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Examination of climate risk using a modified uncertainty matrix framework—Applications in the water sector

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ABSTRACT

Previous climate risk assessments provide important methodological insights into how to derive tractable research questions and the appropriate use of data under uncertainty, as well as identifying steps that benefit from stakeholder involvement. Here we propose the use of a framework for the systematic and objective exploration of climate risk assessments. The matrix facilitates a breakdown of information about aim and context, main results, methodological choices, stakeholder involvement, sources and characteristics of uncertainties and overall weaknesses. We then apply the matrix to three risk assessments in the water sector to explore some methodological strengths and weaknesses of approaches strongly linked to climate model outputs (top-down) versus those that originate from local knowledge of climate exposures (bottom-up), and demonstrate that closer integration with social and physical sciences is more likely to yield robust climate risk assessments.

1. Introduction

Projected anthropogenic climate change could challenge current freshwater management practices (e.g., Wei et al., 2011), and has stimulated much research into different strategies for managing impacts on current hydrological regimes including changes to socio-economic pressures (e.g., Posey, 2009; Pandey et al., 2011). Whilst the physical component of water systems has received greater attention in climate change impact assessments, there is an urgent "need to look deeper into management systems to uncover the full array of costs and risks relevant to successful water delivery" (Dow et al., 2007, p. 236). This demands a shift of focus to the social dimensions of water management, or at least considering decision frameworks that are less dependent on climate change data when adapting to change (Dessai et al., 2009a; Beven, 2011).

Wilby et al. (2009) call for a twin-track approach involving development of: (i) scientific and economic capacity to identify critical thresholds leading to improved understanding and adaption to climate variability, and; (ii) climate scenario tools and data sets that reveal the longer-term changes in climate risk to inform adaptation planning. This echoes views found in the climate change vulnerability literature, where assessments are tending to move from science-driven assessments (impact-orientated research to enlighten mitigation policy) to policy-driven assessments (that identify options for adaptation policy) (Füssel and Klein, 2006).

The concept of *adaptive capacity* is extensively used in the climate change vulnerability and resilience literature albeit with different connotations. In the former case, the term refers to one of three dimensions that define vulnerability: 'exposure' and 'sensitivity' relate to climatic risks, and 'adaptive capacity' overcomes those risks (Ford, 2007, p. 11). Hence, adaptive capacity has a positive meaning. Conversely, in the resilience literature, adaptive capacity may be defined as a property that facilitates transformation of a system into a new state, which could be more or less desirable. In this case, adaptive capacity has a more complex meaning (e.g., Engle, 2011; Smit and Wandel, 2006). In this paper, we refer to the definition of adaptive capacity used by the Intergovernmental Panel on Climate Change (IPCC): "*The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of*

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opportunities, or to cope with the consequences" (IPCC, 2007, p. 869). This is most closely aligned with the vulnerability perspective.

By considering adaptive capacity, vulnerability assessments can examine those factors that influence a system's ability to modify behaviour to better cope with external pressures, such as climate change. Füssel and Klein (2006) consider two types of adaptation activities: *facilitation* and *implementation;* both of which aim to reduce system vulnerability. The former refers to activities that enhance adaptive capacity (such as scientific research, data collection, awareness raising, capacity building, institutions and governance, information networks, and legal frameworks). The latter refers to activities that enable a system to reduce exposure or sensitivity to climatic hazards or alleviate non-climatic pressures. Information about both types of adaptation activity is meaningful to stakeholders in water management, but is difficult to elucidate in a model-driven impact approach. Furthermore, a focus solely on model-impact responses ignores contributions from non-climatic factors (such as agricultural practices, land-use change, new infrastructure, river regulation, areal and point pollutant discharges) to the outcomes of climate change (Bates et al., 2008).

Although the benefits of integrated approaches to climate risk assessment are increasingly recognised (i.e., using both impact and vulnerability information), historically the impact dimension has received more attention. This raises expectations that scientists should be providing projections of climate impacts at regional scales. Some climate and hydrological models produce high-resolution output at catchment scales but there is low confidence in the accuracy of such information. For example, in order to achieve high resolution, the United Kingdom (UK) Climate Impacts Programme 2002 (UKCIP02) scenarios were based on a single climate model, so were unable to quantify attendant uncertainties (Gawith et al., 2009), a weakness that was largely corrected in the subsequent probabilistic climate change projections for the UK (UKCIP09, http://ukclimateprojections.defra.gov.uk). Indeed, Knutti et al. (2010) assert that if model uncertainties are not well characterised in climate risk assessments, their usefulness is questionable.

The first step in understanding the value of a climate risk assessment is to describe the study design and associated uncertainties. Following Walker et al. (2003) we propose a modified version of their 'uncertainty matrix'. The matrix was designed as a tool for systematic uncertainty analysis in regulatory and management sciences and has proved to be a useful platform for communicating uncertainties amongst model operators, policy makers and stakeholders (Refsgaard et al., 2007). Here we combine core aspects of the uncertainty matrix with other descriptors to provide a framework with which to classify climate risk assessments. Key features of the matrix are descriptors of: (i) the context of the assessment (aim and main policy focus); (ii) theoretical strengths and weaknesses, including characteristics of uncertainties; (iii) level of integration of natural and social sciences through methodology choices; (iv) stakeholder involvement (how and when). To distinguish between the two versions, we refer to our framework as the 'climate risk matrix'.

The climate risk matrix is not a climate risk assessment framework, rather it offers a framework with which decision makers can evaluate the robustness of available climate risk information. For example, it can be used as a communication tool in collaboration with stakeholders when discussing the most appropriate pathway for addressing a particular climate threat, or as an information summary framework for distributors of climate change data to illustrate how different climate change data sets complement each other in terms of strengths and weaknesses. Risk assessment frameworks on the other hand, attempt to detail the risk characteristics of an adverse event, such as its nature, likelihood, severity and reversibility or preventability (USPCC RARM, 1997). Jones (2001) proposed a framework for risk assessments within a climate change context, involving the calculation of conditional probabilities for exceeding particular impact thresholds as agreed upon between researchers and stakeholders - the thresholds being either of the biophysical world or ones whose exceedance could trigger behavioural change. Others have proposed risk assessment frameworks for specific events such as flood frequency (Raff et al., 2009) or land-slides (Aaheim et al., 2010) in the context of climate change.

The following sections apply the climate risk matrix to three water sector studies intended to raise preparedness for climate change. The examples were chosen on the basis of differences in their methodology, context, and availability of data–providing useful tests of the versatility of the framework under varied circumstances. The next section provides a summary of the methodologies commonly used in climate risk assessments. Section 3 then describes the climate risk matrix in more detail, before outlining the three water case studies in Section 4. Section 5 evaluates the extent to which our matrix adds useful insights, and Section 6 provides concluding remarks and opportunities for future research.

2. Climate risk assessments

Climate risk assessments typically employ one or more IPCC scenarios to describe plausible future states of the world (IPCC, 2007). These scenarios define the rates of greenhouse gas emissions and corresponding global climate responses, as simulated by coupled Atmosphere-Ocean General Circulation Models (AOGCMs). The IPCC Task Group on data and scenario support for Impact and Climate Assessment (TGICA) describe two complementary pathways for applying AOGCM output in climate impact and adaptation assessment: "*. . . a top-down approach involving the interpretation and downscaling of global-scale scenarios to regional level, and a bottom-up approach, that builds scenarios by aggregating from the local to regional scales*" (IPCC-TGICA, 2007, p. 4).

Downscaling techniques translate coarse-resolution AOGCM output (typically on scales of 100–300 km) into higher resolution outputs, or even point estimates, over defined domains (Fowler et al., 2007a). Downscaling methods are conventionally described as either statistical or dynamical. The former are founded on empirical relationships between large scale atmospheric predictor variables and local surface variables. The latter involve the use of a Regional Climate Model (RCM) to simulate the climate over a limited spatial domain but at a higher spatial resolution than the host AOGCM. Having obtained local or regional scale climate scenarios (whether by statistical or dynamical means), the next step is to apply an impact (e.g., rainfall-runoff) model to assess potential hydrological responses to regional climate change. In most climate risk studies, only the impact modelling, or the downscaling and impact modelling are conducted in house, as AOGCM experiments require significant computing resources.

The top-down approach is largely model driven and intrinsically linked to global emissions scenarios, whereas the bottom-up approach focuses on local scales, and often requires geographically explicit information. Smit and Wandel (2006) characterise bottom-up approaches as those where variables that represent exposure to climate change are sought empirically from the community rather than presumed by the researcher. They further note that the bottom-up approach "*. . . employs the experience and knowledge of community members to characterize pertinent conditions, community sensitivities, adaptive strategies, and decision-making process related to adaptive capacity or resilience. . .*" and "*. . . identifies and documents the decision-making process into which adaptations to climate change can be integrated*" (Smit and Wandel (2006, p. 285). Thus, understanding the system at risk is central to the bottom-up