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Adaptive and risk-based approaches to climate change and the management of uncertainty and institutional risk: The case of future flooding in England



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ABSTRACT

This paper focuses on how scientific uncertainties about future peak flood flows and sea level rises are accounted for in long term strategic planning processes to adapt inland and coastal flood risk management in England to climate change. Combining key informant interviews ($n = 18$) with documentary analysis, it explores the institutional tensions between adaptive management approaches emphasising openness to uncertainty and to alternative policy options on the one hand and risk-based ones that close them down by transforming uncertainties into calculable risks whose management can be rationalized through cost-benefit analysis and nationally consistent, risk-based priority setting on the other hand. These alternative approaches to managing uncertainty about the first-order risks to society from future flooding are shaped by institutional concerns with managing the second-order, 'institutional' risks of criticism and blame arising from accountability for discharging those first-order risk management responsibilities. In the case of river flooding the poorly understood impacts of future climate change were represented with a simplistic adjustment to peak flow estimates, which proved robust in overcoming institutional resistance to making precautionary allowances for climate change in risk-based flood management, at least in part because its scientific limitations were acknowledged only partially. By contrast in the case of coastal flood risk management, greater scientific confidence led to successively more elaborate guidance on how to represent the science, which in turn led to inconsistency in implementation and increased the institutional risks involved in taking the uncertain effects of future sea level rise into account in adaptation planning and flood risk management. Comparative analysis of these two cases then informs some wider reflections about the tensions between adaptive and risk-based approaches, the role of institutional risk in climate change adaptation, and the importance of such institutional dynamics in shaping the framing uncertainties and policy responses to scientific knowledge about them.

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1. Introduction

While the scientific challenges of assessing the impacts of future climate change are enormous, the institutional challenges involved in using that science for policymaking are arguably even greater. A growing body of work has highlighted the difficulties of reconciling the supply of climate science with the demand for research that is useful, useable, and used by policymakers (Sarewitz and Pielke, 2007; Dilling and Lemos, 2011; Kiem and Austin, 2013). Others have pointed to processes of co-production

and institutional boundary-work involved in the construction of science and its use in policymaking and political debate (Shackley and Wynne, 1996; Demeritt, 2001; Lemos and Morehouse, 2005; Lövbrand, 2011). For instance, science agencies often assume that adaptation policymaking requires more accurate and detailed predictions about future climate changes. To this end, the UK Research Council's Living with Environmental Change Strategy has promised to "strengthen the evidence base for policy, by addressing the uncertainties about the impacts of environmental change" (LWEC Partnership, 2011: 3). But that assumption and the associated linear model of upstream science feeding into policy decision-making downstream are both contested (Demeritt, 2006; Dilling and Lemos, 2011; Kirchhoff et al., 2013).

Alongside an increasingly vocal debate among climate scientists about the priority and policy relevance of reducing scientific

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uncertainties (Mearns, 2010, 2012; Meyer, 2012), a growing social science literature has sought to explain how climate policymaking should proceed in the face of uncertainty. While some advocate risk-based approaches to optimizing climate policymaking (Yohe and Leichenko, 2010; Cox, 2012; Ekström et al., 2013; Borgomeo et al., 2014), others endorse flexible, adaptive management strategies for dealing with uncertainty (Holling, 1978; Pahl-Wostl, 2006; Allen et al., 2011) or urge the need for decision-making that is robust to errors in current understanding (Dessai and Hulme, 2007; Lempert and Groves, 2010; Wilby and Dessai, 2010). Although these approaches share some common roots in the traditions of academic decision analysis, we show in this paper how the institutional logics driving the adoption of risk-based climate adaptation are in strong tension with the principles of adaptive management. More specifically, risk-based approaches aim at closing down the vast space of future possibilities by attributing probabilities and consequences to them in order to optimize decision-making and deflect criticism by rationalizing how far it is reasonable to go in seeking to prevent potential adverse outcomes (Power, 2004; Amore, 2013; Oels, 2013). Adaptive management approaches, by contrast, seek to keep the management process open to the uncertainties inherent in future developments by highlighting the conditionality and contestedness of current knowledge about the future (Holling, 1978). While the conceptual distinctions between closing down and opening up are widely acknowledged in academic science studies (Irwin, 2006; Stirling, 2007), if perhaps not always in the normative literature on climate policymaking – compare Hallegatte (2009) and Stern (2006) with Bellamy et al. (2013) – the tensions between them and their practical implications for adaptation and the institutional dynamics of policymaking and implementation are less well understood.

To explore these issues we compare how uncertainties figured in the execution of three related long-term strategic planning processes designed to ensure Flood and Coastal Erosion Risk Management (FCERM) in England is adapted to climate change. With devolution, responsibility for FCERM in other parts of the United Kingdom is now overseen by the devolved administrations in Scotland, Wales, and Northern Ireland. Though differing in some small details, their approaches to FCERM are broadly similar to those in England. England was chosen as the site for this comparative case study analysis because the national adaptation programme for England (Defra, 2013a) and associated policy guidance for taking climate change into account in FCERM (MAFF, 1993, 2000; Defra, 2006a, 2009; EA, 2011a) require decision-makers to follow an adaptive management approach to allow flexibility for responding to future changes that are uncertain or as yet entirely unknown. On the other hand, however, the strategies for FCERM in England are also notable for their full-throated commitment to being ‘risk-based’ (Defra, 2004; Johnson and Priest, 2008; EA, 2011b). In keeping with the UK government’s longstanding advocacy of risk-based approaches to ‘better regulation’ (Dodds, 2006; Rothstein et al., 2013; Demeritt et al., 2015), FCERM uses various risk-based technologies and policy instruments, like risk mapping, risk-based protection standards, and risk-based resource allocation, to calibrate policymaking and ensure that FCERM interventions are proportionate to their expected costs and benefits (Krieger, 2013). In this way, ‘risk’ is not simply an object to be managed, but a central principle for the organization of FCERM itself. Rather than trying to eliminate all potential harms, risk-based approaches aim for an optimal balance between socially acceptable levels of risk and the costs of further risk reduction.

These alternative policy commitments pull those responsible for adapting FCERM in different directions. Adaptive management ideas enjoin policymakers to acknowledge uncertainty and adopt

provisional measures that can be adjusted or even reversed with learning from experience. This emphasis on openness and flexibility can be challenging. FCERM often involves multi-million pound decisions about whether to invest in protection schemes whose up-front costs will only be repaid, if ever, by benefits realized many years into the future. While deferring investment or planning FCERM in stages “through multiple interventions” (Defra, 2009: 23) can preserve the space to adapt to new information, it also introduces delays and opens avenues for criticism and inconsistency that can increase costs and complicate implementation. As well as being adaptive, FCERM must also be risk-based so as to ensure its proportionality and cost-effectiveness (Defra, 2004; EA, 2011b). This requires policymakers to close down uncertainties and transform them into calculable risks (Lane et al., 2011a) whose management can then be rationalized through cost-benefit analysis and nationally consistent, risk-based priority setting. Whatever approach they take to managing uncertainty, the organisations responsible for FCERM also face second-order institutional risks of criticism and blame for their conduct and decision-making in managing the first-order risks to society for which they are accountable (Rothstein et al., 2006). As we will detail below, concern for managing these second-order institutional risks not only shapes how the first-order risks to society from future flooding are understood and managed but also feeds back to inform how uncertainties are framed and science used to inform revisions to the management framework itself.

The paper is organized as follows. After describing our data and methods, we define our conceptual approach to understanding risk and uncertainty and explore their implications for adaptation decision-making and the emergence of institutional risk. An institutional overview of adaptation and FCERM in England then sets up two empirical case studies of how climate change uncertainties about peak flood flows and sea level rise are accounted for in different FCERM processes. In the first the poorly understood impacts of future climate change were represented with a simple precautionary adjustment to peak flow estimates. Although crude, this one-size-fits-all adjustment provided a basis for formulating FCERM plans that was robust to institutional challenges, at least in part because its scientific limitations were only partly acknowledged by all of the various parties involved. By contrast in the second case, greater scientific confidence led to successively more elaborate guidance on how to represent the science. This, however, then led to inconsistencies in how future sea level rise was taken into account in different FCERM planning processes and thus increased controversy and institutional risk for the operational officials involved. Comparative analysis of these two cases then informs some conclusions about the tensions between adaptive and risk-based approaches, the role of institutional risk in adaptation, and the importance of institutional dynamics in shaping the framing climate uncertainties and policy responses to scientific knowledge.

2. Case study design and methodology

Our case study used a mixed methods approach combining policy document analysis with key informant interviews conducted in the summer of 2011. Whereas policy documents disclose the formal basis by which climate change considerations are incorporated into FCERM, interviews illuminate the informal processes and ‘backstage’ understandings shaping the design and implementation of those policies and of the science underwriting them. To exploit these complementarities and the potential for source triangulation to enhance the validity of analysis, research proceeded iteratively, with data collection interspersed with periods of analysis.

Our sample frame for the interviews targeted informants involved in FCERM research and in policymaking at both the operational and strategic level. We conducted interviews with 6 research scientists involved in providing scientific assessments of climate change and its implications for flooding to inform FCERM policymaking in the UK. Additionally we conducted 12 interviews with officials involved in FCERM policymaking from the Department for Communities and Local Government and the Environment Agency (EA) as well as local authorities from four different areas selected from across the EA's Southwest and Thames Valley regions to represent urban, rural, and coastal areas exposed to flood risk. In devising our sample we looked to interview officials working in job roles at both the strategic level, setting the broad framework for FCERM, and at the operational level, putting those policies into everyday practice. While the distinction between strategic and operational policymaking roles was sometimes blurry, the degree of direct public engagement provided one defining measure. Whereas operational staff had regular contact with the public and as such had to defend assessment results and decisions against potential critics, strategic policymaking roles were much less public facing. On this basis we classified 3 policymaking informants as 'strategic' and the other 9 as 'operational'. Individual biographies afforded a few of our informants with experience of more than one job role in FCERM research and policymaking, but for the purposes of both recruitment and analysis we classified our informants according to their current job roles.

Interviews were semi-structured and followed a "problem-centred interview" approach that explicitly considers the "interplay of inductive and deductive thinking" (Witzel, 2000: 1). The interview protocol comprised broadly-framed and open-ended questions inspired by our theoretical concerns with institutional risk and the tensions between adaptive and risk-based approaches

as well as exploratory ones to elicit information about actors' particular roles and responsibilities, their professional routines and practices, views on the uncertainties in FCERM and in climate change projections, and the challenges that may arise from them. Interviews were recorded and transcribed, and iteratively coded. An initial set of deductively derived analytical codes was elaborated further with codes derived inductively through an initial reading of the interview transcripts and policy documents to generate a list of codes that were then applied systematically to the dataset using the qualitative data analysis software package MaxQDA.

3. Adaptive and risk-based approaches to climate change and adaptation

Within the field of risk governance a variety of suggestions have been put forward for improving decision-making about climate change and other problems characterised by 'deep' uncertainties. Risk-based approaches to climate change seek to identify optimal policy solutions based on ex ante assessment to distinguish reasonably acceptable from unacceptable outcomes, given the various costs and benefits involved in reducing their probability and consequences (Yohe and Leichenko, 2010; Webb, 2011; Oels, 2013). Uncertainties are acknowledged in this approach and managed through Monte Carlo simulation, ensemble prediction, and other forms of probabilistic risk assessment to quantify them within confidence intervals (Mastrandrea and Schneider, 2004; Stephens et al., 2012; Ekström et al., 2013; Borgomeo et al., 2014). By contrast, adaptive management approaches endorse flexibility and experimentation to enable policymakers to change course in response to new information (Holling, 1978; Pahl-Wostl, 2006; Allen et al., 2011) and avoid decisions that lock-in long term policy commitments that would

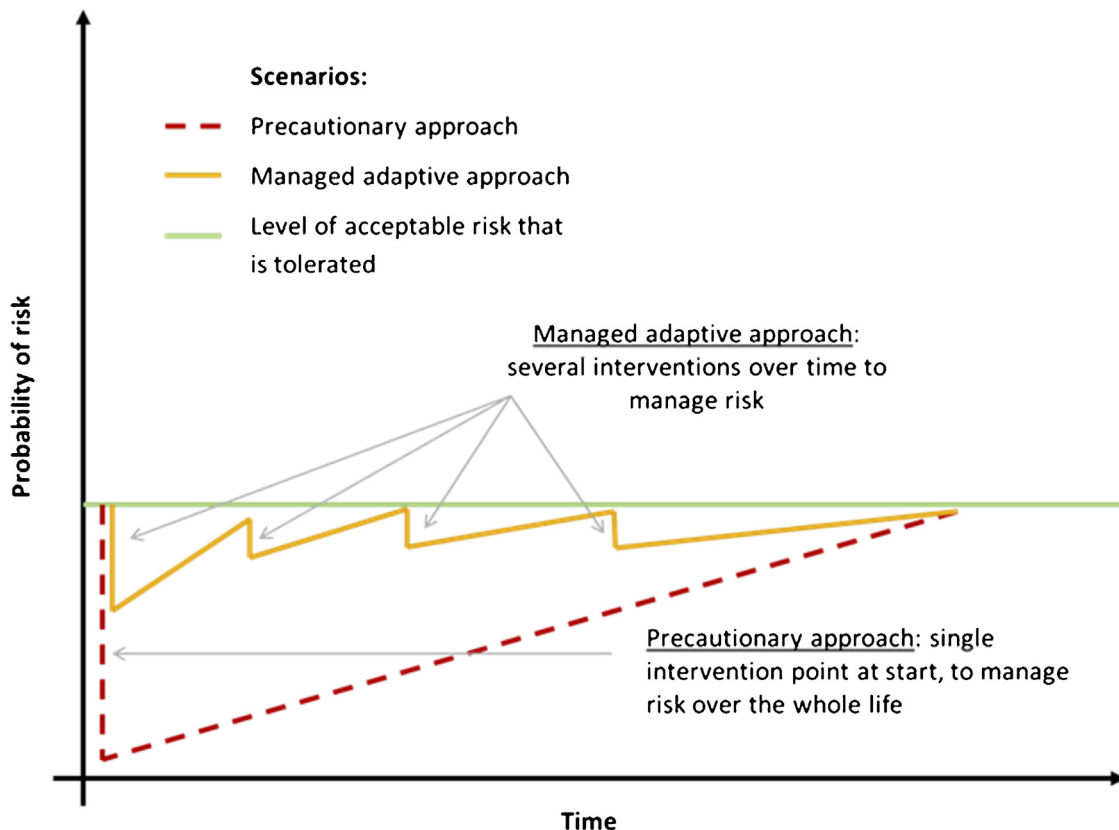


Fig. 1. Alternative precautionary and managed adaptive approaches to risk-based management. After Defra (2009: 23).

be costly to fix if ex ante assessments prove wrong (Wilby and Dessai, 2010; Hall et al., 2012). Embracing the wider participatory turn in science-based policymaking (Irwin, 2006; Stirling, 2007; Demeritt, 2015), adaptive management approaches increasingly also emphasise the importance of pluralism and participation to opening up deliberation about the goals, standards of evidence, and other matters of concern that need to be taken into account as part of any adaptive approach to addressing the complexities of climate change (Leach et al., 2010; Armitage et al., 2011; Lane et al., 2011b; Klinke and Renn, 2012).

The origins of risk-based and adaptive management approaches to climate change lie in the same broad family of anticipatory decision-analysis. As such they are often said to be broadly compatible (Lempert and Collins, 2007; Hallegatte, 2009). Indeed Defra (2009: 23) treats them as complimentary approaches to keeping risk of harm within tolerable limits (Fig. 1). They both emphasise ex ante assessment to inform rational choices about an uncertain future. Where they differ is in the weight they give to the goals of optimization, adaptability, and precautionary avoidance of a so-called 'type II error' (i.e. failing to detect a negative effect although it is actually present) in their formalized approach to decision-making in the face of uncertain future perils. While more deliberative approaches to managing uncertainty share Habermas's scepticism of instrumental reason (Brown, 2009), they share with that decision-analysis tradition a commitment to evidence-based judgment in which arguments are always provisional insofar as they remain open to better reasons and new information about matters of common concern (Stirling, 2007; Klinke and Renn, 2012).

In contrast to this normative concern with how policymaking ought to be done, a more explanatory strand of social science has sought to understand how policymakers manage uncertainty in actual practice. A growing body of work has highlighted the defensive functions of risk-based approaches in deflecting blame and rationalizing policy choices (Power, 2004, 2007; Rothstein, 2006; Rothstein et al., 2006, 2011; Porter and Demeritt, 2012; Demeritt et al., 2015). Rather than championing risk analysis as the only rational approach for coping with uncertainty (Hallegatte, 2009) or as a harbinger of some more reflexive modernization (Beck, 1992), this more critical perspective sees risk-based approaches to regulation and governance emerging in response to external audit and accountability pressures (Power, 2004; Rothstein, 2006). With the shift from government to governance (Rhodes, 1996), organisations increasingly operate in a more transparent and horizontal environment in which they must be open and responsive to others (Walker et al., 2014). At the same time, fashions in corporate governance and new public management are turning organizations 'inside out' through audit regimes that require them to account for the limits of their own performance and to reframe potential obstacles to organizational goals as 'risks' to be managed (Power, 2004, 2007). In turn, this fantasy of control through the 'risk management of everything' then creates a new category of secondary, institutional risks of being criticised or blamed that organisations charged with first order risk management responsibilities must also manage as well (Rothstein et al., 2006). Strategies for limiting those second-order institutional risks of blame, such as protocolization of operational routines (Porter, 1995) and 'strategic ignorance' (McGoey, 2012), can impede management of the first-order risks to society by closing down discussion, discouraging reflexivity, and promoting blame avoidance. Thus risk registers and other risk-based policy instruments designed to encourage organizations to anticipate and engage with the uncertain potential for adverse outcomes may in fact serve to reinforce institutional prejudices about them and to deflect blame for failure by reframing the occurrence of adverse outcomes as acceptable or completely unimaginable risks that

institutions could not reasonably be expected to have prevented (Demeritt and Nobert, 2011; Rothstein and Downer, 2012; Huber and Rothstein, 2013).

This more critical reading points to potential tensions between the ideals of openness, reflexivity, and rationality in the face of uncertainty championed by proponents of anticipatory analytic-deliberative decision-making and the institutional logics of risk-based governance, which emphasise blame avoidance by closing down uncertainties and potential avenues of criticism and risk to reputation. As we discuss in the next section, these alternative approaches to understanding risk in governance not only suggest some new ways to think about the well-recognized paradigm shift in flood management from engineering flood defences to more-risk based, adaptive management approaches (Johnson and Priest, 2008; Butler and Pidgeon, 2011; Porter and Demeritt, 2012), they also highlight the importance of organisational dynamics and institutional risk in shaping how agencies respond to the uncertainties about climate change and future flooding.

4. Adapting flood and coastal erosion risk management in England to climate change

Defra is the lead government department responsible for FCERM and climate adaptation. Apart from statutory duties to consult on the formulation of policy strategies and to report on progress, the state enjoys broadly 'permissive' powers to act in these domains, rather than strict legal duties of protection to uphold. In keeping with broader shifts in the role of government in Britain from 'rowing' and direct service provision to 'steering' and regulatory governance beyond the state (Osborne and Gaebler, 1992; Moran, 2003), Defra relies on partnerships with a variety of other public and private sector actors to deliver its strategic goals for FCERM and climate adaptation within the limits of available resources.

In this context of discretionary state responsibilities and limited resources, risk plays an increasingly central role in both domains in helping to define limited, rather than absolute, policy goals and in prioritizing their implementation. Rejecting the traditional engineering goal of "prevent[ing] flooding and coastal erosion altogether" as "not technically, economically, or environmentally feasible" (EA, 2011b: 16–17), the current FCERM strategy for England, like the 'Making Space for Water' strategy it succeeded (Defra, 2004), uses a "risk-based management approach [to] target resources . . . where they have greatest effect" and to "keep the costs of risk management actions proportionate" (EA, 2011b: 16–17). To that end, Government policy has long required cost-benefit analysis of publicly funded FCERM schemes to "ensure that public investment in risk management activities is justified and that alternative options are properly considered" (Defra, 2009: 10). Queries about the necessity of doing so are met with references to HM Treasury's (2003: v) Green Book and its "binding guidance for departments and executive agencies" on cost-benefit analysis methods. Further technical guidance on such contentious issues as intangible environmental impacts and the valuation of human life (EA, 2010a) serves to pre-empt long-standing controversies over the very application of cost-benefit analysis to environmental management (Davies and Demeritt, 2000). These strategic-level policy-making requirements are designed to ensure that operational-level decisions "are oriented to gaining the maximum economic benefit for the country as a whole" (Defra, 2009: 12). In so doing appraisal guidance sets out the framework for generating the "information that allows management decisions to be made" at all (Lane et al., 2011a: 1792), since a risk-based approach is impossible without risk estimates to drive operational-level implementation.

Under the 2010 Flood and Water Management Act the Environment Agency plays both a strategic role in coordinating

the management of different sources of flooding and an operational one in managing flood risks from main rivers and the sea and advising on local authorities on planning decisions where flooding is an issue. Local authorities are charged, as lead local flood authorities, with operational responsibility for managing local flood risks from small rivers and streams (so-called 'ordinary water courses'), surface water run-off, and groundwater, in addition to their longstanding duties to consider flood risk as part of their spatial planning and land use regulation responsibilities.

In discharging those various duties, FCERM agencies are expected to follow a structured appraisal process to ensure that policymaking is risk-based and proportionate. FCERM appraisal guidance follows the [Treasury \(2003\)](#) Green Book in defining risk in the classical sense as a product of the estimated probabilities and impacts of flooding and coastal erosion ([MAFF, 1993, 1999; Defra, 2009; EA, 2010b](#)). At the same time, it also acknowledges the inherent uncertainties involved in predicting highly variable physical and societal processes and encourages an adaptive management approach to enable the "appraisal options to respond to future change, during the whole life of a measure, as well as the uncertainties" ([Defra, 2009: 23](#)). Flood risk appraisal guidance now also requires "effective public participation and consultation" throughout the entire process ([Defra, 2009: 36](#)), reflecting the widespread hope that opening up risk assessment and appraisal to external participation will improve their quality as well as their public acceptability and organisational accountability ([Irwin, 2006; Demeritt, 2015](#)).

The strategy for climate adaptation also uses risk to inform goal-setting and prioritization as part of a wider cross-government commitment to a "risk-based approach to climate change" ([Defra, 2012: 3](#)). Under the Climate Change Act 2008, Defra is required to prepare a UK Climate Change Risk Assessment (CCRA) every five years, "to give government and other organisations evidence to help them take informed, cost-effective and timely decisions to prepare for the changing climate" ([Defra, 2013b](#)). Exercising its permissive powers "to act mainly where the market is unlikely to act", the Government defines its role as an enabling one:

"to help others make good decisions on climate risks and opportunities (for example from investments in cutting edge science and decision support), and to promote risk-based decision approaches (for example early action on decisions with long-term consequences, and maintaining flexibility by avoiding technical lock-in)" ([Defra, 2012: 7–8](#)).

The CCRA highlighted flooding as the single greatest climate change threat to the UK ([Defra, 2012](#)). Climate change is likely to alter the risks to society from flooding and coastal erosion through two distinct physical processes. First, changes in the hydrological cycle may alter the frequency of inland flooding and through feedbacks on land use, snowpack, and soil moisture, its magnitude as well. For these processes there is only limited scientific confidence in estimates of how climate change may alter the frequency and magnitude of peak flood flows in England ([Reynard et al., 2005, 2009; Lane et al., 2011a; Wilby and Keenan, 2012](#)). Second, rises in sea level will probably increase the rate of coastal erosion and the associated risks from coastal flooding. Compared to fluvial flooding, there is greater scientific confidence about the increases in sea level due to thermal expansion of the oceans ([Defra, 2006a](#)). However the potentially much greater volumes of future sea rise due to accelerated melting of the Greenland and Antarctic ice sheets, like the effects of climate change on coastal flooding and erosion risk due to potential changes in the frequency, magnitude, and location of extra-tropical storms, were considered too uncertain to quantify reliably and so were simply ignored in [Defra \(2006a, 2009\)](#) guidance. The latest EA (2010b: 25) appraisal

guidance now includes scenarios that take these more dangerous potential effects into account.

Those longer-term risks from climate change are incorporated into FCERM through three parallel assessment and planning processes, which are underpinned by regularly updated guidance from central government about how climate change should be taken into account ([MAFF, 1993, 2000; Defra, 2006a, 2009; EA, 2010b](#)). First, long-term strategic plans for managing inland flood risk on the major rivers in England and Wales are set out by the EA in 77 so-called Catchment Flood Management Plans (CFMPs). CFMPs were first required following major flood events in 1998 and 2000 so as to provide a holistic overview of fluvial flood risks at the catchment scale, rather than the fragmented administrative geography through which those risks were being managed at the time. The latest generation of CFMPs considers all sources of inland flooding (rivers, ground water, surface runoff and also tidal flooding from rivers and estuaries) ([EA, 2013](#)). CFMPs are used by the EA to prioritize its own investment and maintenance decisions as well as informing its interactions with other stakeholders, such as lead local flood authorities and local planning authorities, though evidence suggests that in fact those EA-produced CFMPs have only limited influence on the SFRAs undertaken by local planning authorities to inform their own planning and development control ([Thurston et al., 2010; Porter and Demeritt, 2012](#)). Although they are ignored by local authority SFRAs, the CFMPs are sensitively dependent upon them. As [Lane et al. \(2011a: 1797\)](#) note, CFMP assessments of future flood risk often assume that local planning policy will prevent any increases in exposure and therefore consider changes in flood frequency and magnitude due to climate change as the main uncertainties to worry about.

These SFRAs are the second major assessment process through which the long-term risks from climate change are incorporated into FCERM. They were first required of English Local Authorities by the 2006 revisions to the PPS25 guidance on flood risk ([DCLG, 2006](#)). SFRAs are supposed to ensure that LAs and developers alike take appropriate notice of current and future flood risk when planning for local development. They are based on more detailed local modelling than the CFMPs, but are still strategic in the sense that they provide an overview of flood risks across the entire LA, rather than the very detailed flood risk assessment required for individual project-level planning decisions ([Porter and Demeritt, 2012](#)).

Third, Shoreline Management Plans (SMPs) set out a long-term strategic framework for managing coastal flooding and erosion, just as the CFMPs do for inland flooding. But in contrast to the CFMPs and SFRAs, the SMPs are not strictly required by Government regulation and are instead prepared voluntarily on a partnership basis by the EA and cooperating agencies to improve policy coordination and inform deliberation over whether and where to hold the line against rising sea levels. The first generation of SMPs was produced in the mid-1990s. A total of 11 SMP1s, each subdividing the coast into a number of physically coherent sediment 'cells' within which the movement of sand and shingle is largely self-contained, were completed in that first round. In keeping with its commitment to an adaptive management approach, Defra regards the SMPs as 'living documents' and is encouraging authorities to revise their SMPs to take account of the latest research on climate change and extend their planning horizon from the 50 years used in the SMP1s out to 100 years for the second generation of SMP2s. To support those revisions, Defra published, in 2006, two lengthy volumes of revised Shoreline Management Plan Guidance detailing the aims and requirements (vol. 1) and procedures (vol. 2) for a second generation of SMPs ([Defra, 2006b](#)). In the same year, Defra also published a further "supplementary note to Operating Authorities" setting out new instructions for how climate change should be taken into account

in these and other FCERM appraisal and planning processes (Defra, 2006a).

These three parallel assessment and planning processes were governed by the same overarching strategic-level guidance on how climate change should be taken into account. They also involved many of the same participants. As such, they might be expected to have been closely coordinated and internally consistent in their approaches to adapting FCERM to climate change. And yet, as we discuss below, they framed the scientific uncertainties about peak flood flows and sea level rise in strikingly different ways shaped by concerns with managing the institutional risks of adapting FCERM to climate change.

5. Climate change and peak flood flows

Traditionally, estimates of the peak river flows that might be expected over a given time period were derived statistically, based on historically observed flood frequencies in the watershed, sometimes supplemented by regionalizing and other methods for dealing with data sparsity set out in the EA-endorsed Flood Estimation Handbook (Institute of Hydrology, 1999). However with climate change altering the boundary conditions controlling flood frequency, such empirical methods are increasingly acknowledged to be problematic (Milly et al., 2008; Lane et al., 2011a). Climate change uncertainties were not acknowledged in the Government's first FCERM appraisal guidance (MAFF, 1993). Revamped guidance, published in 2000, suggested that it might be "reasonable" to consider the sensitivity of appraisal outcomes to increasing "the flow estimates in the flood frequency curve by up to 20% due to climate change, along with other considerations of uncertainty" (MAFF, 2000: 15), but operational-level officials were given discretion about whether and how to take climate change into account when assessing fluvial flood risk. This changed in 2006, when Defra (2006a: 9) issued revised guidance requiring FCERM authorities to apply a uniform 20% increase to their estimates of river discharges after 2025 as a "single precautionary allowance" for climate change.

Though admittedly simplistic, this 20% adjustment had been endorsed the previous year in a peer reviewed study commissioned by Defra and EA from expert consultants (Reynard et al., 2005). Using the latest climate model scenarios, Reynard et al. (2005: 61) found a wide range of impacts on future flood flows, but since most of them fell "below the 20% increase", that figure was recommended as "appropriate as a precautionary response to the uncertainty of future climate change impacts on flood flows." In this sense applying the 20% adjustment was somewhat akin to the freeboard adjustments often used by flood engineers to provide an added margin of safety to compensate for unknown factors that might compromise a flood defence scheme (Kirby and Ash, 2000). Although it did not explicitly alter flood frequency, as Lane et al. (2011a: 1797) explain, "scaling the peak flow for all flows in the historical record [has] the effect of making a flow with a [given] probability under current climate more frequent as a result of future climate change." This uniform adjustment did not account for variability in response by catchment type, nor did it allow for "regional variations in flood allowances" (Defra, 2006a: 3). These limitations were acknowledged in a footnote as the subject of ongoing research, which would subsequently conclude that "a single national allowance for climate change might not be appropriate" (Reynard et al., 2009). But despite these and other "significant uncertainties", Defra (2006a: 3), nevertheless ordered FCERM authorities to apply the adjustment "until further updates are provided". By taking this "pragmatic approach" to uncertainty, Defra (2006a: 3) transformed the unknown possibility of changes in the magnitude of future flooding due to climate change into a calculable number that

"allows management decisions to be made" (Lane et al., 2011a: 1792).

While Lane et al. (2011a) detail the scientific appraisal processes by which uncertainties about future flood flows are accounted for in the cost-benefit analyses that drive risk-based decision-making at the operational-level, they pay much less attention to whether and how those uncertainties are understood by different actors working at different levels in FCERM. Awareness of these uncertainties varied widely among interview informants. When asked about uncertainties, scientists were usually quick to note how difficult it is to quantify the effects of climate change on the coupled processes of rainfall and runoff. Some also acknowledged how the full scope of uncertainty about future flood risk was closed off by the use of the 20% adjustment to peak flows. As one scientist who had been involved in preparing the latest UKCIP09 climate scenarios went on to explain to us:

"it is a very difficult thing to come up with a quantitative number of how much heavy rain will change and peak flows. We don't really go there. [. . .]. Even in terms of the rainfall, there's a lot of uncertainty. There are a lot of seasonal differences as well as regional differences across the UK as well."

All of the scientists interviewed expressed awareness of recent developments in regional climate modelling since the publication of Defra's 2006 guidance; many were also aware of the work, still ongoing at the time of our fieldwork, to revise the climate change guidance so as to take account of the latest probabilistic UKCIP09 scenarios provided by the Met Office Hadley Centre (EA, 2011a).

There was also some awareness of these uncertainties among the 3 informants working in strategic policymaking roles. Pointing to the regionally differentiated projections provided by the latest UKCIP09 projections, one high-level policymaker with long experience of reforming spatial planning policy guidance on flood risk noted that the problems of applying the 20% increase uniformly were clear enough to see, at least in retrospect:

"But having looked at that again in UKCIP09, it's apparent that there's a huge amount of variation in there. Some areas it's 20%. In others it's 50%. It all depends on the local conditions."

But s/he was also quick to defend the 20% figure, albeit on instrumental as much as scientific grounds:

"It was the best figure we had in previous UKCIP2, but it's very shaky. It was basically better than nothing. We had that figure because we found from experience that if local people don't have specific instructions, they won't do anything. So what we did is we gave them some indicative figures."

Having been involved in revising planning policy guidance on flood risk, this informant was acutely conscious of the need for clear and unambiguous guidance to drive the policy process and reduce the institutional risks of taking climate change into account. Five years ago, "people weren't doing anything about climate change . . . because . . . everything was based on the Environment Agency flood zones, which are just snapshots" that ignored future climate change altogether (cf. Porter and Demeritt, 2012). But with the revised Defra (2006a) guidance, this policymaker noted approvingly that operational-level staff now "have to take into account climate change" in spatial planning and development control regulation.

In this context the attraction of the 20% allowance was not its scientific status—its reasonableness as "the best figure we had" at the time was largely taken for granted. Instead specifying "some indicative figures" was appealing to strategic-level officials because it overcame the hesitancy of operational level policymakers to act on the longstanding recommendation that it would

be “reasonable” for them to consider sensitivity of appraisal outcomes to increasing “the flow estimates in the flood frequency curve by up to 20% due to climate change” (MAFF, 2000: 15). While they acknowledged its flaws in retrospect, strategic-level policy-makers endorsed the use of a single precautionary allowance as the only way to get “local people” at the operational level to take the uncertain but nevertheless broadly calculable risks from climate change into account in FCERM.

Interviewees working at the operational-level and involved in preparing and using CFMPs and SFRA's reported no such uncertainties, either about the treatment of peak flows or the science underpinning it. Only 2 out of the 9 operational-level informants could say anything about where the 20% allowance had come from or the uncertainties associated with its use, whether in those longer term planning processes or in appraising the project-level designs their plans would inform. Its scientific basis was of no interest to them. This is partly because they typically outsourced the underlying technical analyses to scientific consultants and so did not appreciate the scientific uncertainties involved in applying the 20% allowance (Lane et al., 2011a; Haughton et al., 2015). Even if operational-level staff possessed the necessary expertise, their institutional distance from those analyses, combined with the imprimatur lent by Defra's (2006) recommendation, lent enchantment to the 20% adjustment (Latour, 1999; Collins and Evans, 2007). Having a number to follow, and, if challenged, a rationale for justifying its use was much more important to operational-level policymakers than any uncertainties embodied by the recommended figure. Indeed, when pressed, one official, responsible for preparing and implementing the CFMPs in one of the EA regional offices, simply retorted: “Why should people question it? Why? We have a policy and this is the way we're going to do it.” If doubts about the number were expressed, they were typically downplayed, as this quote from a local authority informant underlines:

“Again we're talking about a 100-year extent. That 20% extra flow doesn't make a lot of difference in terms of extent. It may make a little bit more on damages. But again if you're already flooded, what would that extra mean?”

This attitude partly reflects the relative insensitivity of flood inundation estimates to the additional 20% peak flow adjustment (Parkes, 2015), as well as the very distant time horizon over which it is being applied in these more strategic FCERM planning exercises whose connections to resource allocation and to more immediate and contentious decisions about project-level appraisal of flood protection schemes were not always clear to outsiders. These factors tend to attenuate public interest in the results of the underpinning climate change risk assessments and thus the institutional risks of being challenged over them.

By contrast, operational-level staff expressed much greater concern about uncertainties in how present-day exposure to flood risk is calculated and externally communicated in different FCERM plans and assessments. Different types of flooding and different datasets and models for assessing them can result in wide variation in the number and location of properties estimated to be at risk of flooding (Parkes, 2015). While there are good scientific reasons for those variations, members of the public do not always understand or accept them, and operational officials were concerned about the institutional risks of being criticised as result, both from the public at large and, in particular, from their elected representatives. Expressing a sentiment shared by many interviewees, one informant explained, “It's a minefield. It's a very tricky one.” He explained how much effort his team at the EA was devoting to pre-empting possible criticisms of the numbers it published in its CFMPs and other risk management plans:

“A colleague of mine, his task at the moment is looking at all these numbers of properties and start to say which one as a

region will we quote when asked. We get a standard list of questions which we expect the media to ask us. We'll have an answer which we can all say the same.”

Although they could offer a multitude of answers, because different assessments had been conducted at different times using different methods and data for different purposes, operational staff in the EA region office felt obliged to close down that uncertainty and provide a single authoritative answer that they could quote back consistently when asked.

Local authority officials face similar pressures, and they too devote considerable effort to trying close off potential lines of external complaint. One local authority informant with a strong background in hydrology explained how in preparing a SFRA, he was already anticipating the external scrutiny it would have to withstand:

“I wanted to be able to come up with an assessment that treated everywhere the same, so that if a councillor says ‘why isn't my town listed as a flood risk area?’, I can say we did this assessment and it didn't come up that high.”

Consistency of approach – treating everywhere the same – was seen as crucial to pre-empting criticism and managing institutional risk. It was also central to Defra's (2009: 3) wider optimizing goal of allocating resources according to risk so as to “be sure maximum benefit is achieved with every £1 of taxpayers' money.” As Ted Porter (1994: 391) has noted, standardization is often “more important to a public measurement system than is close approximation to true values as defined by elite research laboratories”. Although there are often good scientific grounds for making different assumptions in different places so as to reflect differing and dynamic levels of knowledge about them, the resulting inconsistencies can be problematic for risk-based approaches. First, as Lane et al. (2011a) note they undermine the consistency on which risk-benefit comparisons and risk-based prioritisation and resource allocation depend. Second, as we will see in the case of adapting FCERM to sea level rise, they also amplify the institutional risks about how to take climate change into account.

6. Sea level rise and coastal flood risk

In contrast to peak flood flows, the effects of climate change on sea level rise have long been considered in FCERM, but efforts to adopt an adaptive management approach to scientific uncertainty led to inconsistencies in implementation that undermined commitments to risk-based policymaking. The first generation of SMPs had used figures for regional rates of sea level rise set out by the Ministry for Agriculture, Fisheries, and Food (MAFF, 1993) in its official Flood and Coastal Defence Project Appraisal Guidance Note (PAGN). The PAGN figures, in turn, were derived from estimates published in the first IPCC assessment report (Warrick and Oerlemans, 1990). In 1999, MAFF revised and substantially expanded its project appraisal guidance for coastal and flood defence, but left its recommended allowances for sea level rise unchanged from those originally set out in the 1993 PAGN based on IPCC projections from 1990. As MAFF explained in the third technical volume of its appraisal guidance (sometimes referred to as FCDPAG3), while sea level rise projections are “continually being refined” to take “more complex feedback effects . . . into account”, they must be “treated with caution”, and “with the degree of uncertainty involved, there is no current justification” for changing the previously published estimates (MAFF, 1999: 43–44). By 2006, however, Defra's (2006b: 26) SMP guidance could point to the UKCP02 climate scenario work done under the UK Climate Impacts Programme as well as the extensive research on future

flooding commissioned by the Government's foresight programme (OST, 2004) as the scientific basis for issuing more detailed and spatially and temporally precise projections of sea level rise than were used for the very first SMPs in the mid-1990s.

Such confidence meant the approach taken to translating the uncertain impacts of climate change on sea level into a calculable risk was quite different to that followed for estimating future peak flows under climate change (Fig. 2). Whereas a uniform adjustment was made to all peak flows over time, Defra (2006a) recommended using an exponential curve for sea level rises to reflect the latest IPCC projections about how they will evolve dynamically over time. Furthermore, sea level rise projections were also regionally differentiated to reflect differences in sea level due to local land subsidence and isostatic post-glacial rebound of the earth's crust. Whereas the north of England is expected to rise on the order of 0.8 mm/year over the next century, the land surface across the East of England, East Midlands, London and the South East of England is projected to recede by 0.8 mm/year. But these regionally differentiated assumptions about isostatic rebound are not the main reason that different planning documents often made wildly inconsistent assumptions about future sea level rise affecting the same or adjoining stretches of coastline.

Rather inconsistencies were created by the institutional geographies of FCERM itself. One of the main reasons for apparent inconsistencies is that SMPs were not the only FCERM plans making allowances for future sea level rises. Sea level rise

assumptions were also made by a number of CFMPs and SFRAs to inform their assessments of flood risk to tidal estuaries, and these assumptions often differed from those made in SMPs for the same stretch of coastline. Additionally, the SMPs, CFMPs, and SFRAs were institutionally separate processes involving different sets of actors and proceeding without any formal mechanisms for coordinating the one with the other. Moreover, these FCERM planning processes were also based on fundamentally different administrative geographies. The 77CFMPs (whose boundaries are outlined in Fig. 2) were organized according to a riverine geography of catchments and fluvial flooding that was very different to the sediment cells and more localized 'policy units' that were the foundation for the 22 SMP2s. SFRAs, meanwhile, were prepared by local authorities at the local authority scale. These different institutional geographies resulted in different management plans based on different sea level rise allowances generated through different local assessment processes.

Finally, inconsistencies also arose from the diverse temporalities involved in FCERM assessment and planning processes. Following Defra's commitment to an adaptive management approach to climate change, the CFMPs and SMPs were supposed to be 'living documents' that would evolve and change to keep up with the latest science (Defra, 2006a, p.2; MAFF, 2001, p.21). But the process of revising central guidance was not closely coupled to the timetable for local revisions to the SMPs and CFMPs. Updating these plans can take years, and with different authorities

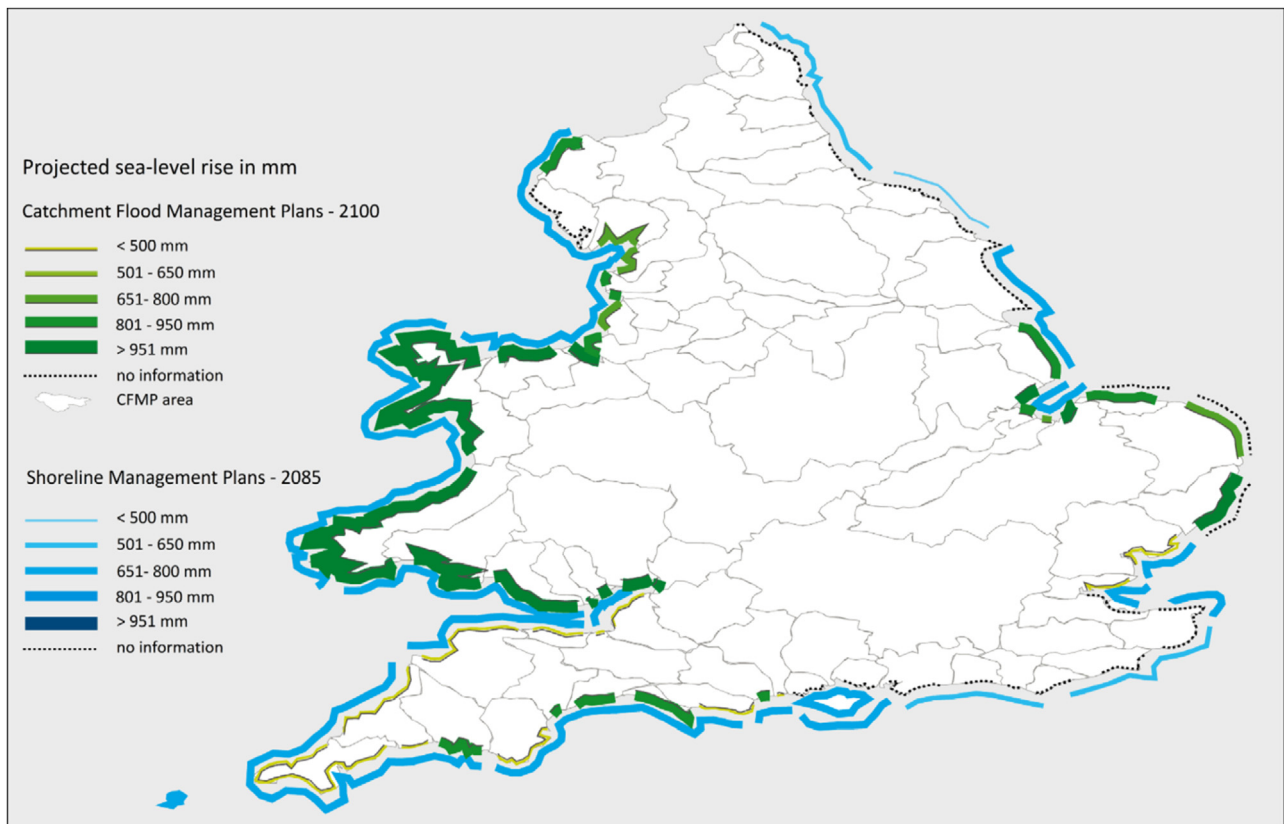


Fig. 2. Sea level rise allowances (mm) used for the second generation SMPs (blue, outer line) and CFMPs (green, inner line) for England and Wales. The differing magnitudes of assumed sea level rise for the years 2085 (SMPs) and 2100 (CFMPs) are represented by the thickness and hue of the various line segments. Their length represents the different stretches of shoreline to which those assumptions were applied in various SMP and CFMP planning documents prepared as part of two separate revision processes, based on different administrative geographies and observing different central guidance depending on how far revisions to local baseline planning assumptions had progressed when Defra (2006a) guidance superseded FCDPAG3 (MAFF, 1999). Coastal segments for which there is no information about sea level allowances, either because the revisions to the CFMPs and SMPs were not yet complete or the sea level rise assumptions not publicly available online at the time of writing, are represented with a dotted line. The boundaries between the 77CFMP areas are outlined in grey. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

proceeding at different speeds, and the background guidance subject to regular updates to maintain its scientific currency and the institutional credibility of the central Government departments responsible for it, different planning processes followed different sets of central guidance about how to treat the uncertainties about future sea level rise. As one informant responsible for overseeing the modelling done by consultants in support of the SMPs recalled:

“We were working on the standard guidance when there was the UKIP02 that came out. That had the lower levels of sea level rise estimates. So some of the early catchment flood management plans started working on that. But then we got the 2006 DEFRA guidance for the operating authorities and that used the later version of the climate change levels.”

The combined effect of these institutional processes was that radically different assumptions about future sea level rise could be applied to the same or adjoining stretches of coastline by different planning processes. For example, the CFMPs for the Wye and Usk and for the Welsh side of the Severn Estuary, prepared under the direction of the Wales regional office of the EA, assume 1000 mm sea level rise by 2100, or twice as much as the more optimistic 500 mm rise assumed by the CFMP for the Parrett catchment on the English side of the Severn (EA, 2012), prepared somewhat earlier by officers from the EA’s Southwest region office and informing FCERM plans for the Somerset Levels that would later prove to be so politically explosive during the winter floods of 2013–2014 (Demeritt, 2014; Thorne, 2014).

These inconsistencies in planning assumptions were a subject of considerable concern to those working at the operational-level. One EA official explained that inconsistencies created “problems” for him and his colleagues, particularly during the required public consultation phases of FCERM planning. Public pressure at these meetings could be intense, as another EA informant working as a community liaison manager explained:

“Coastal erosion, storms, and all that kind of things. People are fairly aware of it and they can become quite nasty about it.”

In this context credibility and trust were crucial resources, but they were easily eroded if errors, inconsistencies, or uncertainties were exposed. Another EA official recalled how the Agency struggled to regain public confidence after its SMP1 estimates of coastal erosion rates along the east coast of England proved inaccurate:

“On the east coast had that as a problem, in that the original coastal report, the SMP 1 prior to that, predicted quite low rates of erosion, yet the locals were seeing much higher rates at times, which is gonna happen, because you get a major storm that’s one of the difficulties, isn’t it? It changes rapidly sometimes and it is not a continuous stepwise process. So we have seen that. That has slightly eroded the credibility of the engineers.”

Inconsistencies in sea level allowances left operational officials feeling similarly exposed. Areas that might have been economically viable to defend using one set of sea level allowances might no longer be if different, higher estimates were applied. The variability in sea level rise allowances was particularly problematic because, compared to the peak flood flow adjustments, they had a much greater impact on assessments of flood risk. The number of properties estimated to be at risk of flooding was sensitive to changes of even just a few centimetres in projected sea level rise, as this operational-level official noted:

“So even if you add on 20% of extra flood, it’s not really impacting on any more properties. The sea level rise, it suddenly changes everything. The places that weren’t thought of at risk becomes in the risk zone.”

This technical sensitivity was magnified by the political sensitivities involved in debates about whether and where to hold the line against rising sea-levels. It was difficult enough for operational-level officials to close off these high stakes debates, without having their controversial decisions about whether it was worth defending particular areas against the sea undermined by complaints that they were based on different sea level allowances to those used for cost-benefit analysis in neighbouring areas.

Even if operational-level officials were inclined to publicly acknowledge the scientific uncertainties of coastal flood risk modelling, their dependence on consultant scientists and their proprietary coastal erosion models made it difficult to do so:

“again each of the plans that the consultants would have done is a slightly different approach for the coastal evolution. They’re largely, and again they have quite proprietary methodologies . . . it’s not like the flooding one where it’s working to sort of FEH [Flood Estimation Handbook] and they’re doing some prescribed upfront, publicly visible, it’s much more proprietary. So it’s almost a black box from where we get our erosion estimates.”

Most operational-level officials were less sophisticated in their appreciation of these scientific uncertainties.

Their institutional position discouraged them from expressing scepticism of prevailing sea level rise projections, for fear it might undermine efforts to communicate the seriousness of the threat. Several informants noted the difficulties of getting local publics to understand and accept the medium- to long-term risks from sea level rise:

“So it’s a lack of believability for some people in the higher levels of predictions. You’ve got a real problem in actually getting them to think about the response ahead. I had one little community which when you look at the road runs right along the back of the beach. Even the coastal engineer down there says, ‘the highway, we can’t lose that, it’s got to stay there’ But the model is saying well, you could be seeing it retreat going 20 m, not a huge distance, but that’s going to almost take up the highway.”

Uncertainty makes it difficult to dispel this ingrained optimism bias. Thus the 20 Year Flood Action Plan for the Somerset Levels calls for the resumption of widespread dredging (Somerset Rivers Authority, 2014), but the sustainability of those plans over even the medium-term is very sensitive to sea level rise. With dredging acknowledged to increase the present risk of tidal flooding to the town of Bridgwater and the Parrett CFMP projecting an additional 10,000 properties there at risk of flooding under just a 500 mm sea level rise assumption (EA, 2012), it is not clear what the risk-benefit ratio for dredging would be under the 1000 mm rise assumption used for the more recently completed SMP for the opposing Welsh side of the Severn Estuary, but it is almost certain to be less favourable. Politics matters, of course. Backed with a special line of £20 million from a panicked Prime Minister facing re-election and pledging that money would no object (Demeritt, 2014), these plans for Somerset were not subject to the normal risk-based disciplines of FCERM in England. Operational-level officials elsewhere need to be able to rationalize their plans in terms of definitive risk calculations and those decisions can be complicated –both technically and institutionally – if uncertainties are acknowledged.

7. Discussion

These contrasting cases highlight important institutional tensions between the injunction to remain open to uncertainty and allow room to change direction in response to new

information, as adaptive management counsels, while also translating the uncertainties about future flooding into actionable risk estimates for rationalizing risk-based management. These tensions resulted in climate change uncertainties about peak flood flows and sea level rise being framed and managed in very different ways in three otherwise similar and inter-dependent FCERM processes for long term shoreline and catchment flood management planning and strategic flood risk assessment for spatial planning and development control regulation.

In assessing fluvial flood risks, those planning processes accounted for climate change by applying a blanket 20% increase to estimated peak flows to produce a calculable number required for risk-based decision-making. Although this adjustment was scientifically crude and readily acknowledged as such by scientific experts and strategic policymakers, this was rarely acknowledged by operational staff. For them the 20% adjustment was easy to understand, and so they were quick to apply it in the consistent way set out for them in the strategic guidance. Even if they possessed the scientific expertise to appreciate the complexities of future peak flow estimates, which most did not, there was every incentive for operational-level staff to adopt a position of 'strategic ignorance' (McGoey, 2012), since acknowledging uncertainty would open up another line of potential criticism at the various public fora at which they had to defend decisions about the management of future fluvial flooding. In this way proscriptive, one-size-fits-all guidance reduced the institutional uncertainties about whether and how climate change would get taken into account, even as it tended to close down the space for reflexivity about the scientific uncertainties involved in its application.

This tendency for those relying on climate projections for operational policy implementation to ascribe greater certainty to them than the scientists involved in doing the actual modelling has been noted before (Shackley and Wynne, 1995; Demeritt, 2001; Lahsen, 2005). However our focus on institutional risk provides a richer explanation of the drivers of this 'certainty trough' (MacKenzie, 1993: 371–372) than differences in expertise (Collins and Evans, 2007) or tacit, and therefore also often somewhat underspecified, processes of 'co-production', binding policymakers to scientific results they depend upon but may not necessarily understand in full.

The dynamics in the case of sea level rise offer some interesting contrasts. Here, the underlying scientific knowledge was framed as comparatively solid, and policy guidance sought to reflect this with more spatio-temporally differentiated and detailed advice about how uncertainties about future sea level rises should be translated into calculable risks to be anticipated and managed. The sensitivity of flood inundation estimates to assumptions about sea level rise made the scientific credibility of those allowances critical. In an effort to shore up their credibility and to protect their own institutional reputation for sound, science-based advice, strategic-level policy makers at the EA, Defra, and its predecessor MAFF regularly reviewed and revised their guidance about how to represent the uncertainties in the science. However the timing of their revisions in appraisal guidance was only loosely coupled to implementation. Operational-level officials had their own timetables for preparing SFRAs and revising their CFMPs and SMPs, which proceeded at different speeds in different regions and made different allowances for sea level rise depending on the guidance prevailing at the time each plan was being completed. The resulting inconsistencies in operating assumptions about sea level rise then created institutional uncertainties about whether operational plans for managed realignment of the coastline would face public challenge, given both their contentiousness and the sensitivity of their underlying assessments of risk and benefit to even small

shifts in sea level rise allowances. Operational-level staff were acutely conscious of these risks to their authority and sought to manage those institutional risks by closing down the uncertainties about the analysis underpinning their policy decisions. This response, in turn, tended to subvert the stated purpose of the CFMP, SFRA, and SMP processes as a means for encouraging deliberation and reflexivity about the long term strategic challenges of climate change.

Our cases highlight the institutional geographies shaping risk governance and climate change policy. Adaptation decisions depend on scientific assessments, and a wealth of recent research has explored the ways in which these coupled but institutionally distinct processes are co-produced and mutually constitutive (Shackley and Wynne, 1996; Demeritt, 2001; Lane et al., 2011a; Lövbrand, 2011; Webb, 2011). Whereas the SFRAs were rhetorically positioned as an assessment and planning process that merely informs but is institutionally distinct from the resource allocation decisions necessary to deliver on its plans, the CFMPs and SMPs did not distinguish scientific risk assessment from political risk management quite so sharply. Nevertheless their authority still depended on the rhetoric of being science-based and was therefore vulnerable if the credibility of the underlying science were to be challenged or change. Those involved in FCERM were very conscious of these second-order risks to their institutional authority, and their efforts to guard against them exemplify a wider "defensive dynamic" (Power et al., 2009: 309) in the organizational culture of risk management in Britain.

Two distinct strategies for managing these institutional risks can be identified from our cases. First, in the case of peak flood flows, challenges to the 20% adjustment were managed through deferral of responsibility and blame deflection. Operational-level staff avoided personal responsibility for adding this arbitrary figure by pointing to the guidance and to the wider institutional requirements to follow it, while at the strategic-level those responsible for formulating that guidance appealed to the 'science' and to the independent peer reviewed research they commissioned to legitimate it. The second common strategy is what Hood and Rothstein (2001: 41) refer to as "prebutter", by which institutions seek to respond "to anticipated criticisms or demands for information before they materialize". Protecting against such criticisms is one reason why strategic-level officials have been so keen to keep updating their appraisal guidance. In so doing however, they were not mindful of the institutional risks created for operational-level officials by the resulting inconsistencies in the climate change assumptions used to drive risk-based plans for coastal flooding. Central guidance for peak flood flows has now also been updated, with the uniform 20% allowance recommended by Defra (2006a) abandoned in favour of more locally differentiated adjustments (EA, 2010b). However, the SFRAs and CFMPs prepared under the old guidance still stand and will continue to shape operational and strategic decision-making until they are eventually updated locally.

But unlike the case of sea level rise, amendments to peak flow allowances are unlikely to cause much public controversy. Peak flood flows are catchment specific and the resulting fluvial flood risk estimates are more difficult to compare with one another. As a result inconsistencies in the basis for decisions about inland flooding made under the old and revised guidance are less apparent than for coastal flooding where the de-coupling of the timetables for revising the central guidance from the separate processes for preparing SMPs and CFMPs exposed operational-level officials to potential criticism and increased the institutional risks involved in taking the uncertain effects of future sea level rise into account in adaptation planning and flood risk management.

8. Conclusion

In this paper we have explored the tensions between risk-based and adaptive management approaches to policymaking in the face of uncertainty. While these approaches may share common decision-analytical roots, they involve very different institutional logics. With its emphasis on optimising resource allocation and standardising administrative decision-making, risk-based approaches fit uneasily alongside the emphasis given in adaptive management to provisionality, flexibility, and openness to uncertainty, which can expose policymakers to potential criticism and amplify the institutional risks of operational decision-making.

Our cases also highlight how institutional concern with defensibility and with managing the second-order institutional risks to the reputations of those charged with FCERM responsibilities can influence the ways in which the first-order risks to society from climate change are themselves understood and managed. While there may be reasons to suspect that Britain is particularly prone to this defensive dynamic (Porter et al., 2015; Power et al., 2009; Rothstein et al., 2013), risk-based approaches to FCERM are increasingly common internationally, and there is evidence elsewhere that concerns with reputation and institutional risk may be influencing how institutions discharge their first-order risk management responsibilities (Kuhlicke et al., 2015).

Finally, our paper shows that greater scientific certainty about climate change does not necessarily lead to more certain or more effective policy outcomes. Despite being regarded by experts as, at best, a makeshift estimate, the 20% adjustment to peak flood flows proved quite effective in getting operational-level plans for risk-based management of fluvial flooding to take the incompletely understood impacts of climate change into account. With sea level, however, efforts at the strategic-level to follow an adaptive management approach by iteratively updating the guidance to keep it in line with the very latest scientific advances led to inconsistencies in the implementation of that guidance that exposed operational authorities to potential criticism and amplified institutional anxieties about whether and how to adapt FCERM to climate change. These institutional risks arose, not so much from the limitations of scientific knowledge of climate change as from the very institutional architecture for translating those uncertainties into actionable policy.

Our research thus suggests reasons for caution about the heavy emphasis sometimes given in climate change research and policymaking to generating ever more elaborate and probabilistic scenarios of future climate change to underpin policy decisions (LWEC Partnership, 2011). While it is certainly important to clarify and correctly communicate scientific uncertainties, this is not sufficient for effective policymaking, particularly if it fails to acknowledge the conflicting interests and institutional demands of the various actors involved in science-policy processes. Indeed several recent studies have pointed to situations in which probabilistic representations of scientific uncertainty, so prized by the climate research community, are not simply unwanted by those charged with policy decisions but actively resisted (Demeritt and Nobert, 2011; Tang and Dessai, 2012).

Our findings show that institutional dynamics are as important for the effectiveness of adaptation as the quality of the underlying science and the sensitivity of those policy decisions to uncertainties or error in their assumptions, as emphasised by advocates of adaptive management and robust decision-making. Those institutional dynamics and the ways in which they shape the framing and response to scientific uncertainties and risk are typically ignored in normative theories of decision analysis for policy making. If these considerations about the practical use of science in governance continue to be ignored, there is a risk not just of poorer adaptation

policy, but also of poorer science too, insofar as climate policy processes reciprocally influence the underlying science.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.gloenvcha.2016.01.007>.

References

- Allen, C.R., Fontaine, J.J., Pope, K.L., Garmestani, A.S., 2011. Adaptive management for a turbulent future. *J. Environ. Manag.* 92, 1339–1345. doi:<http://dx.doi.org/10.1016/j.jenvman.2010.11.019>.
- Amoore, L., 2013. *The Politics of Possibility: Risk and Security Beyond Probability*. Duke University Press, Durham, NC.
- Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., Patton, E., 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environ. Change* 21, 995–1004. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2011.04.006>.
- Beck, U., 1992. *Risk Society: Towards a New Modernity*. SAGE.
- Bellamy, R., Chilvers, J., Vaughan, N.E., Lenton, T.M., 2013. 'Opening up' geoengineering appraisal: Multi-Criteria Mapping of options for tackling climate change. *Global Environ. Change* 23, 926–937. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2013.07.011>.
- Borgomeo, E., Hall, J.W., Fung, F., Watts, G., Colquhoun, K., Lambert, C., 2014. Risk-based water resources planning: incorporating probabilistic nonstationary climate uncertainties. *Water Resour. Res.* 50, 6850–6873. doi:<http://dx.doi.org/10.1002/2014WR015558>.
- Brown, M.B., 2009. *Science in Democracy: Expertise, Institutions, and Representation*. MIT Press, Cambridge, Mass.
- Butler, C., Pidgeon, N., 2011. From 'flood defence' to 'flood risk management': exploring governance, responsibility, and blame. *Environ. Plann. C* 29, 533–547. doi:<http://dx.doi.org/10.1068/c09181j>.
- Collins, H., Evans, R., 2007. *Rethinking Expertise*. University of Chicago Press, Chicago.
- Cox, L.A., 2012. Confronting deep uncertainties in risk analysis. *Risk Anal.* 1607–1629. doi:<http://dx.doi.org/10.1111/j.1539-6924.2012.01792.x>.
- Davies, A.R., Demeritt, D., 2000. Cost-benefit analysis and the politics of valuing the environment. *Radic. Stat.* 73, 24–33. <http://www.radstats.org.uk/no073/article3.htm>.
- DCLG, 2006. *Planning Policy Statement 25: Development and Flood Risk*. Department for Communities and Local Government, London.
- Defra, 2004. *Making Space for Water: Developing a New Government Strategy for Flood and Coastal Erosion Risk Management in England*. A Consultation Exercise. Department for Environment, Farming, and Rural Affairs, London. <http://www.look-up.org.uk/2013/wp-content/uploads/2014/02/Making-space-for-water.pdf>.
- Defra, 2006a. *Flood and Coastal Defence Appraisal Guidance FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities: Climate Change Impacts October 2006*. Department for Environment, Farming, and Rural Affairs, London. <http://archive.defra.gov.uk/environment/flooding/documents/policy/guidance/fcdpag/fcd3climate.pdf>.
- Defra, 2006b. *Shoreline Management Plan Guidance Volume 1: Aims and Requirements*. Department for Environment, Farming, and Rural Affairs, London.
- Defra, 2009. *Appraisal of Flood and Coastal Erosion Risk Management: A Defra Policy Statement*. June 2009. Available at: <http://www.defra.gov.uk/publications/files/pb13278-erosion-manage-090619.pdf>.
- Defra, 2012. *UK Climate Change Risk Assessment*. London. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69487/pb13698-climate-risk-assessment.pdf.
- Defra, 2013. *The National Adaptation Programme: Making the country resilient to a changing climate*. Department for Environment, Farming, and Rural Affairs, London. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf.
- Defra, 2013. *2010 to 2015 government policy: climate change adaptation*. Available at: <https://www.gov.uk/government/publications/2010-to-2015-government->

- policy-climate-change-adaptation/2010-to-2015-government-policy-climate-change-adaptation (accessed 28.06.15).
- Demeritt, D., 2001. The construction of global warming and the politics of science. *Ann. Assoc. Am. Geographers* 91, 307–337. doi:<http://dx.doi.org/10.1111/0004-5608.00245>.
- Demeritt, D., 2006. Science studies, climate change and the prospects for constructivist critique. *Economy Soc.* 35, 453–479. doi:<http://dx.doi.org/10.1080/03085140600845024>.
- Demeritt, D., 2014. Spooked politicians are undermining flood defence policy with short term decisions. *New Civil Eng.* 9.
- Demeritt, D., 2015. The promises of participation in science and political ecology. In: Perreault, T., Bridge, G., McCarthy, J. (Eds.), *The Routledge Handbook of Political Ecology*. Routledge, London, pp. 224–234.
- Demeritt, D., Nobert, S., 2011. Responding to early flood warning in the European Union. In: Meyer, C.O., de Franco, C. (Eds.), *Forecasting, Warning, and Transnational Risks: Is Prevention Possible?* Palgrave Macmillan, Basingstoke, pp. 127–147.
- Demeritt, D., Rothstein, H., Beaussier, A.-L., Howard, M., 2015. Mobilizing risk: explaining policy transfer in food and occupational safety regulation in the UK. *Environ. Plann. A* 47, 373–391. <http://dx.doi.org/10.1068/a140085p>.
- Dessai, S., Hulme, M., 2007. Assessing the robustness of adaptation decisions to climate change uncertainties: a case study on water resources management in the East of England. *Global Environ. Change* 17, 59–72. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2006.11.005>.
- Dilling, L., Lemos, M.C., 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environ. Change* 21, 680–689. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2010.11.006>.
- Dodds, A., 2006. The core executive's approach to regulation: from 'better regulation' to 'risk-tolerant deregulation'. *Soc. Policy Adm.* 40, 526–542. doi:<http://dx.doi.org/10.1111/j.1467-9515.2006.00503.x>.
- EA, 2010a. *Flood and Coastal Erosion Risk Management Guidance on Applying the Scoring and Weighting Methodology*. Environment Agency, Bristol.
- EA, 2010b. *Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG)*. Environment Agency, Bristol. <http://webarchive.nationalarchives.gov.uk/20131108051347/http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0310bsdb-e-e.pdf>.
- EA, 2011a. *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*. Environment Agency, Bristol. <http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/geho0711btzu-e-e.pdf>.
- EA, 2011b. *Understanding the Risks, Empowering Communities, Building Resilience: The National Flood and Coastal Erosion Risk Management Strategy for England*. Environment Agency, London https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228898/9780108510366.pdf (accessed 26.03.15).
- EA, 2012. *Parrett Catchment Flood Management Plan*. Environment Agency, Exeter.
- EA, 2013. *Catchment Flood Management Plans Annual Report 2012*. Environment Agency, Bristol. http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/LIT7568_e080a1.pdf.
- Ekström, M., Kuruppu, N., Wilby, R.L., Fowler, H.J., Chiew, F.H.S., Dessai, S., Young, W. J., 2013. Examination of climate risk using a modified uncertainty matrix framework—applications in the water sector. *Global Environ. Change* 23, 115–129. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2012.11.003>.
- Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. *Global Environ. Change* 19, 240–247. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2008.12.003>.
- Hall, J.W., Lempert, R.J., Keller, K., Hackbarth, A., Mijere, C., McInerney, D.J., 2012. Robust climate policies under uncertainty: a comparison of robust decision making and info-gap methods. *Risk Anal.* 32, 1657–1672. doi:<http://dx.doi.org/10.1111/j.1539-6924.2012.01802.x>.
- Haughton, G., Bankoff, G., Coulthard, T.J., 2015. In search of 'lost' knowledge and outsourced expertise in flood risk management. *Trans. Inst. Br. Geographers* 40, 375–386. doi:<http://dx.doi.org/10.1111/tran.12082>.
- Treasury, H.M., 2003. *The Green Book: Appraisal and Evaluation in Central Government*. The Stationery Office/Tso, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf.
- Adaptive Environmental Assessment and Management*. In: Holling, C.S. (Ed.), John Wiley & Sons, New York.
- Hood, C., Rothstein, H., 2001. Risk regulation under pressure problem solving or blame shifting? *Adm. Soc.* 33, 21–53. doi:<http://dx.doi.org/10.1177/00953990122019677>.
- Huber, M., Rothstein, H., 2013. The risk organisation: or how organisations reconcile themselves to failure. *J. Risk Res.* 16, 651–675. doi:<http://dx.doi.org/10.1080/13669877.2012.761276>.
- Institute of Hydrology, 1999. *Flood Estimation Handbook*. Wallingford.
- Irwin, A., 2006. The politics of talk coming to terms with the 'new' scientific governance. *Soc. Stud. Sci.* 36, 299–320. doi:<http://dx.doi.org/10.1177/0306312706053350>.
- Johnson, C.L., Priest, S.J., 2008. Flood risk management in England: a changing landscape of risk responsibility? *Int. J. Water Resour. Dev.* 24, 513–525. doi:<http://dx.doi.org/10.1080/07900620801923146>.
- Kiem, A.S., Austin, E.K., 2013. Disconnect between science and end-users as a barrier to climate change adaptation. *Clim. Res.* 58, 29–41. doi:<http://dx.doi.org/10.3354/cr01181>.
- Kirby, A.M., Ash, J.R.V., 2000. *Fluvial freeboard guidance note*. R&D Technical Report W187, Environment Agency, Bristol.
- Kirchhoff, C.J., Carmen Lemos, M., Dessai, S., 2013. Actionable knowledge for environmental decision making: broadening the usability of climate science. *Ann. Rev. Environ. Resour.* 38, 393–414. doi:<http://dx.doi.org/10.1146/annurev-enviro-022112-112828>.
- Klinke, A., Renn, O., 2012. Adaptive and integrative governance on risk and uncertainty. *J. Risk Res.* 15, 273–292. doi:<http://dx.doi.org/10.1080/13669877.2011.636838>.
- Krieger, K., 2013. The limits and variety of risk-based governance: the case of flood management in Germany and England. *Regul. Gov.* 7, 236–257. doi:<http://dx.doi.org/10.1111/rego.12009>.
- Kuhlicke, C., Callsen, I., Begg, C., 2015. Reputational risks and participation in flood risk management and the public debate about the 2013 flood in Germany. *Environ. Sci. Policy* doi:<http://dx.doi.org/10.1016/j.envsci.2015.06.011>.
- Lahsen, M., 2005. Seductive simulations? Uncertainty distribution around climate models. *Soc. Stud. Sci.* 35, 895–922. doi:<http://dx.doi.org/10.1177/0306312705053049>.
- Lane, S.N., Landstrom, C., Whatmore, S.J., 2011a. Imagining flood futures: risk assessment and management in practice. *Philos. Trans. R. Soc. A* 369, 1784–1806. doi:<http://dx.doi.org/10.1098/rsta.2010.0346>.
- Lane, S.N., Odoni, N., Landström, C., Whatmore, S.J., Ward, N., Bradley, S., 2011b. Doing flood risk science differently: an experiment in radical scientific method. *Trans. Inst. Br. Geographers* 36, 15–36. doi:<http://dx.doi.org/10.1111/j.1475-5661.2010.00410.x>.
- Latour, B., 1999. *Circulating reference: Sampling the soil in the Amazon forest. Pandora's Hope: Essays on the Reality of Science Studies*. Harvard University Press, Cambridge, Mass, pp. 24–79.
- Dynamic Sustainabilities: Technology, Environment, Social Justice*. In: Leach, M., Scoones, I., Stirling, A. (Eds.), Routledge, London.
- Lemos, M.C., Morehouse, B.J., 2005. The co-production of science and policy in integrated climate assessments. *Global Environ. Change* 15, 57–68. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2004.09.004>.
- Lempert, R.J., Collins, M.T., 2007. Managing the risk of uncertain threshold responses: comparison of robust, optimum, and precautionary approaches. *Risk Anal.* 27, 1009–1026. doi:<http://dx.doi.org/10.1111/j.1539-6924.2007.00940.x>.
- Lempert, R.J., Groves, D.G., 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technol. Forecasting Social Change* 77, 960–974. doi:<http://dx.doi.org/10.1016/j.techfore.2010.04.007>.
- Lövbrand, E., 2011. Co-producing European climate science and policy: a cautionary note on the making of useful knowledge. *Sci. Public Policy* 38, 225–236.
- LWEC Partnership, 2011. *Living with Environmental Change: A major interdisciplinary partnership to tackle living with environmental change. Strategy 2008–2013* Available at: <http://www.lwec.org.uk/sites/default/file/LWEC%20Strategy%202008~2013.pdf> (accessed 29.08.13.).
- MacKenzie, D.A., 1993. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. MIT Press.
- MAFF, 1993. *Flood and Coastal Defence Project Appraisal Guidance Notes (PAGN)*. Ministry of Agriculture, Fisheries, and Food, London.
- MAFF, 1999. *Flood and Coastal Defence Project Appraisal Guidance: Economic Appraisal (FCPAG3)*. Ministry of Agriculture, Fisheries, and Food.
- MAFF, 2000. *FCDPAG4: Flood and Coastal Defence Project Appraisal Guidance: Approaches to Risk (FCPAG4)*. Ministry of Agriculture, Fisheries, and Food, London.
- Mastrandrea, M.D., Schneider, S.H., 2004. Probabilistic integrated assessment of 'dangerous' climate change. *Science* 304, 571–575. doi:<http://dx.doi.org/10.1126/science.1094147>.
- McGoey, L., 2012. The logic of strategic ignorance. *Br. J. Sociol.* 63, 533–576. doi:<http://dx.doi.org/10.1111/j.1468-4446.2012.01424.x>.
- Mearns, L.O., 2010. The drama of uncertainty. *Clim. Change* 100, 77–85. doi:<http://dx.doi.org/10.1007/s10584-010-9841-6>.
- Mearns, L.O., 2012. Response to 'uncertainty as a science policy problem'. *Clim. Change* 110, 3–4. doi:<http://dx.doi.org/10.1007/s10584-011-0051-7>.
- Meyer, R., 2012. Uncertainty as a science policy problem. *Clim. Change* 110, 1–2. doi:<http://dx.doi.org/10.1007/s10584-011-0050-8>.
- Milly, P.C.D., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., 2008. Stationarity is dead: whither water management? *Science* 319, 573–574. doi:<http://dx.doi.org/10.1126/science.1151915>.
- Moran, M., 2003. *The British Regulatory State: High Modernism and Hyper-innovation*. Oxford University Press, Oxford.
- Oels, A., 2013. Rendering climate change governable by risk: from probability to contingency. *Geoforum* 45, 17–29. doi:<http://dx.doi.org/10.1016/j.geoforum.2011.09.007>.
- Osborne, D., Gaebler, T., 1992. *Reinventing Government: How the Entrepreneurial Spirit is Transforming the Public Sector*. Addison-Wesley Publishing Company, Reading, MA.
- Ost, 2004. *Foresight Future Flooding: Executive Summary*. Office of Science and Technology, London. <http://www.bis.gov.uk/foresight/our-work/projects/published-projects/flood-and-coastal-defence/project-outputs>.

- Pahl-Wostl, C., 2006. Transitions towards adaptive management of water facing climate and global change. *Water Resour. Manag.* 21, 49–62. doi:<http://dx.doi.org/10.1007/s11269-006-9040-4>.
- Parkes, B.L., 2015. Uncertainty in flood risks and its implications for management. PhD Thesis. King's College London, London.
- Porter, J., Demeritt, D., 2012. Flood-risk management, mapping, and planning: the institutional politics of decision support in England. *Environ. Plann. A* 44, 2359–2378. doi:<http://dx.doi.org/10.1068/a446660>.
- Porter, T.M., 1994. Making things quantitative. *Sci. Context* 7, 389–407.
- Porter, T.M., 1995. *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton University Press, Princeton.
- Porter, J., Demeritt, D., Dessai, S., 2015. The right stuff? Informing adaptation to climate change in British local government. *Global Environ. Change* 35, 411–422. doi:<http://dx.doi.org/10.1016/j.gloenvcha.2015.10.004>.
- Power, M., 2004. *The Risk Management of Everything: Rethinking the Politics of Uncertainty*. Demos.
- Power, M., 2007. *Organized Uncertainty: Designing a World of Risk Management*. Oxford University Press, Oxford.
- Power, M., Scheytt, T., Soin, K., Sahlin, K., 2009. Reputational risk as a logic of organizing in late modernity. *Organ. Stud.* 30, 301–324. doi:<http://dx.doi.org/10.1177/0170840608101482>.
- Reynard, N.S., Crooks, S.M., Kay, A.L., 2005. Impact of climate change on flood flows in river catchments—final report. R&D Technical Report W5-032/TR, Environment Agency, Bristol. <http://a0768b4a8a31e106d8b0-50dc802554eb38a24458b98ff72d550b.r19.cf3.rackcdn.com/scho0305biwe-e-e.pdf>.
- Reynard, N.S., Crooks, S.M., Kay, A.L., 2009. Regionalised impacts of climate change on flood flows. R&D Technical Report FD2020/TR, Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme, London. <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=13958>.
- Rhodes, R.A.W., 1996. The new governance: governing without government. *Political Stud.* 44, 652–667. doi:<http://dx.doi.org/10.1111/j.1467-9248.1996.tb01747.x>.
- Rothstein, H., 2006. The institutional origins of risk: a new agenda for risk research. *Health Risk Soc.* 8, 215–221. doi:<http://dx.doi.org/10.1080/13698570600871646>.
- Rothstein, H., Downer, J., 2012. 'Renewing Defra': exploring the emergence of risk-based policymaking in UK central government. *Public Adm.* 90, 781–799. doi:<http://dx.doi.org/10.1111/j.1467-9299.2011.01999.x>.
- Rothstein, H., Borraz, O., Huber, M., 2011. From the 'neurotic' to the 'rationalising' state: risk and the limits of governance. In: Meyer, C.O., de Franco, C. (Eds.), *Forecasting, Warning, and Transnational Risks: Is Prevention Possible?*, pp. 187–207. Available at: <http://pub.uni-bielefeld.de/publication/2447313> (accessed 6.02.13.).
- Rothstein, H., Borraz, O., Huber, M., 2013. Risk and the limits of governance: exploring varied patterns of risk-based governance across Europe. *Regul. Gov.* 7, 215–235. doi:<http://dx.doi.org/10.1111/j.1748-5991.2012.01153.x>.
- Rothstein, H., Huber, M., Gaskell, G., 2006. A theory of risk colonization: the spiralling regulatory logics of societal and institutional risk. *Economy Soc.* 35, 91–112. doi:<http://dx.doi.org/10.1080/03085140500465865>.
- Sarewitz, D., Pielke Jr., R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. *Environ. Sci. Policy* 10, 5–16. doi:<http://dx.doi.org/10.1016/j.envsci.2006.10.001>.
- Shackley, S., Wynne, B., 1995. Integrating knowledges for climate change: pyramids: nets and uncertainties. *Global Environ. Change* 5, 113–126.
- Shackley, S., Wynne, B., 1996. Representing uncertainty in global climate change science and policy: boundary-ordering devices and authority. *Sci. Technol. Hum. Values* 21, 275–302. doi:<http://dx.doi.org/10.1177/016224399602100302>.
- Somerset Rivers Authority, 2014. *The Somerset Levels and Moors Flood Action Plan: A 20 Year Plan for a Sustainable Future*. Available at: <https://somersestnewsroom.files.wordpress.com/2014/03/20yearactionplanfull3.pdf>.
- Stephens, E.M., Edwards, T.L., Demeritt, D., 2012. Communicating probabilistic information from climate model ensembles—lessons from numerical weather prediction. *Wiley Interdiscip. Rev. Clim. Change* 3, 409–426. doi:<http://dx.doi.org/10.1002/wcc.187>.
- Stern, N., 2006. *The Stern Review on the Economics of Climate Change*. Cambridge University Press, Cambridge, UK. Available at: <http://www.hm-treasury.gov.uk/independent%5Fviews/stern%5Freview%5Fecconomics%5Fclimate%5Fchange/stern%5Freview%5Freport.cfm> (accessed 16.09.13.).
- Stirling, A., 2007. Risk, precaution and science: towards a more constructive policy debate. *EMBO Rep.* 8, 309–315. doi:<http://dx.doi.org/10.1038/sj.embor.7400953>.
- Tang, S., Dessai, S., 2012. Usable science? The U.K. climate projections 2009 and decision support for adaptation planning. *Weather Clim. Soc.* 4, 300–313. doi:<http://dx.doi.org/10.1175/WCAS-D-12-00028.1>.
- Thorne, C., 2014. Geographies of UK flooding in 2013/4. *Geog. J.* 180, 297–309. doi:<http://dx.doi.org/10.1111/geoj.12122>.
- Thurston, N., Finlinson, B., Glynn, J., Brooks, A., Frost, M., 2010. Policy evaluation of the first generation catchment flood management plans (CFMPs). Technical Report RMP 5357/TR, Department for Environment, Farming, and Rural Affairs, London. <http://archive.defra.gov.uk/environment/flooding/documents/interim2/cfmp-policy-eval-techreport.pdf>.
- Walker, G., Tweed, F., Whittle, R., 2014. A framework for profiling the characteristics of risk governance in natural hazard contexts. *Nat. Hazards Earth Syst. Sci.* 14, 155–164. doi:<http://dx.doi.org/10.5194/nhess-14-155-2014>.
- Warrick, R., Oerlemans, J., et al., 1990. Sea level rise. In: Houghton, J. (Ed.), *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press, New York, pp. 257–281.
- Webb, J., 2011. Making climate change governable: the case of the UK climate change risk assessment and adaptation planning. *Sci. Public Policy* 38, 279–292.
- Wilby, R.L., Dessai, S., 2010. Robust adaptation to climate change. *Weather* 65, 180–185. doi:<http://dx.doi.org/10.1002/wea.543>.
- Wilby, R.L., Keenan, R., 2012. Adapting to flood risk under climate change. *Prog. Phys. Geogr.* 36, 348–378. doi:<http://dx.doi.org/10.1177/0309133312438908>.
- Witzel, A., 2000. *The Problem-centered Interview*. Forum Qualitative Sozialforschung/Forum: Qualitative Social Research 1. Available at: <http://www.qualitative-research.net/index.php/fqs/article/view/1132> (accessed 16.09.13.).
- Yohe, G., Leichenko, R., 2010. Adopting a risk-based approach. *Ann. N. Y. Acad. Sci.* 1196, 29–40. doi:<http://dx.doi.org/10.1111/j.1749-6632.2009.05310.x>.