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Adaptation pathways in practice: Mapping options and trade-offs for London's water resources

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ABSTRACT

London's ability to remain a world-leading city in an increasingly globalised economy is dependent on it being an efficient, low-risk place to do business and a desirable place to live. However, increasing climate risk from flooding, overheating and water scarcity threatens this, creating the need for adaptation. An adaption pathway describes a structured sequence of adaptation decisions that are designed to manage climate risk in a wide range of possible future conditions. Analysis of sequential adaptation decision 'pathways' helps to demonstrate how climate risk can (or cannot) be managed, whilst retaining the flexibility to respond to future uncertainties. Whilst adaptive planning has gained increasing attention, the uptake of such methods has been relatively limited compared to the scale of the adaptation challenge due to institutional, financial and methodological barriers. This paper introduces a framework for adaptation planning in urban water supply systems that links existing risk-based decision-making with the development of long-term adaptation pathways. We present a quantified assessment of how the risk of water shortages in London is predicted to vary dynamically through to 2100 depending on the choice of adaptation pathways and under different long-term transient population and climate scenarios. This approach helps to reconcile multiple decision timescales and demonstrates the value of strategic long-term adaptation planning to stakeholders by outlining long-term futures that may influence medium-term decision-making. Adopting a flexible approach to adaptation will be critical to the management of risk under uncertainty. This adaptation pathways approach demonstrates an effective framework for informing such decision processes.

1. Introduction

The prosperity of cities worldwide requires reliable water supply systems. A high degree of uncertainty exists however, as to how drivers such as population growth and climate change will affect the reliability of water supply in the future. Climate change adaptation is an ongoing process of risk assessment, action, re-assessment, and response (IPCC, 2012). Water resource management decisions on how and when to invest in infrastructure or demand management are being made now that will affect the long-term resilience of water supply systems (Hall et al., 2012c; Hallegatte, 2009). Such decisions will contribute to enhanced water security, flexibility and robustness; or adversely, reduced resilience, mal-adaptation and undesirable lock-in (Ranger et al., 2010). Their importance makes overcoming the barriers to adaptation faced by resource managers crucial (Barnett et al., 2015; Hallegatte, 2009).

Successful adaptation will require combinations of adaptation actions to be implemented through time in complex systems. Adaptation decision support needs to consider the timing, rate and scale of implementation of multiple actions distributed throughout a system as part of dynamic adaptive portfolios. Dynamic adaptive plans have been proposed as an effective mechanism for managing issues characterised by deep uncertainty (Walker, Haasnoot, & Kwakkel, 2013). A range of approaches for developing adaptive plans have been proposed; however, the uptake of such methods has been relatively limited compared to the scale of adaptation that is required around the world (Nakhooda et al., 2013; Walker et al., 2013). This may be because of the perceived complexity of such formal decision analysis methods, or because of a proliferation of alternative approaches. Institutional path dependency and capacity constraints are barriers to adaptation, and they restrict how readily practitioners may incorporate a long-term adaptation perspective into decision-making processes that are already explicitly

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(e.g., flood risk management) or implicitly risk-based (e.g. water resources planning).

A clearly defined yet flexible approach to adaptation can provide structure to guide the decision-making process. A range of frameworks have been developed, many building on the pioneering adaptation approach of Willows and Connell (2003), each with unique strengths. 'Bottom-up', vulnerability-based approaches have been found to be well suited to addressing an existing adaptation deficit, when planning horizons are short and climatic and non-climate risks are inter-related (Brown, Ghile, Laverty, & Li, 2012; IPCC, 2012; Nazemi, Wheater, Chun, & Elshorbagy, 2013). Policy-first approaches are effective in incorporating stakeholder input (Ranger et al., 2010). Risk-based approaches are suited to the management of well-characterised uncertainties (Hall, Brown, Nicholls, Pidgeon, & Watson, 2012). Robustness based approaches can be difficult to apply in the development of dynamic long-term plans (Walker et al., 2013), but it is important that any approach considers the robustness of near-term decisions that have long-term implications given the deep uncertainties surrounding future climate and socioeconomic change (Ben-Haim, 2006; Hall, Lempert et al., 2012; Hallegatte, 2009; Lempert & Schlesinger, 2000; Wilby & Dessai, 2010).

Adaptation pathways are a policy-first approach to decision-making that targets analysis at the adaptation challenge (Ranger et al., 2010). A pathways approach that sequences the implementation of actions over time to ensure the system adapts to the changing social, environmental and economic conditions will build flexibility into the overall adaptation strategy (Haasnoot, Middelkoop, Offermans, Beek, & Deursen, 2012; Ranger et al., 2010). An adaptation pathway provides a visual representation of the potential sequencing and type of actions that may be implemented in the future. Monitoring of decision-relevant variables is an important component of implementing a pathways approach (Yohe & Leichenko, 2010) as it establishes a link between risk assessment and action that many adaptation approaches lack.

Risk and vulnerability assessments are increasingly recognised as complimentary processes. Adaptation frameworks, such as the one developed by Wilby and Dessai (2010), that combine top-down and bottom-up assessments can leverage the advantages of both (IPCC, 2012, 2014). Pathways approaches should explicitly recognise and respond to existing management practices, which decision makers are familiar with and may have a legislative requirement to fulfil (Brown, Gawith, Lonsdale, & Pringle, 2011), to more fully capture the benefits of considering near and long-term planning horizons.

A pathways approach was first applied as part of the Thames Estuary tidal flood risk management project in London (Ranger et al., 2010). Adaptation pathways allow for a broad framing of the adaptation decision problem and have subsequently been used in a range of contexts (Barnett et al., 2014; Haasnoot et al., 2012; Haasnoot, Kwakkel, Walker, & ter Maat, 2013; Lawrence, Reisinger, Mullan, & Jackson, 2013; Rosenzweig & Solecki, 2014; Siebentritt, Halsey, & Stafford-Smith, 2014; Wise et al., 2014). Pathways approaches show significant potential for contributing to long-term adaptation planning (Barnett et al., 2014; Haasnoot et al., 2012; Lawrence et al., 2013; Park et al., 2012; Rosenzweig & Solecki, 2014; Wise et al., 2014); however, pathways have not been applied to long-term planning of urban water supply systems to date, which restricts their potential for uptake in such contexts. There is a need to continue developing, trialling, critiquing and demonstrating how pathways approaches can respond to barriers and be utilised in informing and motivating adaptation planning in different contexts (Barnett et al., 2015; Haasnoot et al., 2012; Wise et al., 2014).

To address this need, this paper introduces a framework for adaptation planning in urban water supply systems under transient population and climate scenarios. The framework links existing risk-based decision-making, adopting the risk based appraisal framework proposed by Hall and Borgomeo (2013) and first demonstrated by Borgomeo, Mortazavi-Naeini, Hall, O'Sullivan, and Watson (2016), with the development of long-term adaptation pathways. However, it goes beyond the work described in these papers by linking, for the first time, quantified risk analysis with consideration of adaptation pathways. We illustrate how adaptation pathways can be used to inform urban water resources adaptation planning by developing long-term pathways for London's water resources. We present a quantified assessment of how risk of water shortages in London is projected to vary dynamically depending on the choice of adaptation pathway and under different transient climate and population scenarios. This approach has helped to reconcile multiple decision timescales and demonstrate the value of strategic long-term adaptation planning to stakeholders by outlining long-term futures that may influence medium-term decision-making.

Demonstrating our proposed framework with a case study is critical to advancing adaptation theory and practice, as climate change adaptation cannot be separated from the context in which it is occurring (Rosenzweig & Solecki, 2014). In the next section we provide an overview of London's water resources, before outlining our pathways methodology and its alignment with existing decision making in Section 3. Section 4 describes the application of our methodology to our case study, including the development of a range of plausible pathways for London's long-term water supply to 2100. Section 5 presents an adaptation pathway diagram and results from the appraisal of the pathways in managing long-term water supply risk. Finally, the process of developing adaptation pathways and the results are discussed in Section 6.

2. London's water resources

London's water supplies are being stretched by increasing population and reducing water availability (EA, 2013). London's drinking water demands are primarily supplied by surface water abstraction from the Rivers Thames and Lee and, to a lesser extent (approximately 20%), groundwater sources. Furthermore, a 150 Ml/day desalination plant and reserve aquifers can be activated to supply water to London during times of drought. Water supply in London is managed by four private water companies, and regulated by the Environment Agency and the water supply regulation authority. This study focuses on the London Water Resource Zone (LWRZ), which includes 85% of London's residents. The LWRZ was chosen as it has been extensively studied, data for quantitative analysis is available, and the technical and institutional challenges being faced are representative of those being addressed across London. London has been classified as a water-stressed city and already faces water scarcity challenges (EA, 2013). In March 2012, water restrictions came into force across London as two consecutive dry winters caused very low levels in the River Thames and exceptionally low groundwater (GLA, 2012). The water restrictions were lifted in April, when exceptional rains terminated the prolonged drought (Parry, Marsh, & Kendon, 2013).

Climate change projections for the area suggest that by 2040 summer river flows and annual rainfall may decrease whilst temperature may increase (Diaz-Nieto & Wilby, 2005; Murphy et al., 2009). Overall water demand is expected to rise due to population growth and increasing single household occupancy (HM Government, 2012). Significant investment in water resource management is anticipated this century to maintain the existing levels of supply reliability and account for population growth and climate change (LCCP, 2012).

Every five years water companies in London prepare asset and water resource management plans (WRMPs) that consider cli-