVivo 11 in order to answer the research questions. The following are examples of key themes that built the analysis structure in NVivo:

- a first introductory theme was general information about drought plans and drought management options (which environmental science knowledge is used in drought plan drafting and in relation to specific regulatory tools, thereby covering items such as historical environmental science data, gaps in environmental science data, HRA, SEA and WFD aspects)
- the RSA process in its different dimensions, such as its relation to abstraction reform and the process of modifying or revoking a licence.
- a further key theme were the boundaries of the drought governance space. This sheds light on who is ‘in’ and who is ‘out’ of the drought governance space and thus helps to further understand relationships of power between key actors in the drought governance space.

5 Results

This section first provides an overview of the main results before it presents an account of key regulatory tools, key environmental science knowledges. It then presents a typology of environmental science knowledges and regulatory tools, followed by key themes and key research gaps derived from the data. The section ends with a discussion of the results.

A key objective of this research is, as mentioned in the introduction, to identify key environmental science knowledges that inform the use of regulatory tools in relation to drought and water scarcity management, in particular in England and Wales. The interviews asked stakeholders what environmental science data they rely on when drafting statutory or voluntary Drought Plans or commenting on these or what environmental science data they used when deploying a regulatory tool for managing drought, such as writing applications for a drought permit or drought order in the past. Appendix A1 provides an overview of the results based on the interview data. It shows which and how often a regulatory tool and environmental science knowledge was mentioned by interviewees. This is supported by Appendix A2, which presents a 'ranking' of environmental science knowledges. The basis for this assessment are the environmental science knowledges that are categorised under 'other types of knowledge interviewees mentioned' captured in Appendix A1.

Key regulatory tools are drought orders, drought permits, drought planning itself and Water Resources Management Plans. Key environmental science knowledges are Water Framework Directive assessments, Habitats Regulation Assessments and Strategic Environmental Assessments[1].

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1 Though SEAs are not always carried out for water company statutory Drought Plans, and are perceived by some water companies as more appropriate to be carried out in relation to Water Resource Management Plans.

These regulatory tools and environmental science knowledges are referred to by the formal legal framework. But it is interesting that also a range of other regulatory tools and environmental science knowledges, such as monitoring, water reuse/recycling and modelling, are considered as important by regulators and water companies for managing drought and potentially preventing water scarcity.

5.1 Key regulatory tools

The term 'regulatory tool' refers to measures that are deployed by either a water company or a state regulator, such as the Environment Agency for England (EA) or Natural Resources Wales (NRW), in order to prevent the occurrence of water scarcity or alleviate water scarcity during a drought. The following is a list of key regulatory tools based on the analysis of interviews.

In-drought:

Temporary use bans (TUBs)

Water companies can implement temporary water use restrictions under their own powers. These restrictions are temporary measures that reduce the demand for water and are usually one of the first steps a water company will take to protect its supplies during a drought. The water company does not require any prior approvals from a regulator to restrict these uses of water but must run a period of public notice and allow for representations to be made before the restriction comes into force. The use of TUBs is, however, an aspect of the 'level of service' that water companies provide to their customers. The economic regulator, Ofwat, may express views about the economic efficiency and customer service implications of water companies' use of water supply restrictions. Examples are restrictions on watering gardens and cleaning a private motor vehicle.

Drought orders

A drought order, issued by the Secretary of State heading Defra or the Welsh Minister, authorises increased abstraction from the environment by water companies in order to meet statutory duties for public water supply. It can also restrict the demand from commercial water users or limit abstraction by a water company or the EA.

Drought permits

A drought permit, issued by the EA to a water company, enables to increase supply of water abstracted from the natural environment.

Before drought:

Water company Water Resources Management Planning

Water Resource Management Plans (WRMPs) look 25 years ahead and should, in accordance with legislation and Environment Agency guidelines ensure that water companies have sufficient water to supply the public and maintain adequate water in the environment.

Water company statutory drought planning and EA voluntary drought planning

Water company statutory Drought Plans cover the range of actions necessary to deal with various drought situations. They set out how a water company will continue to meet its duties to supply water during drought periods with as little recourse as possible to drought permits or drought orders. The Environment Agency produces voluntary area drought plans for its 14 operational areas. The plans describe the different operational responsibilities, the steps the EA will take to recognise, monitor and where possible reduce the effects of a drought at a local level. EA voluntary area drought plans set out the actions the EA will take at different stages throughout the drought and detail the indicators that will determine these various actions. They also give details on arrangements for reporting and communications during drought with stakeholders.

Restoring Sustainable Abstraction (RSA) / licence change

Abstraction licences provide abstractors with a licence to take a fixed volume of water from the natural environment. The RSA programme worked with licence holders to reduce the amount of water taken from the environment or to change abstraction points. This could involve modifying or revoking existing abstraction licences and looking for alternative solutions.

Water recycling / water reuse

This regulatory tool describes the utilisation of treated or untreated water for a variety of purposes. For example, household discharge could be reused for non-potable uses such as watering gardens.

Reservoirs (including on-farm reservoirs and enlargement of existing reservoirs)

Reservoirs are artificially created lakes for storing water. Reservoirs are fed by rivers or glaciers and usually provide drinking water and irrigation water. Reservoirs and dams are also used to generate electricity through hydropower.

Desalination (including mobile desalination)

Desalination describes the process of removing salt from saline water (sea water, brackish water) either through thermal desalination or reverse osmosis. Desalination plants are energy intensive and so far in the UK only Thames Water operates a desalination plant for emergency purposes.

5.2 Key environmental science knowledges

According to our working definition of environmental science knowledges these are specific types of expertise that identify causes, incidence and impacts of drought and water scarcity. Environmental science knowledges characterise the state of the natural environment from a natural science perspective, and can be deployed in practice by water companies or regulators when a proposal is made for using a particular regulatory tool during drought. The following is a list of key environmental science knowledges based on the analysis of interviews.

Strategic Environmental Assessment (SEA)

SEAs are based on the European Directive 2001/42/EC and a key aim is 'to provide for a high level of protection of the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programmes with a view to promoting sustainable development'. SEAs provide information about significant environmental impacts of plans and programmes – rather than specific projects (Lange & Cook, 2015). Hence, in the case of drought plans, an SEA should also consider various alternatives for achieving a project's objectives, ultimately choosing that which has the least environmental impact (*ibid*.).

Habitat Regulations Assessment (HRA)

HRAs are required when an abstraction licence or drought management option affects a nature conservation site. Thus, an HRA assesses whether an option will adversely affect sites such as Special Areas of Conservation (SAC) or Special Protection Areas (SPAs) (Lange & Cook, 2015).

Water Framework Directive Assessment (WFD)

WFD assessments require water companies to consider how their drought management options may affect regulatory objectives of the WFD, such as those set out in programs of measures that are drawn up as part of the river basin planning process required by the WFD. This addresses the quality and to some extent water quantity of water courses in a river basin (Lange & Cook, 2015).

Environmental Assessment Report (EAR)

The objective of an Environmental Assessment Report is to identify potential environmental impacts of regulatory tools and it seeks to develop mitigation measures before a drought order or permit is applied for. It is necessary when the legal framework does not require specific environmental science knowledge produced for example through a WFD assessment, SEA or HRA (Lange & Cook, 2015).

(Historical) monitoring data

Monitoring is the gathering of data, for example about rainfall, river flow or groundwater levels, at different geographical locations. Monitoring data is for example the basis for Environmental Assessment Reports. Monitoring data can be reviewed, analysed statistically and used in modelling. Monitoring also allows to identify trends in water available, it is the basis for forecasting and helps to understand hydrological processes. It was considered by some interviewees as both an environmental science knowledge and a regulatory tool.

Modelling (groundwater, surface water, river flows)

Models are simplified and idealised versions of reality. They are used to make distinct parts or features of the world more understandable. Thereby they visualise, simulate, define or quantify, for instance by relying on monitoring data. These mathematical-numerical models are an essential part of water resources management in the UK and they support planning and forecasting.

EA Drought Planning Guideline

The EA Drought Planning Guideline (Environment Agency, 2015c) is a form of legally non-binding soft law that shapes how drought plans are written. The drought planning guideline identifies and thus presents to water companies a range of environmental science knowledges they should consider in the writing of the Drought Plan. In itself, it constitutes not just guidance, but, we argue, constitutes in its own right what are considered as relevant environmental science knowledges and what form they should take. The EA Drought Planning Guideline provides a structure for the environmental science data that water companies consider in the writing of their statutory Drought Plans.

5.3 Typology of environmental science knowledges and regulatory tools

A wide range of environmental science knowledges are mobilised in the prevention and management of water scarcity and drought as set out in section 5.2 above. The section below further expands on this list of key environmental science knowledges also by identifying key characteristics of these knowledges, and by highlighting how these knowledges vary with reference to these key characteristics. The typology set out in Table 1 is intended to further indicate how different types of environmental science knowledges and regulatory tools contribute to governing water scarcity and drought.

Table 1. Typology of environmental science knowledges and linked regulatory tools in England and Wales for preventing and managing water scarcity and drought	
Standard vs. exceptional	This captures that water companies generate and use not only standard regulatory tools and environmental science knowledges about water but also more exceptional regulatory tools and environmental science knowledges. Example: Drought orders are a standard regulatory tool referred to in a range of water companies' Drought Plans, desalination is an exceptional regulatory tool.
Large infrastructure vs. on the spot	This relates to the spatial dimension of the regulatory tool and linked environmental science knowledge. Here the regulatory tool and linked environmental science knowledges vary according to whether they refer to the water supply system as a whole or to a specific site. Example: A water company's Water Resources Management Plan refers to the whole geographical area for which a water company can supply water, whereas a Habitat Regulations Assessment assesses environmental impacts of water use on a specific site.
Agency vs. technical	Here the regulatory tool and linked environmental science knowledge vary according to whether their production and use involve a high degree of human agency or whether they are simply a self-executing technical device. The term 'agency' suggests that a significant amount of human involvement is necessary to make the regulatory tool work, whereas 'technical' refers to a tool for managing drought that is 'engineered into' water supply infrastructures and requires only a limited amount of specific human involvement during drought. Example: drought planning involves significant deliberation by various actors involved in the writing of the Drought Plan, whereas engineering works enhancing interconnection of the water supply system can alleviate water scarcity during drought without further human intervention.
Less contested vs. more contested	This refers to the degree of acceptance of a tool or type of knowledge by stakeholders. Example: gathering data through monitoring is widely accepted while the Environmental Flow Indicator (see section 5.5) is contested by some stakeholders.
Pre-defined vs. shaped by users	This refers to whether a regulatory tool and linked environmental science knowledge is pre-defined or mainly shaped *ad hoc* by water users. Example: a model is pre-defined while an expert judgement is shaped by the expert. A drought order is pre-defined by the legal framework, whereas a water sharing agreement between farmers in a particular catchment is defined by the water users.
Structuring v. pinpointing	Environmental science knowledges deployed for the use of regulatory tools can vary depending on whether these knowledges provide an entire structure for understanding drought risk or whether they provide discrete, pin-pointed sources of information about a very specific aspect of drought and water scarcity. Some of the environmental science knowledges referred to by interviewees have more of a structuring function, i.e. they scope what are the most relevant issues when assessing the state of water scarcity and drought. Example: A range of legislative provisions specify 'structuring' types of knowledge for assessing the state of water scarcity or drought, such as the European Union SEA or EIA Directives and national conservation legislation. This is in contrast to 'pinpointed' very specific environmental science knowledges that focus on a very specific aspect of water scarcity or drought, e.g. a salmonid flow requirement for a river.

DIY versus professionalised	Environmental science knowledges and regulatory tools vary according to the degree to which they are 'professionalised'. By 'professionalisation', we mean environmental science knowledges that draw on scientific understandings of the links between causes and manifestations of drought. A further indicator of professionalised environmental science knowledges are that these knowledges are generated by organisations that are recognised for their expertise in the production of knowledges about drought and water scarcity. 'Professionalised' environmental science knowledges can be distinguished from 'lay' or 'citizens' or DIY knowledges. Example: Environmental science knowledges produced on the basis of a hydrological model of a water company used for the writing of a Water Resources Management Plan are 'professionalised'. Examples of DIY environmental sciences knowledges are local citizens' historic knowledge of the impact of drought on rivers as well as 'walk over surveys' carried out e.g. by local Rivers Trusts as part of catchment partnerships engagement with drought risk.
Rendering visible vs. analysing drought risk	Environmental science knowledges further vary in terms of the functions that knowledge plays in describing and managing drought and water scarcity. Some environmental science knowledges, simply name and thus render visible receptors of drought and water scarcity in the natural environment. Other environmental science knowledges provide complex causal assessments of drought risk. Example: The National Vegetation Classification helps to identify and thus render visible plants potentially at risk from water scarcity and drought. The EU Habitats Directive provides an entire structure for assessing drought risk in relation to nature conservation.
Learning about drought risk vs. its strategic management	Environmental science knowledges referred to by interviewees vary in the degree to which they are linked to a managerial response to drought. Hence, some of the environmental science knowledges are more 'pure' environmental science knowledge, developed with reference to traditional academic criteria of what constitutes scientific knowledge, being open-ended and thus also enabling further wide-ranging learning about 'drought'. Other environmental science knowledges are more 'applied' knowledge, which are used to inform directly a specific managerial response to drought and water scarcity. Environmental science knowledges for learning can be prospective, in the sense that e.g. the water company is considering to use them in the future to enhance their environmental science knowledge base. Some of these environmental science knowledges are also reflexive, in the sense that they enable feedback-loop learning from the knowledge generated and adjustment of management responses. Example: The monthly water situation reports and the weekly rainfall and river flow reports from the EA generate environmental science knowledge that can inform short-term direct managerial responses by water companies. Monitoring after the implementation of a drought order is an example of an environmental science knowledge that can inform wider learning, for instance about where best to place abstraction points for drought orders.
Water company internal knowledge vs external knowledge	Water company internal environmental science knowledge refers to knowledge that is generated within a water company and either adds to existing knowledge that e.g. is required by the regulatory bodies or goes beyond knowledges required by the legal framework and/or regulatory agencies. External knowledge refers to bodies of knowledge compiled by organisations outside water companies and not just directed by a specific water company. Examples of water company internal knowledge are internal drought dashboards and post-drought monitoring. Examples of water company external knowledge are UK WIR Reports and EA reports.

In the next section we discuss ‘modelling’ as an example of how to ‘read’ and interpret our typology. Modelling is a *standard* environmental science knowledge applied by water companies and regulators. It can be applied comprehensively to *larger infrastructures* such as a water supply system as a whole or to a specific site, i.e. *on the spot*. It is a *technical* process that requires limited human involvement once a model is fed with data. While modelling is a standard type of environmental science knowledge and widely applied there are also instances where models are *contested* because they may not be appropriate for geological and hydrological characteristics of a particular water supply zone (see for example section 6). Sometimes models are contested with reference to their origins, with questions being raised about who has developed them and for what purpose. Models are usually *pre-defined*, i.e. existing models are used and they can provide *pin-pointed* sources of information about a very specific aspect of drought and water scarcity, for example about a groundwater body. Models are complex in their nature and application. Therefore, using them involves a high *degree of professionalisation*.

5.4 Links between regulatory tools and environmental science knowledges

The previous sections 5.1 and 5.2 provide some answers to our first research question, i.e. what key environmental science knowledges are gathered and relied upon when regulatory tools are applied for or actually deployed for preventing and managing drought and water scarcity. Regulatory tools and environmental science knowledges are, however, not mutually exclusive phenomena. For instance, some environmental science knowledges, such as Water Framework Directive assessments, can be closely linked to the use of a particular regulatory tool, such as drought permits. Sometimes the boundary between an environmental science knowledge and a regulatory tool can become blurred.

Our overview of regulatory tools and environmental sciences knowledges (Appendix A1) highlights which particular regulatory tools and environmental sciences knowledges are used by regulators and water companies.

The Drought Planning interviews reveal a strong focus on regulatory tools such as Temporary Use bans (TUBs), drought permits, drought orders, WRMPs, (drought planning) followed by water recycling, water reuse, reservoirs and desalination. SEAs, HRAs, WFD assessment and drought planning followed by monitoring make up the body of environmental science knowledges relied upon for drought planning.

Compared to the Drought Planning Interviews, the Historic Drought interviews show a similar pattern with regard to regulatory tools and a similar pattern with regard to environmental science knowledges. Monitoring data is an important environmental science knowledge here and, as argued above, a quasi regulatory tool since past monitoring data are an important source for the regulator to evaluate, for example, drought permit applications.

The Restoring Sustainable Abstraction (RSA) case study shows the largest variety of environmental science knowledges being generated by abstractors and being relied upon by regulators. Environmental science knowledges deployed here involve different models, a range of documents relied upon for the implementation of statutory provisions, such as the National Vegetation Classification as well as other sometimes very site specific types of environmental science knowledges, such as the conceptual understanding of a site.

5.5 Key themes

The analysis of the data first of all yielded an understanding of the range of regulatory tools and environmental sciences knowledges mobilised in the prevention and management of water scarcity and drought. The data analysis also included the identification of key themes that emerged from the interviews. Themes are recurring ideas, issues or statements expressed by interviewees often not necessarily as a direct answer to questions from the interview schedule. Therefore identifying themes can help to discover further dimensions of drought and water scarcity management. Themes emerged during the reading and coding phase of the interviews. For example, the theme ‘importance of hydroecological data’ was identified because a large number of interviewees mentioned issues around hydroecological data. In the following, key themes are presented and discussed in relation to the research questions.

The importance of hydroecological data

Many respondents stressed the importance of hydroecological data for drought management, yet they also noticed the current lack of such data. Therefore, it was also one of the key knowledge gaps identified by stakeholders (see section 5.6). The importance of generating and integrating more hydroecological data into drought management was expressed across the range of interviewees, i.e. water companies, consultants, regulators but also abstractor groups. Hydroecological data cover the interaction between water and wildlife habitats of a catchment delivering an integrated view of drought risk and thus enabling a more holistic approach to drought management. Thus, besides standard monitoring data like river and ground water flows integrating hydroecological knowledge into drought planning provides stakeholders with more and better data and knowledge to make informed decisions.

> “From my point of view, understanding how resilient different rivers are to different levels of drought and human pressure on top of the droughts. That’s much more ecological research I think, but I think it’s very useful to understand that a bit better so water companies and regulators can have more confidence in that.” (Interview DP1.CON1).

One water company stressed that environmental resilience and what is happening with river ecology in the future are key areas that need more research (Interview DP1.WC12). Another water company also emphasised the importance of knowledge about environmental state baselines:

“ When we go into a drought, it’s all very well throwing loads of money at it then and looking at it but if you’ve got nothing to compare it to, it’s pretty worthless. So I’d like to see a bit more the environment aspect pushed a bit further than just as an afterthought.” (Interview DP1.WC4).

The view from abstractor groups is that they would like to see more research into knowledge about soil, water and irrigation (Interview RSA.ABS1). The Environment Agency states that it would like to see more research around the environmental monitoring side, suggesting that their guidance is currently not particularly clear with regard to what they want companies to provide in advance of a drought permit so that they can understand what damage it could do (Interview DP1.REG5).

The Catfield Fen example (see section 6.2 below) provides an example of how the influence of a particular specific hydoecological data set, in this case about the rare fen orchid, exerts regulatory influence and also shows how access to a very specific data set can shape relationships of power. In the Catfield Fen example the data weakened the farmer’s case as an abstractor whose abstraction rights were curtailed on the basis of this very pinpointed information.

The significance of hydroecological data is probably the most important among the key themes identified because the issue was mentioned and stressed by a large number (13) of interviewees. Reference to the significance of hydroecological data also helped to identify a gap in drought and water scarcity managment, i.e. a lack of these data (see also section 5.6). If more and better hydroecological data is to be included in decision making in relation to drought and water scarcity in the future the question arises who – regulators, water companies or both – should collect the data. As mentioned before, although a key environmental science knowledge and also a quasi regulatory tool, monitoring is fragmented among the different actors in the drought governance space. Thus, also with regard to relationships of power in the drought governance space, who collects hydroecological data becomes an important question and a governance challenge.

The usefulness of the Environmental Flow Indicator (EFI)

The Environmental Flow Indicator (EFI) is used to indicate where abstraction pressure may start to cause an undesirable effect on river habitats and species. The EFI is a percentage deviation from the natural river flow represented using a flow duration curve[2]. This percentage deviation is different at different flows. It is also dependant on the ecological sensitivity of the river to changes in flow. The EFI is calculated within the Resource Assessment and Management (RAM) framework. This assessment gives an indication where and when water is available for new abstractions.

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2 The flow duration curve is a plot that shows the percentage of time that flow in a stream is likely to equal or exceed some specified value of interest. Flow duration curves can be provided for a given river over two different time periods to illustrate if and how the range of flows has changed over time.

Flow standards for the Water Framework Directive (WFD) developed by the UK Technical Advisory Group have been adapted to set the EFI (Environment Agency, 2013).

Hence, the EFI is set with reference to expert opinion and at a level to support 'good ecological status', the legal standard required to be achieved under the EU Water Framework Directive. The EFI is used in Catchment Abstraction Management Strategies (CAMS) where resource availability is expressed as surplus or deficit of water resources in relation to the EFI. The EFI is also used in the hydrological classification for the WFD to identify water bodies where reduced river flows may be causing or contributing to a failure of 'good ecological status.' This is called a compliance assessment (EA, 2013). For the EA, the EFI constitutes an 'ecological protection line'(Interview RSA.REG2).

Some stakeholders are critical of the EFI though. One interviewee from a water company mentions that the information that goes into a model is important and getting that information right is crucial:

> “(…) quite often they're [river flows] limited to maybe just one gauging station at the bottom end of a catchment and it hasn't necessarily got all of the information you need for all the upstream parts. (…) I think they're probably the critical pieces and that's the bit we sometimes struggle with and have discussions around, about how much confidence do we have in these numbers that are being generated, because quite often we're producing something, this environmental flow indicator, that's a bit of a made up number and actually how sensitive is that river to those flows?” (Interview RSA.WC2)

Another member of staff from a water company suggested that they could often show the EFI was wrong:

> “It's set at the wrong value in some places because it's based on no or very little data. Generally speaking, the EA wants more data to understand water companies' options: (…) I think they welcome the fact that we do all this information gathering of data. The more information we get, the better. They use our information, as I said before, and put it in their models. So we've collected lots of flow data and we've shown the EFI might be wrong and challenged the EFI, they will use our information.” (Interview RSA.WC8).

Another water company expressed a similar opinion:

> “You can get these statements by the EA that 50% of rivers are over-abstracted and that may be true against the EFI standards but not true once you've investigated them and shown that actually for half of those rivers, they're not as sensitive to flow as you thought when you applied the EFI which is just purely applying the EFI standards.” (Interview RSA.WC4)

This theme has clear links to the theme "hydroecological data", because the EFI is another way of indicating where abstraction can cause an undesirable effect on river habitats and species. Yet, in a wider context this theme is an example of another fundamental issue emerging from the data: Discussing the usefulness of the EFI raises the question whether regulating by 'numbers' – as a form of bureaucratic regulation – solves a resource problem for the regulator and thus enhances its regulatory control. If there are, however, only limited data underpinning instruments such as the EFI, then it may actually limit regulatory control and legitimacy.

Unclear relationship between water company drought planning and Environment Agency (voluntary) drought plans

The Environment Agency produces voluntary area drought plans for its 14 operational areas. The plans describe the different operational responsibilities and the steps the EA will take to recognise, monitor and where possible reduce the effects of a drought at a local level. They set out the actions it will take at different stages throughout the drought and detail the indicators that will determine these various actions. They also provide information about arrangements for reporting and communications. The EA reviews its drought plans annually and area offices will also update their drought plans following major droughts to implement lessons learnt. However, differently from water company drought plans, there is no legislative requirement for the EA to consult on and publish its area drought plans. (EA, Drought response: our framework for England, 2017).

In contrast, water companies produce statutory drought plans with reference to the EA Drought Planning Guideline. The EA is a statutory consultee for each water company Drought Plan, and the Secretary of State heading Defra can give directions to the water company in relation to the content of the Drought Plan. Yet, the 14 EA operational areas do not match the water resource zones covered by water companies. The definition of drought invoked in EA area drought plans and water company drought plans may also vary. EA drought plans focus more on the impact of water scarcity on the natural environment, while water company statutory drought plans focus on the implications of water scarcity on public water supply in the first instance, while also considering environmental impacts. This leads to an unclear relationship between the EA voluntary drought plans and statutory water company drought plans.

The EA is clear that the EA area drought plans and the water company drought plans do not seek to influence each other. They are two separate plans, however they need to be informed by one another (Interview DP1.REG3). Hence, EA drought plans do not seem to affect on a *strategic* level the writing of a water company drought plan. Yet the EA refers to its drought plans when considering drought permit applications. The statutory water company drought plans follow guidelines and the EA assesses these plans against the guidelines.

This theme suggests that the regulatory regime is limited in matching different governance spaces in this case boundaries of EA area offices with water resource zones as one of the key scales water companies work with. This suggests a degree of institutional misfit (Moss, 2012). The fact that the two plans are not linked is also a missed opportunity with regard to aligning data that is collected in each case. This theme of a potential institutional misfit between various scales at which drought is managed was also illustrated by a water company which suggested during an interview that they would like to see more research into groundwater drought triggers since they considered the Drought Planning guideline to be biased towards chalk aquifers in the south of England (Interview DP1.WC3).

How flexible is drought planning?

A key issue in the governance of water resources, and drought specifically, is how much water companies are restricted in how they plan for dealing with drought. This also has a bearing on relationships of power in the governance space, with tight restrictions on what water companies can do being potentially indicative of significant influence and power of regulators over the water company drought planning process.

The EA Drought Planning Guideline (Environment Agency, 2015c) is the legally non-binding soft law that shapes how drought plans are written. The drought planning guideline identifies and thus presents to water companies a range of and structure for environmental science knowledges they should consider in the writing of the Drought Plan. Despite being a guideline some water companies said that they found the drought planning guideline to be too restrictive. They considered the Guideline to restrict water companies in developing and exploring alternative ideas and options (Interview DP1.WC8, DP1.WC9, HIS. WC7). Other water companies found it both helpful and a hindrance:

> “So it’s either been far too detailed and prescriptive in the methods that you should apply to certain areas of those two plans, or it has been very, very high level and allows you to choose which direction you go in as a company, which is fine.” (Interview DP1. WC7).

However, water companies are trying to overcome this lack of clarity by liaising with the Environment Agency to make sure the EA is happy with a drought plan and that it complies with the requirements (Interview DP1.WC6). Regulators share the perspective that it can be debated how restricted or open the guidance should be. They point towards a tension:

> “I suppose the more guidance, it gives them I suppose a bit of comfort that they’re doing things the right way rather than less guidance means that we’ve got more opportunities to say to them you’re not doing this right, you haven’t done a good enough job here.” (Interview DP1.REG4).

The questions that arise from this theme are how important flexibility is and how much steering by the regulator is justifiable. The picture presented is mixed, i.e. some water companies are content with the current EA Drought Guideline, while others want more flexibility. The solution adopted by some water companies seems to be, as indicated above, to liaise closely with the regulator. In this regard, the 'inflexibility' of the EA Drought Planning Guideline brings regulators and water companies closer together.

A stronger, formal link between Drought Plans and Water Resources Management Plans as well as drought and flood management

An issue related to flexibility in drought planning is the relationship between statutory Drought Plans and Water Resource Management Plans. This issue highlights a more general feature of the drought governance space in the UK, i.e. the challenge to integrate or at least avoid inconsistency between various strategic and operational planning processes related to water resources, and drought specifically, including water company Business Plans.

While water companies' Water Resources Management Plans are strategic, Drought Plans are operational. Some stakeholders expressed the possibility to merge and integrate Drought Plans with Water Resources Management Plans (Interview DP1.WC4, DP1.CON1, DP1.WC8). According to stakeholders this would ensure a continuous process, avoid confusion and link them up better.

> “That [a stronger formal link between DPs and WRMPs] is certainly something that some of the companies and some people in the Environment Agency are looking to do, to make it much more of a… not a continuous process but not completely separate processes, which they are at the moment.” (Interview DP1.CON1).

Again, the EA recognises the issue of a disconnection between the two plans and sees a drive to try and connect them up a bit (Interview DP1.REG2), even going as far as saying the Drought Plan should really be an extension of the Water Resources Management Plan (Interview DP1.REG1).

This theme fits into the wider discussion about more integrated water resources management in the UK. This could be achieved, for example, by putting in place a water resource system-wide water policy or refocussing the policy-framing (cf. Robins, Burt, Bracken, Boardman, & Thompson, 2017). This entails to take a systemic, long-term view of UK water resources management that develops and articulates a broader and UK wide vision for water use and management (*ibid*.) One stakeholder hinted at the current initiatives in Northern Ireland:

> “We'll see what happens in Northern Ireland which has basically borrowed the guidelines from the EA and has put them together into a single document. This integration would be useful because stakeholders get confused with the different engagement processes (…)” (Interview DP1.CON3)

Local (expert) knowledge

Our analysis shows that local knowledge can fill gaps left by more abstract and formal environmental science knowledges and add new perspectives. Moreover, including local knowledge in the application of regulatory tools for preventing and managing drought and water scarcity can empower stakeholders and strengthen the legitimacy of regulatory decisions. Our research suggests, however, that so far, local knowledge remains largely 'untapped'. In the course of the RSA programme, however, many water companies appraised its benefits:

> “ One of the things about these investigations is it's become clear while we're doing it, is to involve other stakeholders because there's a lot of information out there that's useful information to us that we want to use as well.” (Interview RSA.WC8).

The same water company now involves, for example, Rivers Trusts and Wildlife Trusts who provide them with useful information as part of RSA investigations:

> “ We didn't know any of that just looking at maps and the [Environment] Agency didn't know a lot of it either. So it has really been useful involving these stakeholders and we'll involve them through the whole process (*ibid*.).”

Natural England blames a lack of resources for missing local knowledge of sites, because at those sites that are National Nature Reserves they have officers out on site every day gathering knowledge which they lack for a lot of other sites (Interview RSA.REG4). 'I think in a drought, you do rely on local expertise', concludes the EA, emphasising the fact that you rely on people who know how a river, reservoir or groundwater reacts to water scarcity (Interview DP1.REG2). A consultant mentioned that similar limits to local expertise within the EA are also due to the EA's practice of moving its staff around. This leads to recruitment problems and an increasing lack of local knowledge (Interview DP1.CON3). This view is supported by local abstractor groups who also emphasise the value of local knowledge. They see local knowledge as a basis to sustainable abstraction, with local knowledge generated by people who watch borehole levels go up and down over the years or who have seen a chalk stream dry out and regenerate a few times (Interview RSA.ABS1).

This theme of local knowledge shows, first of all, that there is a continuum of knowledge about drought and water scarcity, ranging from anecdotal, often unsystematic local knowledge to knowledge generated by local professionals for example officers in National Nature Reserves. As Lange & Cook (2015) have shown the drought governance space in England and Wales is confined with reference to the range of stakeholders involved and, as this report shows, at times also with reference to the range of environmental science knowledges and regulatory tools relied upon.

Local (expert) knowledge can therefore be a valuable addition to the body of knowledge about drought and water scarcity mobilised in the prevention and management of drought and water scarcity in the UK. Open questions with regard to local knowledge, however, remain such as how to deal with strongly biased views and how to systematise local knowledge, which so far is produced outside of the formal drought governance space.

5.6 Knowledge gaps

We asked interviewees what further knowledge they would like to have in order to govern water scarcity and drought. The answers crystallised around three key themes.

1. Clarifying normative benchmarks. Interviewees suggested they would welcome a clearer definition of the drought event they are planning for and the levels of service they should be aiming for.
2. Better and more environmental science data. In particular interviewees would welcome more attention to hydroecological data and its collection, also through monitoring.
3. Knowing about water use. Interviewees were interested in more knowledge about customer behaviour and customers' awareness of drought and water scarcity.

In the following section, we further discuss this aggregated list of knowledge gaps. Appendix A4 provides a detailed overview.

Clarifying normative benchmarks

A number of water companies and consultancies suggested that it was not clear what drought event they should be planning for:

> “What sort of event are we actually trying to cover? Are we trying to cover an event that might occur or are we trying to cover a real emergency? And that would be quite high up. I think there's a gap there.” (Interview DP1.WC10).

Others stated in more detail:

> “(…) it does not have to be absolutely prescriptive but some sort of steer from Government as to what type of events we're trying to plan to, because at the moment, if anybody said to us what's the frequency or magnitude of drought are you preparing to, as we were saying earlier, we're looking through the 91 year record that we've got but in terms of flooding, there's a standard that's been set. I have to be careful what I ask for but it's certainly something we have been talking about, something like that for drought just so everyone knows a bit more and they've got a benchmark, that's what you're aiming for. If you can plan to that and you can invest up to meeting the drought, that type of drought, that drought event, then that is good. If you get something that is more severe than that, then Government or the public would not expect you to be able to cope with it. So that little bit of direction I think would be really good.” (Interview DP1.WC2).

The view from consultancies was also in line with this:

“ One is the severity or to define the event that you’re planning to the systems needs to cope with or your responses need to cope with, and as I explained before, using a historic drought I believe is no longer appropriate.” (Interview DP1.CON1).

Closely related to this issue is the definition of what constitutes ‘exceptional lack of rainfall’. As one interviewee from a water company put it:

“ The Environment Agency can only grant a drought permit in the event of an exceptional lack of rainfall. There is no definition of what that means. So in 2011/12, we were having big debates with the EA about whether the driest 12 months sequence of a 100 years was an exceptional lack of rainfall or not and how do you define it and all the rest of it. And that was getting quite frustrating as to having some certainty that you were going to be able to secure this thing or not. So I think that would benefit, getting some clear criteria about when a drought permit would be granted.” (Interview DP1.WC3).

Staff in other water companies expressed similar thoughts, for instance asking how to define drought (Interview DP1.WC8), or that more knowledge about extreme drought events is necessary (Interview DP1.WC11).

Better and more environmental science data

The desire to generate and integrate more hydroecological data into drought governance was expressed across the range of interviews, i.e. by water companies, consultants, regulators but also abstractor groups. Hydroecological data cover the interaction between water and wildlife habitats of a catchment delivering an integrated view and providing a potentially more holistic approach towards water resource management (see also section 5.5).

Water companies stressed environmental resilience and what is happening with river ecology in the future as key areas that need more research:

“ We know on the Wye, the salmon run, there will be a point at which the salmon will not run and it won’t because there’s not enough water in the river, it’ll be because of the temperature. So there’s probably quite a lot to do there in understanding how the ecology might change and what the ecology needs in the future (…)” (Interview DP1.WC12).

Knowing more about water use

Expressed mainly by regulators was the wish to gain more insight into customer behaviour in relation to drought.

“ I suppose it is customer views and what we can learn from customer views and how we can potentially influence customers to ensure that, when we go into drought, everyone should be responsible and understand that water’s a finite resource and we all have a responsibility to make sure it lasts when it’s under pressure.” (Interview DP1.REG1).

Other remarks by regulators in this regard addressed the issue of starting a wider public discussion about drought and how to deal with it (Interview DP1.REG2) or aspects of fairness of drought restrictions and drought powers. This also included the suggestion to look at other countries and how they use regulatory powers and their range of drought options (Interview DP1.REG3).

5.7 Discussion

The previous sections identified key regulatory tools and key environmental science knowledges gathered and relied upon in drought and water scarcity management in England and Wales. Furthermore we commented, also in the context of a typology, of how environmental science knowledges inform the use of key regulatory tools. We presented key themes emerging from the interviews with regard to drought and water scarcity management and we identified knowledge gaps in relation to drought governance as identified by interviewees.

Our results identify a particular range and specific types of environmental science knowledges being gathered and relied upon to inform the use of specific regulatory tools. For example, the RSA interviews suggest a strong link between licence modifications/revocations and EU WFD assessments. Our results also suggest that at times a clear distinction between environmental science knowledges and regulatory tools can become blurred, with monitoring being one example of this. While monitoring is foremost an environmental science knowledge, it is also understood, especially by water companies, as quasi regulation.

The development of the typology of environmental science knowledges and regulatory tools is a key result discussed in this report. Based on the interview data and the subsequent list of key environmental science knowledges and regulatory tools we were able to highlight characteristics of environmental science knowledges that also influence their use. These characteristics refer to type (standard vs. exceptional; structuring vs. pinpointing; less contested vs. more contested; DIY environmental science knowledge vs. professionalised knowledge), aspects of scale (e.g. large infrastructure vs. on the spot), aspects of agency (agency vs. technical; pre-defined vs. shaped by users) as well as whether knowledge practices are primarily generated within or outside a particular organisation (water company internal and external knowledge) and some of the consequences of these knowledge practices (e.g. rendering visible vs. analysing drought risk, learning about drought risk vs. its strategic management). This novel typology helps to understand characteristics of and relationships between environmental science knowledges and regulatory tools, which, is also a significant aspect of drought governance in practice.

Furthermore, a number of key themes and knowledge gaps emerged from the interview data. These reveal trends in current thinking about drought and water scarcity management among major stakeholders.

The call for more hydroecological data, questions about the usefulness of the EFI and interest in clarifying normative benchmarks point not just towards the need for a larger, better and more varied data set to inform decisions about drought and water scarcity management, but also suggest that without such data it becomes difficult to specify the objectives of drought management. The themes regarding the relationship between water company drought planning and EA drought plans as well as links between drought and flood management further illustrate institutional aspects of managing drought and water scarcity and a potential need for greater integration of drought risk into existing institutional structures for water resource management. Local (expert) knowledge and the importance of knowing more about water users, such as customer behaviour with regard to water efficiency campaigns and how citizens perceive the fairness of drought restrictions, point towards an opening up of the drought governance space and the potential for including more stakeholders and their local (expert) knowledge.

The identification of the key themes and knowledge gaps also enabled us to comment on how relationships of power are shaped between the key actors in the drought governance space. For instance, shared monitoring responsibilities shift the balance of power from regulatory bodies to water companies and consultancies. The latter provide environmental science knowledges in case water companies lack the necessary in-house capacity to generate it. In order, however, for Drought Plans or drought permits/orders to be approved water companies have to provide the necessary data to support their arguments. This, though by some water companies described as ‘ticking boxes’, retains power for regulatory agencies who sometimes also employ consultancies to generate environmental science data. It would therefore be interesting to see how in the case of, e.g., more hydroecological data being gathered, this would tilt power relationships among the key stakeholders. Figure 1 exemplifies current power relationships in the UK drought governance space. The scale’s centre of gravity at the base is moveable indicating that shifts in power relationships are possible. The blue lines indicate the provision of environmental science knowledges as a resource for actors in this governance space that may influence relationships of power, e.g. consultants provide environmental science knowledge to water companies or Natural England which, in turn, provides knowledge to the EA.

Legal resources refer to primary and secondary legislation that grant legal powers and impose legal duties upon regulatory agencies and regulated organisations and thereby shape relationships of power between actors in the drought governance space.

Economic resources refer to financial means of regulatory agencies and regulated organisations in drought governance e.g. to implement particular drought management options, which is also shaped by decisions of the economic regulator of water companies in England and Wales, Ofwat.

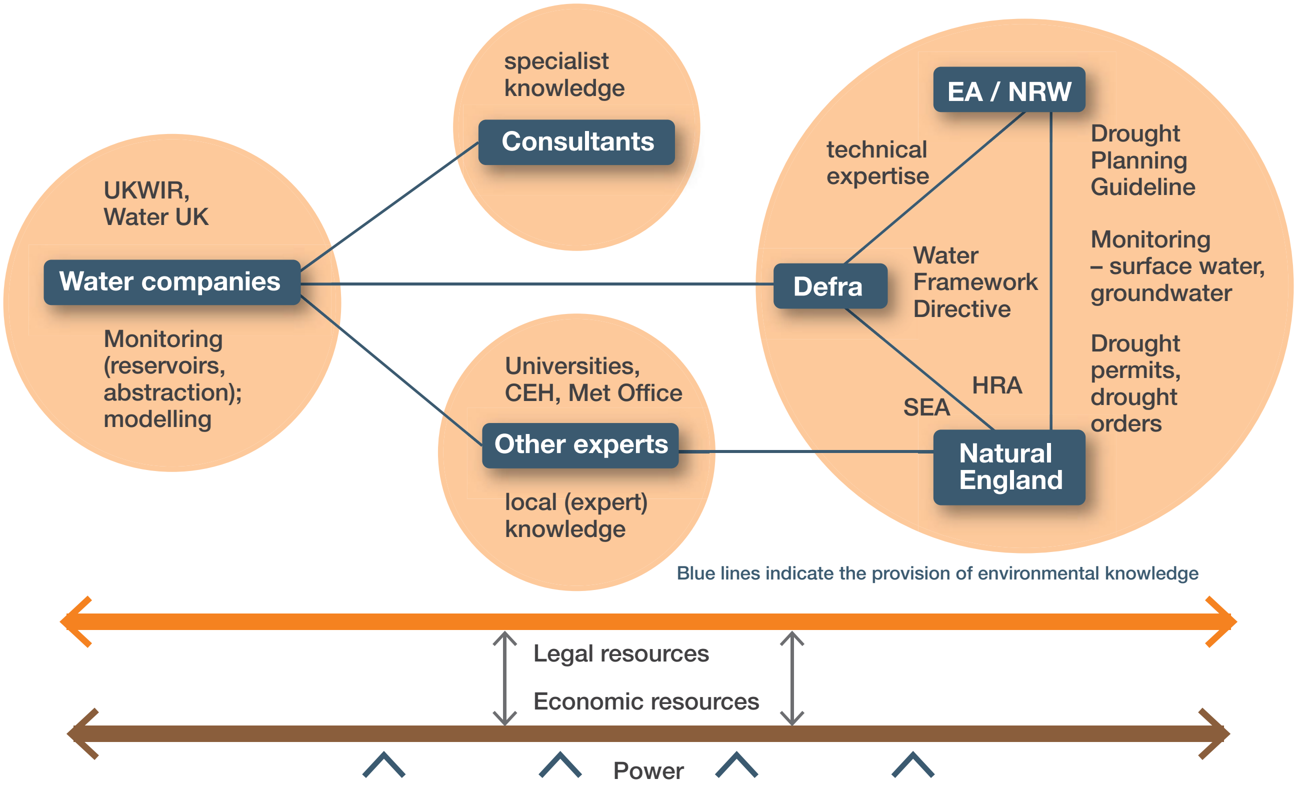


Figure 1. Relationships of power in the drought governance space in England & Wales

We have further identified through the research who the providers of environmental science knowledges are and what type of environmental science knowledges they provide. Appendix A3 provides an overview of the knowledge providers differentiated by case study, what type of environmental science knowledge they provide and how often knowledge providers were mentioned by interviewees. In the case of Drought Planning, Natural England is the most important environmental science knowledge provider followed by the two water industry bodies UKWIR and WaterUK. Natural England provide HRA related knowledge and they provide knowledge, such as data about river flows, groundwater levels, habitat or biological data during drought permit and drought order applications. UKWIR and WaterUK and their codes of practice and guidelines are a further important reference point especially for water companies during drought planning.

The Historic Drought interviews saw again Natural England as the most important environmental science knowledge provider especially with regard to feedback about SEAs and Sites of Special Scientific Interests (SSSI), followed by UKWIR and their Code of Practice ‘Managing Through Drought’.

The Environment Agency (EA), universities and other research institutions and consultants are the top three environmental science knowledge providers in the Restoring Sustainable Abstraction (RSA) case study. The EA delivers expert judgments, monitoring data and, for instance, groundwater models.

Universities and other research institutions such as Centre for Ecology and Hydrology Wallingford (CEH) also deliver expert judgements or reports on issues such as soil moisture or economic aspects. Consultants who are often hired by water companies if water companies lack sufficient in-house expertise provide specialist ecological, hydrological or hydroecological knowledge as well as technical investigations.

While the Historic Drought case study suggests that Natural England and UKWIR are two main environmental science knowledge providers during drought, the other two case studies pointed to a larger number of environmental science knowledge providers active during the Restoring Sustainable Abstraction Program and Drought Planning, such as the National Trust, RSBP, DWI, CCW but also local experts from angling clubs (see also section 5.5).

6 Example: Catfield Fen

The purpose of this example is to highlight the environmental science knowledges that were used in this case, how they link to the application of a regulatory tool and to showcase challenges but also opportunities with regard to what knowledge is applied and which stakeholder provides which type of knowledge. The chosen example involves contestation of environmental science knowledges, and thus also sheds light on relationships of power between key actors in the drought governance space. The example will be introduced, different stakeholder views will be presented and this section will conclude with a discussion of the example in relation to the research questions.

Catfield Fen is a wetland nature reserve in the county of Norfolk. It is one of the most important areas of fen in the United Kingdom providing habitat to many rare species, especially invertebrates but also rare plants such as the fen orchid. Catfield Fen is not open to the public. It is partly owned by Butterfly Conservation, a large butterfly conservation organisation, owning 24 ha (Butterfly Conservation, n.d.). The remainder is owned privately by the Catfield Hall Estate.

In the context of Restoring Sustainable Abstraction, Catfield Fen is a good example of how environmental science knowledges can be generated and contested. So far it represents the longest running controversy over an abstraction site. Two abstraction licences held by a farmer were up for renewal, yet site managers, local ecologists, the Broads Authority and Natural England raised doubts over the hydrological modelling carried out by the Environment Agency. Opponents claimed that it was insufficient to conclude that the abstractions would have no effect on the integrity of the site (BAWAG, 2018).

A public inquiry was held, during which, however, the farmer's claim to renewal of the licences was not upheld. The farmer also lost his appeal against the Planning Inspector's decision in September 2016 (Case, 2016). The public inquiry concluded that the fen is in danger due to ecological change, increasing acidification is the cause and that water abstraction is the most likely explanation because it reduces the flow of alkaline groundwater to the fen (Environment Agency, 2015a).

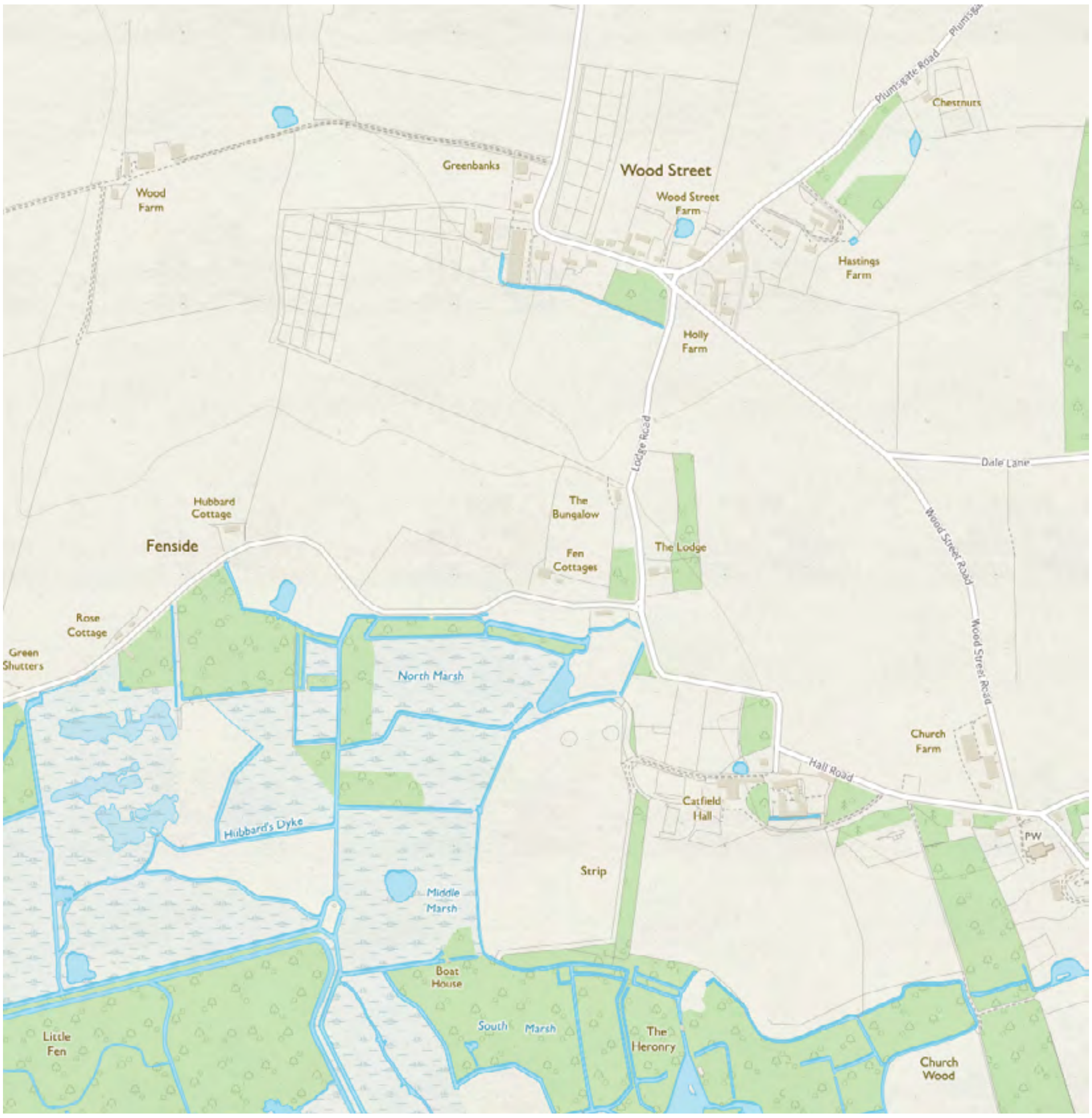


Figure 2. Catfield Fen (centre of map)

The Catfield Fen example illustrates the use of one of the primary sources of environmental science knowledges in drought and water scarcity management: modelling, in this case: the EA's Northern East Anglia Chalk (NEAC) groundwater model. Several stakeholders challenged the applied groundwater model and found it to be inadequate in this particular instance.

Originally, the Environment Agency granted an extension of the abstraction licences to the farmer. However, the licences came under reconsideration after new information was provided by the Catfield Hall Estate landowner.

This concerned the model used by the EA as well as water quality issues. The water quality aspect addressed the assumption that the water abstraction by the farmer is pulling away alkaline groundwater and that the fen is affected by a reduction in alkaline water and more acidic rainfall. This is changing the pH of the soil on the fen, which is having an adverse impact on the population of fen orchids.

In 2008, the Environment Agency undertook groundwater modelling to assess if the fen is drying out, as claimed by the landowner. The EA concluded that the site is not drying out but that there is ecological change in the form of acidification caused by a reduction in base rich groundwater. The landowner and other organisations such as the Broads Authority subsequently provided the EA with more and new information leading to the decision to revoke the two abstraction licences for the farmer based on the grounds that the EA cannot ascertain beyond reasonable scientific doubt that the abstractions will not adversely affect the site's integrity (Environment Agency, 2015a). The applied groundwater model was then criticised. The Broads Authority expressed concerns regarding the model in a response to the EA's groundwater report:

> “ An inadequate groundwater model development process has been followed; failing to use the Environment Agency modelling guidelines; (…); Given the shortcomings of the conceptual models and computational modelling, the results from the modelling are not reliable and should not be used for licence determination.” (Kelly, 2014, p. 8)

Natural England concluded that there are instances where new data becomes available and the groundwater model may not haved picked up the sensitivities of the site (Interview RSA.REG4). The regional water company, who is affected by this through an in-combination effect (see below) wondered where it is taking them:

> “ Because it is fundamentally questioning what's happening in terms of all this groundwater modelling and where we've got to previously, and that's my concern and I think the EA's concern on that as well. (…) It does not take long before you can start unravelling a model and say that's where I'm concerned. It's the best tool that we have available now, do we really want to be unpicking these things? I am not comfortable with where we could end up, but I know that is where the challenges are coming in at the moment.” (Interview RSA.WC2).

The Catfield Fen example also touches upon how legal principles, such as the precautionary principle may shape the generation and use of environmental science knowledges.

The precautionary principle states that the burden of proof for the proposition that an action is not harmful falls on those taking that action (Fisher, Lange, & Scotford, 2013, Ch. 11; Knill & Liefferink, 2007). In other words, in the case of Catfield Fen the farmer who wanted his two licences renewed had to prove that his abstraction for agricultural purposes does not cause harm to the Catfield Fen site with regard to water quality issues.

According to abstractor groups, individual farmers usually lack the resources or the knowledge to oppose regulatory action on biological grounds and that this requires usually significant sums of money (cf. Interview RSA.ABS3).

> “ A possible cause of the revocation of those licences in Norfolk was the fact that the guy [the landowner of Catfield Estate] who wanted them revoked was able to finance as many different reports and researchers and solicitors and lawyers as he could care to do, because he's always got an unlimited pit of money where that particular subject was concerned. So he could do that but the farmers, who are on notice really, were unable to provide evidence of their own to refute what's been put forward because they just hadn't got the resources to do it, or to fight the case.” (Interview RSA.ABS1).

Furthermore the example incurred an in-combination effect because not only the farmer applied for the renewal of his two existing licences but Anglia Water also hold a large abstraction licence (of right) in the same area. According to the local water company:

> “ We've had some letters and we've reached an agreement with the EA to say that as an interim measure, you haven't flagged this soon enough for us to put a solution in place now, we will do something in AMP7 and as for AMP6 we will reach an interim solution that we try and reduce our abstraction on Ludham [Catfield Fen site], recognising that you've had these challenges from elsewhere.” (Interview RSA.WC2).

In summary, the Catfield Fen example shows how the use of a key environmental science knowledge, in this case modelling, informs a decision about an abstraction licence. It also shows that the decision relied significantly upon this particular environmental science knowledge. With reference to the typology of environmental science knowledges presented in section 5.3 above, Catfield Fen provides an example of contested knowledge. The originally applied model was heavily disputed by several stakeholders and declared as inadequate. However, further local expert knowledge, an overall key theme identified by our research, was provided and influenced the final decision.
In addition, Catfield Fen is a good example of the value of hydroecological data. The data that was used to contest the existing data was essentially hydroecological data that provided a more holistic view of the Catfield Fen site and the effect that a continued water abstraction could have. With regard to relationships of power in the drought governance space the Catfield Fen example is unusual as it only involves water companies marginally. Instead, relationships of power between a well-resourced landowner who was able to commission expertise as opposed to a farmer with fewer resources were a key feature of the particular Catfield Fen example. The example, however, does show how multiple expertise by mostly non-regulatory bodies can challenge an environmental science knowledge basis gathered by one of the main regulatory bodies in the drought governance space. The validity of the EA's groundwater model was questioned, a key environmental science knowledge and usually a strong lever for decisions made by the EA.

7 Conclusions & recommendations

The aim of this report was to identify key regulatory tools, key environmental science knowledges and links between them as a key aspect of drought and water scarcity governance in England and Wales. We presented data from three case studies which examined the link between environmental science knowledges and regulatory tools in different contexts – the revision of abstraction licences, drought planning and the use of regulatory tools during recent UK drought episodes.

In addition, the research identified providers of environmental science knowledges and sought to explore how a specific range of environmental science knowledges shape relationships of power between the key institutional actors in the drought governance space. Addressing this question helps to understand how the governance space in relation to drought and water scarcity is configured, enabling us to draw some conclusions about key lines of influence between various actors in this governance space.

The Catfield Fen example highlights a controversy over a particular abstraction site, it further illustrates key themes of the research: shifting relationships of power, the validity of environmental data and the emerging relevance of local (expert) knowledge.

Based on our results we recommend the following for drought and water scarcity management in England and Wales:

To explore the potential for including more hydroecological data in drought and water scarcity management.

As pointed out before this was identified as a key research theme and as a knowledge gap. Including hydroecological data could provide a more holistic picture of e.g. catchments thereby leading to better informed decisions.

To include local (expert) knowledge.

Besides formal knowledge generated and gathered at a national or regional scale by the current key actors in the drought governance space, local knowledge – generated and provided by semi-professional or professional bodies such as local environmental non-governmental organisations or local experts in their capacity as professionals working for example for a regulatory body – can be a valuable addition to the existing stock of environmental science knowledges. Water companies have started to recognise the potential. It remains, however, unclear so far how to successfully integrate local knowledge, which can be unsystematic, anecdotal or strongly biased, into decision-making about drought risk.

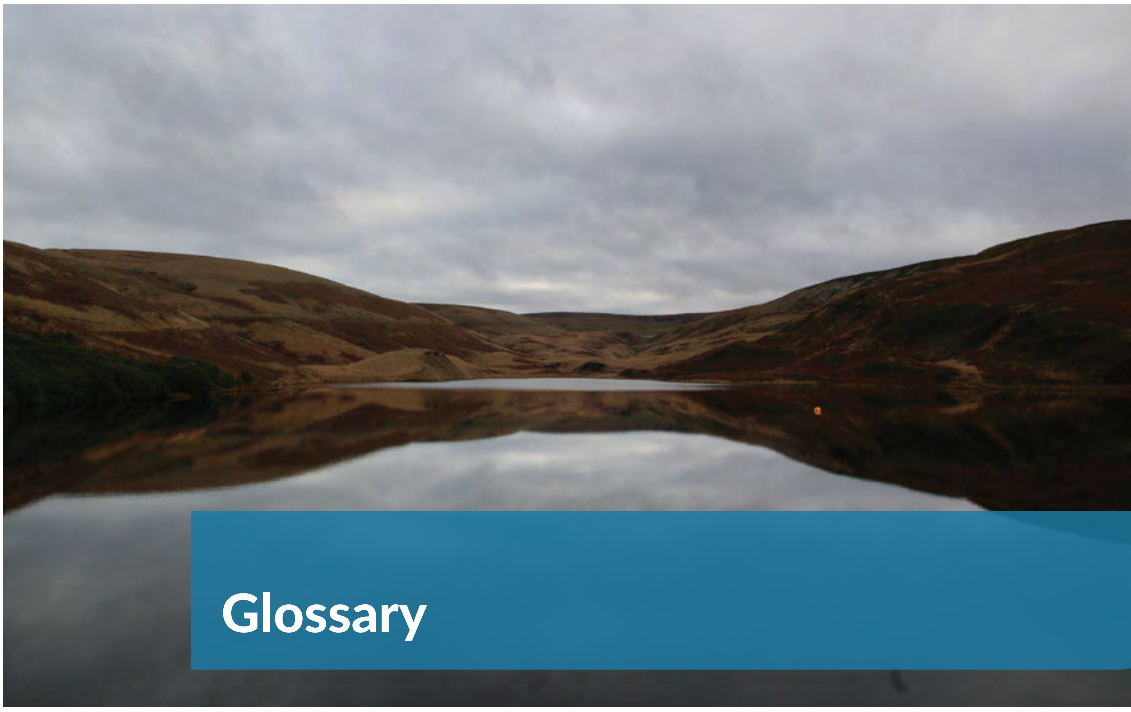
To 'streamline' regulations and policies.

Water company Drought Plans, EA area voluntary drought plans, WRMPs, and flood management plans are all cornerstones of water resources management yet these plans and the legal regulations shaping their drafting are not aligned. We recommend to research the potential for aligning these regulations and plans in order to achieve more integrated water resources management. Especially the statutory water company Drought Plans and the currently voluntary EA area drought plans can be more valuable resources if they are more aligned.

To use the typology to identify the most appropriate type of environmental science knowledge and regulatory tool.

The typology highlights characteristics of environmental science knowledges and regulatory tools. It refers, for instance to type, agency, scale and consequences of knowledges linked to tools. The typology may be useful for water companies and regulators for understanding the implications for drought governance of environmental science knowledges linked to regulatory tools.

Photo of Wessenden Head Reservoir, Holmfirth by Michael Podger via Unsplash



Glossary

Abstraction	Removal of water from any source.
Abstraction licence	Legal authorisation granted by the Environment Agency to allow the removal of water from a source.
Aquifer	Geological formation containing or conducting groundwater.
Catchment	An area of land defined by its topographic watershed – including streams, rivers, wetlands and lakes – from which precipitation collects and discharges to a defined outlet such as a river mouth, tributary confluence or lake.
Drought	According to the EA (2015b) there is no single definition of drought. All droughts are characterised by some degree of rainfall shortage. Each drought is different, with the nature, timing and impacts varying according to location and which sectors are affected such as public water supply, agriculture, the environment or industry. The EA differentiates between three main types of drought: environmental, agricultural and water supply.
Governance	governance describes steering mechanisms and new modes of coordination, cooperation and management across multiple levels that include various interdependent actors from politics, economy and civil society aiming at making binding political decisions based on negotiations.
Groundwater	Water found underground stored in aquifers.

Levels of service	Planned average frequency of potential drought induced restrictions on water supply imposed upon customers by water companies.
Resilience	extent to which a system can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or even unexpectedly flipping into less desirable states.
Surface water	Term used to describe all water features such as rivers, streams, springs, ponds and lakes.
Water resource zone	The largest possible zone in which all resources, including external transfers, can be shared and hence the zone in which all customers experience the same risk of supply failure from a resource shortfall.
Water scarcity	Lack of sufficient available water resources to meet demand.

Sources: own, Defra, EA, UKWIR

Photo of Wilsden by Richard Horne via Unsplash

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Appendix

Appendix A1 – Overview of regulatory tools and environmental science knowledges

Regulatory Tools								
Interview	Interview Type*	TUBs	Drought Orders	Drought Permits	Drought Planning	RSA	WRMP	what else? (e.g. flood management, desalination etc.)
A2.DP1.CON1	DP		x	x	x		x	Drought planning exercise
A2.DP1.CON2	DP		x	x	x		x	
A2.DP1.CON3	DP	x	x	x	x			
A2.DP1.REG1	DP		x	x	x	x	x	
A2.DP1.REG2	DP	x	x	x	x	x		
A2.DP1.REG3	DP		x	x	x	x	x	Standpipes
A2.DP1.REG4	DP		x	x	x	x	x	
A2.DP1.REG5	DP		x	x	x	x	x	Emergency drought orders
A2.DP1.REG6	DP				x			Monitoring
A2.DP1.WC1	DP	x	x	x	x	x	x	Desalination
A2.DP1.WC2	DP	x	x	x	x			Industrial reuse of water

Environmental Science Knowledges									
Interview	Interview Type*	SEA*	HRA	WFD	EAR	Drought Planning Guideline	Knowledge from /collaboration with + type of knowledge they provide		Other types of knowledge interviewees mentioned
A2.DP1. CON1	DP	x	x	x		x	Natural England		
A2.DP1. CON2	DP	x	x	x	x	x	Natural England, English Heritage, National Trust, local angling club, rivers trust	For drought permits and orders: river flows, groundwater levels, habitat, river flow, morphology, biological data	Environmental monitoring
A2.DP1. CON3	DP	x	x	x	x	x	Natural England; UKWIR	HRA related (Natural England); guidance on SEAs and HRAs (UKWIR)	
A2.DP1. REG1	DP	x	x	x				Water situation reports	EA voluntary drought plan, CROW Act
A2.DP1. REG2	DP	x			x		MetOffice, local expertise	Water situation reports, historic data	
A2.DP1. REG3	DP	x	x	x	x	x	Natural England	Water situation reports	
A2.DP1. REG4	DP	x	x	x		x			
A2.DP1. REG5	DP	x	x	x		x	Natural England		
A2.DP1. REG6	DP	x	x				Rivers and Fisheries Trusts	Monitoring and surveying	Nature Conservation Act; monitoring; consultation responses
A2.DP1. WC1	DP	x					UKWIR; consultants; CC Water; Natural England	Drought permit baseline monitoring (consultants)	
A2.DP1. WC2	DP			x		x	Water UK	Managing Through Drought Code and Practice	

Regulatory Tools								
Interview	Interview Type*	TUBs	Drought Orders	Drought Permits	Drought Planning	RSA	WRMP	what else? (e.g. flood management, desalination etc.)
A2.DP1. WC3	DP	x	x	x	x		x	
Water UK	Code of Practice on TUBs							
A2.DP1. WC4	DP		x	x	x	x	x	Desalination, aquifer storage, effluent reuse
A2.DP1. WC5	DP	x	x	x	x	x	x	
A2.DP1. WC6	DP	x		x	x			Water recycling
A2.DP1. WC7	DP	x	x	x	x	x	x	Water reuse, (temporary) desalination, new reservoirs
A2.DP1. WC8	DP		x	x	x	x	x	Smart metering, constructing wetlands, farm storage, aquifer recharge, water recycling
A2.DP1. WC9	DP	x	x	x	x			Voluntary hosepipe ban
A2.DP1. WC10	DP	x	x	x	x	x	x	Metering, water recycling; strategic reservoir
A2.DP1. WC11	DP	x	x	x	x	x	x	Bankside storage tanks
A2.DP1. WC12	DP	x	x	x	x	x	x	Effluent recycling, enlargement of existing reservoir; water efficiency promotion; (mobile) desalination
A2.HIS. REG1	HIS		x	x	x			
A2.HIS. CON1	HIS	x	x	x		x	x	Metering, RV, water efficiency campaigns, water trading, SUDS
A2.HIS. WC1	HIS		x	x	x			Monitoring

Environmental Science Knowledges									
Interview	Interview Type*	SEA*	HRA	WFD	EAR	Drought Planning Guideline	Knowledge from /collaboration with + type of knowledge they provide		Other types of knowledge interviewees mentioned
A2.DP1. WC3	DP	x	x	x	x	x	UKWIR/		
Water UK	Code of Practice on TUBs								
A2.DP1. WC4		x	x	x		x	Natural England		
A2.DP1. WC5		x	x	x	x	x	UKWIR	Code of Practice	
A2.DP1. WC6		x		x					
A2.DP1. WC7		x	x				Water UK		Benefit Assessment Guide, Real Options Appraisal, Multi Criteria Analysis
A2.DP1. WC8		x				x	Rivers trusts, wildlife trusts		
A2.DP1. WC9		x	x	x	x	x	Natural England; UKWIR		Environmental monitoring plan (internal); Flood and Water Management Act
A2.DP1. WC10		x	x	x		x	Water UK; UKWIR; (both+ committees and steering groups) ; Natural England	Water resources planning	
A2.DP1. WC11		x	x	x		x			Drought monitoring
A2.DP1. WC12		x	x			x	Natural England		National Environment Plan, drought action monitoring plans
A2.HIS. REG1						x	UKWIR, Water UK	Code of Practice	
A2.HIS. CON1				x					Waste Water Directive
A2.HIS. WC1					x	x			

Regulatory Tools								
Interview	**Interview Type***	**TUBs**	**Drought Orders**	**Drought Permits**	**Drought Planning**	**RSA**	**WRMP**	**what else? (e.g. flood management, desalination etc.)**
A2.HIS. WC2	HIS		x	x			x	Monitoring
A2.HIS. WC3	HIS	x	x	x	x		x	Monitoring
A2.HIS. WC4	HIS	x	x	x	x		x	Monitoring
A2.HIS. WC5	HIS	x	x	x	x			Monitoring; metering; storage rainwater tanks (for businesses), on-site storage
A2.HIS. WC6	HIS	x	x	x	x			Metering, water efficiency education; leakage reduction, district metering
A2.HIS. OTH1	HIS	x	x	x	x		x	Effluent reuse; desalination; leakage reduction; metering
A2.HIS. WC7	HIS		x	x	x		x	
A2.RSA. REG1	RSA					x		Aquifer recharge; new reservoirs; winter storage reservoirs
A2.RSA. REG2	RSA					x		
A2.RSA. REG3	RSA					x		Reservoirs, joint licenses
A2.RSA. REG4	RSA					x		drought agreement with EA
A2.RSA. REG5	RSA					x	x	

Environmental Science Knowledges									
Interview	Interview Type*	SEA*	HRA	WFD	EAR	Drought Planning Guideline	Knowledge from /collaboration with + type of knowledge they provide		Other types of knowledge interviewees mentioned
A2.HIS. WC2		x	x	x	x	x			
A2.HIS. WC3		x	x		x	x	Natural England		Statement of Reason; monitoring; drought hearings
A2.HIS. WC4							Natural England		Statement of Need; monitoring; drought hearings; company internal drought dashboard
A2.HIS. WC5				x			Natural England		Baseline monitoring; hearings; catchment management
A2.HIS. WC6		x					Natural England		
A2.HIS. OTH1							Natural England		Monitoring Plan (part of DP); Building Codes for PCC
A2.HIS. WC7		x	x				Natural England		Monitoring; hydrological modelling
A2.RSA. REG1				x			University (MSc students)	Reports (on economics)	Monitoring
A2.RSA. REG2			x	x			Cranfield University	Soil moisture deficits	Modelling (done by EA); precautionary principle
A2.RSA. REG3			x	x					Environmental stewardship
A2.RSA. REG4							FDF		
A2.RSA. REG5				x			MetOffice	Hydrometric data	Benefits Assessment Guide (BAG); Environmental Flow Indicator (EFI); LIFE Scores, Physical Habitat Simulation Modelling

Regulatory Tools								
Interview	Interview Type*	TUBs	Drought Orders	Drought Permits	Drought Planning	RSA	WRMP	what else? (e.g. flood management, desalination etc.)
A2.RSA. REG6	RSA					x		Licence change
A2.RSA. CON1	RSA		x	x		x		Licence change
A2.RSA. WC1	RSA					x	x	
A2.RSA. WC2	RSA					x		
A2.RSA. WC3	RSA					x		
A2.RSA. WC4	RSA					x		
A2.RSA. WC5	RSA			x		x	x	

Environmental Science Knowledges

Interview	Interview Type*	SEA*	HRA	WFD	EAR	Drought Planning Guideline	Knowledge from /collaboration with + type of knowledge they provide		Other types of knowledge interviewees mentioned
A2.RSA. REG6				x					Flow data, abstraction data, CAMS (Catchment Abstraction Management Strategies); Licence Change Proposal Report; Ram reports (flow and abstraction)
A2.RSA. CON1				x					Environmental Flow Indicator, hydromorphological river studies; sediment analysis, salmonid flow requirements; pearl mussel flow requirements; serious damage assessment
A2.RSA. WC1				x			Water companies	They do all the investigation regarding licence changes	CAMS, BAG (Benefits Assessment Guide), NWEBS WFD; ecological data
A2.RSA. WC2				x			EA; National Nature Reserves	Hydrological Impact Assessment; local knowledge, site officers	Conservation objectives; Common Standards Monitoring; NVC (National Vegetation Classification)
A2.RSA. WC3				x					
A2.RSA. WC4				x					Modelling; Life model
A2.RSA. WC5				x			EA; CEH and academics	Expert judgements; groundwater	Catchment Review; LIFE; Dried Up (ecological impact and river morphology); RIVPACS (community); signal test

Regulatory Tools								
Interview	**Interview Type***	**TUBs**	**Drought Orders**	**Drought Permits**	**Drought Planning**	**RSA**	**WRMP**	**what else? (e.g. flood management, desalination etc.)**
A2.RSA. WC6	RSA					x	x	
A2.RSA. WC7	RSA					x	x	
A2.RSA. WC8	RSA		x	x		x		
A2.RSA. ABS1	RSA			x		x	x	
A2.RSA. ABS2	RSA	x	x	x		x	x	Sediment removal; lowering abstraction cessation level; tankering water
A2.RSA. ABS3	RSA					x	x	Water reuse schemes; desalination; wetlands; aquifer recharge; changes in channel morphology

Environmental Science Knowledges									
Interview	Interview Type*	SEA*	HRA	WFD	EAR	Drought Planning Guideline	Knowledge from /collaboration with + type of knowledge they provide		Other types of knowledge interviewees mentioned
A2.RSA. WC6				x			EA, consultants		Modelling (groundwater); WRGIS; CAMS
A2.RSA. WC7				x					CAMS; modelling
A2.RSA. WC8				x			EA, Natural England	Scoping document, monitoring, shared groundwater model (EA)	CAMS, hydrogelogical, hydrological, surveys, modelling; EFI; AIM
A2.RSA. ABS1				x			EA, consultants	Site Action Plan	Low Flows Enterprise (software developed by CEH), acoustic fish barrier; PHABSIM; LIFE; hydrological modelling; hydrometric stations
A2.RSA. ABS2			x	x			Academia	Groundwater/ surface water model	Post-implementation monitoring; observation boreholes; piezometer; groundwater monitoring; ecological surveys; water quality sampling; modelling; AIM
A2.RSA. ABS3				x					Hydroecology; BAG; stochastic methods; modelling; Willingness to Pay surveys

Regulatory Tools								
Interview	Interview Type*	TUBs	Drought Orders	Drought Permits	Drought Planning	RSA	WRMP	what else? (e.g. flood management, desalination etc.)
A2.RSA. ABS4	RSA			x		x		Group licences; storage increase (reservoir; decrease compensation flow)

* SEA – quantitative assessment; “x” only indicates interviewee mentioned SEA

* Interview Type – DP= Drought planning; HIS= Historic Droughts; RSA= Restoring Sustainable Abstraction

Environmental Science Knowledges									
Interview	**Interview Type***	**SEA***	**HRA**	**WFD**	**EAR**	**Drought Planning Guideline**	**Knowledge from /collaboration with + type of knowledge they provide**		**Other types of knowledge interviewees mentioned**
A2.RSA. ABS4				x			Other stakeholders (local, NGOs)	Local data	Impact assessment; CAMS; (complete) monitoring; EFI; modelling; LIFE scores; West Midlands Worfe Groundwater Model (hydroecology); site investigation plan; spot flow gauging, invertebrate monitoring, walk-over surveys, habitat surveys; short and long term trials (reduced flow); BAG; WAG; Willingness to Pay surveys

* SEA – quantitative assessment; “x” only indicates interviewee mentioned SEA

* Interview Type – DP= Drought planning; HIS= Historic Droughts; RSA= Restoring Sustainable Abstraction

Appendix A2 – Ranking environmental science knowledges

Environmental Science Knowledge	total	DP	HIS	RSA
Monitoring	12	4	4	4
Modelling	11		1	10
LIFE Scores	5			5
Catchment management + CAMS	5		1	4
Benefit Assessment Guide	5	1		4
Environmental Flow Indicator	4			4
AIM (Abstraction Incentive Mechanism)	2			2
PHABSIM	2			2
Willingness to pay surveys	2			2
Drought hearings	2		2	
Common Standards Monitoring	1			1
Post-implementation monitoring	1			1
Licence Change Proposal report	1			1
Hydromorphological river studies	1			1
Environmental stewardship	1			1
Serious damage assessment (WFD context)	1			1
National Vegetation Classification	1			1
Stochastic methods	1			1
West Midlands Worfe Groundwater model	1			1
Dried Up	1			1
RIVPACS	1			1
WRGIS (Water Resources GIS system)	1			1
Low Flows Enterprise	1			1
RAM report	1			1
Salmonid flow requirements	1			1
Pearl mussel flow requirements	1			1
Acoustic fish barrier	1			1
Flow data	1			1
Abstraction data	1			1
Sediment analysis	1			1
Hydrometric stations	1			1

Environmental Science Knowledges	total	DP	HIS	RSA
Observation boreholes	1			1
Piezometers	1			1
Spot flow gauging	1			1
Invertebrate monitoring	1			1
Walk-over surveys	1			1
Habitat surveys	1			1
Short and long term trials	1			1
Site investigation plan	1			1
Statement of reasons	1		1	
Statement of need	1		1	
company internal drought dashboard	1		1	
Nature Conservation Act	1	1		
CROW Act	1	1		
Flood and Water Management Act (sections on water use restrictions)	1	1		
National Environment Programme	1	1		
Consultation responses (to proposed legislation)	1	1		
Real Options Appraisal	1	1		
Multi Criteria Analysis	1	1		
EA voluntary drought plan	1	1		

This table is a list of all environmental science knowledges mentioned by interviewees and which were categorised as ‘other types of knowledge’ (see Appendix 1). An example how to read the table is: ‘monitoring’ was mentioned 12 times, 4 times in the Drought Planning Interviews (DP) etc.

Appendix A3 – Providers of environmental science knowledges

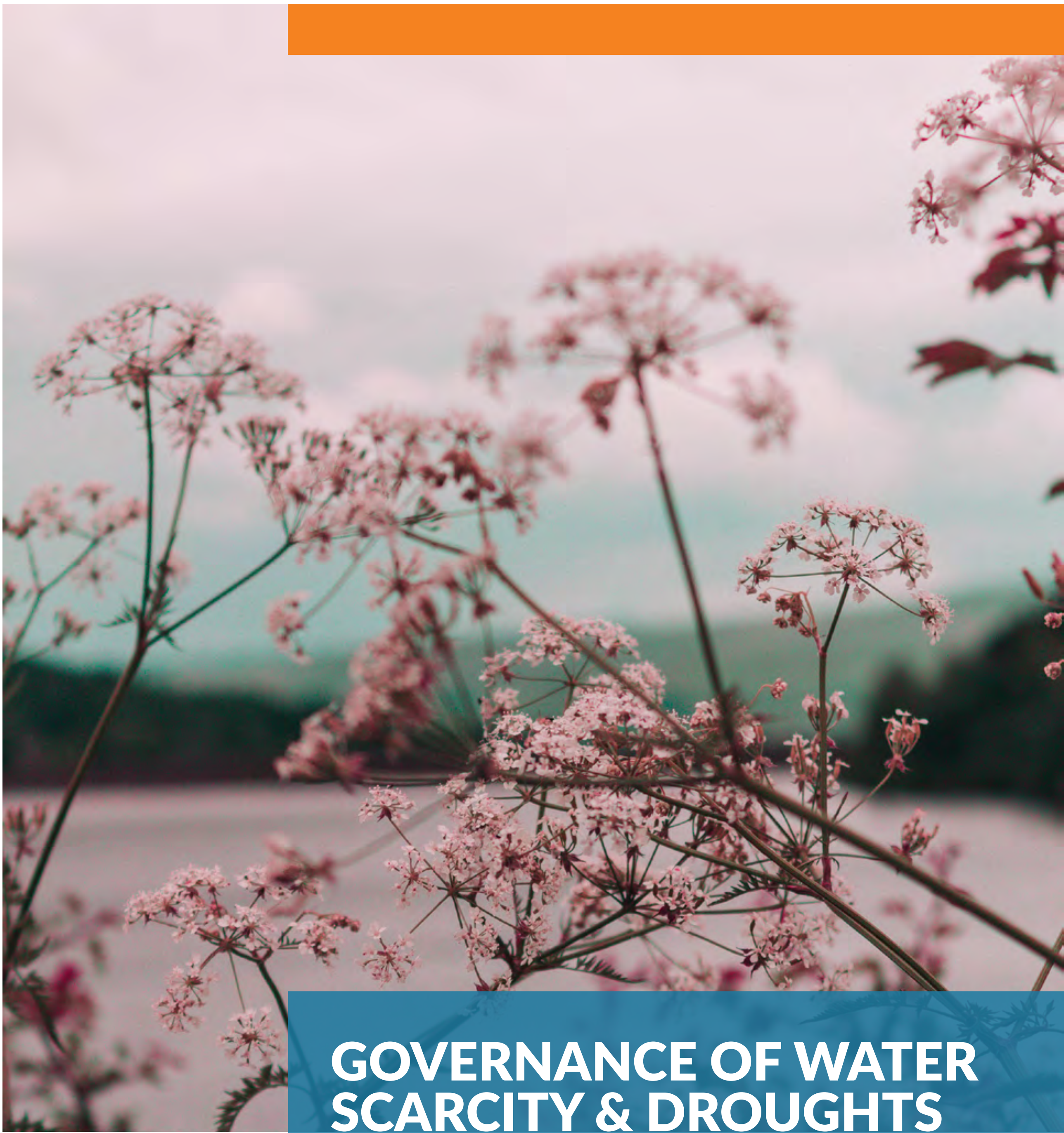
Drought Planning		
Knowledge provider		**Which knowledge?**
Natural England	10	For drought permits and orders:river flows, groundwater levels, habitat, river flow, morphology, biological data; HRA related
UKWIR	6	Guidance on SEAs and EARs; Code of Practice
Water UK	4	Managing Through Drought Code of Practice
Rivers Trust	3	Monitoring and surveying
English Heritage	1	Consulting them and assessing if an option could affect them
National Trust	1	Consulting them and assessing if an option could affect them
Local angling club	1	Consulting them and assessing if an option could affect them
Met Office	1	Water situation reports
Local expertise	1	Historic data
Consultants	1	Drought permit baseline monitoring
CC Water	1	Water company consulting with them re Drought Plan (asking for input and comments)
WWF	1	Water company consulting with them re Drought Plan (asking for input and comments)
Local authorities	1	Water company consulting with them re Drought Plan (asking for input and comments)
RSPB	1	Water company consulting with them re Drought Plan (asking for input and comments)
DWI	1	Water company consulting with them re Drought Plan (asking for input and comments)
Wildlife Trust	1	Water company consulting with them re Drought Plan (asking for input and comments)

Historical Droughts		
Knowledge provider		**Which knowledge?**
Natural England	6	Feedback regarding SEA, SSSIs
UKWIR	1	Code of Practice
Restoring Sustainable Abstraction		
Knowledge provider		**Which knowledge?**
Environment Agency	5	Hydrological Impact Assessment; expert judgements; scoping document; monitoring;
Shared groundwater model (with water company); site action plan		
Academia (universities, CEH)	5	Reports on economics; soil moisture deficits; expert judgements; groundwater and surface water models
Consultants	2	Specialist knowledge (ecology, hydroecology, hydrogeology);
Technical investigations; critical reviews of outputs (from reports) re scientific robustness		
Met Office	1	Hydrometric data
Water companies	1	Investigations re licence changes
National Nature Reserves	1	Local knowledge and site officers
Natural England	1	Scoping document (within NEP; boundaries of a study, timescale, techniques etc.)
Local stakeholders	1	Local data
NGO	1	Local data
Trade association (FDF)	1	Meetings, consultation responses

This table provides an overview of who provides knowledge and which knowledge they provide. The 2nd column displays how often a knowledge provider was mentioned.

Appendix A4 – Environmental science knowledge gaps and interests

Gap or interest	Type of gap or interest	Brief description of gap or interest	Type of organisation that identified gap or interest
Knowing about water use: Customer behaviour and awareness	Customer behaviour	Customer behaviour and awareness	Regulator
	Customer behaviour	Water efficiency (education, behaviour change)	Regulator
	Customer behaviour	Interested in fairness of drought restrictions and drought powers (such as Section 57)	Regulator
Better and more environmental science data: more attention to hydroecological data and its management (including monitoring)	Data (management)	Where does the responsibility lie for maintaining data?	Consultancy
	Data (management)	National library of baseline data and other things would exist – in other words a recognised dataset	Consultancy
	Hydroecology	Ecological resilience of rivers	Consultancy
	Hydroecology	More research into environmental monitoring (what the EA want the water companies to provide in advance of a drought permit so that they better understand the potential damage; currently not particularly clear in the guideline)	Regulator
	Hydroecology	Ecological aspects of drought (fish and water temperatures)	Water company
	Hydroecology	More research into groundwater triggers and sandstone aquifers (current research tends to chalk aquifers in the south)	Water company
	Hydroecology	More attention to the environmental side (what are we monitoring?)	Water company
	Hydroecology	Knowledge about soil, water and irrigation	Abstractor group
	Monitoring	Good, long term baseline monitoring	Consultancy
	Monitoring	National rainfall record	Water company
Clarifying normative benchmarks: Definition of the drought event we are planning for and levels of service	Planning	Defining the event (severity) you are Planning for	Consultancy
	Planning	Identify weaknesses and cost effective solutions	Regulator
	Planning	What sort of event we are actually planning/trying to cover?	Water company
	Planning	More knowledge about extreme drought events	Water company
	Planning	What event are we planning for?	Water company
	Planning	Definition of "exceptional lack of rainfall" needed	Water company
	Planning	What Levels of Service and outcome do regulators want for UK water	Water company
	Planning	How has the WFD and abstraction reform been assessed in terms of the economics of the implications arising from the legislation, and is there expectation that water company customers will be paying for that?	Water company
	Planning	Definition of drought	Water company
	Planning	What event are we planning for?	Water company



GOVERNANCE OF WATER SCARCITY & DROUGHTS

Dr Kevin Grecksch & Dr Bettina Lange, Centre for Socio-Legal Studies, University of Oxford and MaRIUS (Oxford) project.

Managing the Risks, Impacts and Uncertainties of drought and water Scarcity (MaRIUS) introduces a risk-based approach to drought and water scarcity in order to inform management decisions and prepare households.

www.mariusdroughtproject.org

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