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Research papers

Coupling stated preferences with a hydrological water resource model to inform water policies for residential areas in the Okanagan Basin, Canada

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ABSTRACT

To improve the behavioural realism of a water resource model, this study coupled hydrologic modelling with stated preference research, thereby incorporating an empirical estimate of behavioural parameters to represent residents' landscape decisions in an urban environment. The stated preference data came from a discrete choice experiment in which residents were asked to choose among several possible lawn plots — varying in size, turf variety, and aesthetic qualities. The discrete choice experiment also included subsidies for lawn replacement, and information about estimated water use and watering costs for each lawn choice. We prepared a behavioural model utilizing coefficients from a mixed logit model estimated from the stated preference data, and then coupled it with a water resources model of the Okanagan Basin using the Water Evaluation and Planning System. We then conducted a scenario analysis using the coupled socio-hydrological model to simulate the extent to which residents would adopt alternative lawns under varying incentives and subsequently computed corresponding changes in water demand. The results indicate that proposing alternative lawn configurations to residents and providing site-specific information about the potential for reduced watering costs, along with a small subsidy, could lead to considerable reduction of outdoor water use through voluntary adoption. Under a scenario in which the attributes of the suggested lawn configuration matched those most preferred by residents in the choice experiment, the suggested configuration was widely adopted in the Okanagan, but a scenario with a more extreme water conserving lawn configuration reduced overall outdoor water use by a greater amount even though the configuration was adopted by a smaller percentage of residents. This study illustrates the relationship between lawn preferences and water use and supports calls to integrate hydrological and social modelling in order to capture the complex interactions between human behaviour and water use.

1. Introduction

Water resource planning increasingly recognizes that human and ecological systems are complex adaptive systems, characterized by cross-scale interactions and high uncertainty (Folke et al., 2005; Levin, 1998; Mitchell et al., 2012). Accordingly, scholars have called for new research on the development of coupled socio-ecological models, which represent human interactions with water resource systems. For example, Sivapalan et al. (2012) argue for a new science of socio-hydrology to explore how coupled human-water systems co-evolve. Socio-hydrology can generate quantitative descriptions of system behaviour for modelling and forecasting possible future states. Carey et al. (2014) propose a framework for hydro-social modelling to capture the human variables critical to hydrological modelling. Troy et al. (2015) explore the development of socio-hydrologic modelling, noting that it is still unclear whether existing examples of coupled human-water models reflect an over-emphasis on calibrated data or an accurate representation of known human-water relationships. The recognition of human-water interconnections has also fostered research on hydro-ecological modelling (Akter et al., 2014), hydro-economic modelling (Boehlert and Jaeger, 2010; Hurd and Coonrod, 2012; Kragt et al., 2011), socio-economic tools applied to water systems (Koundouri et al., 2015), socio-hydrosystems (Lanini et al., 2004), and applications of socio-hydrology (Di Baldassarre et al., 2013; Elshafei et al., 2014).

While the constructs for socio-hydrological modelling have been studied in various forms, the parameterization of human behaviour in water resource models remains relatively rare. This lack of attention prompts for investigation into approaches for the integration of socio-economic research with hydrological models in order to simulate the interactions of human systems with hydrological systems, address water

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needs for society and ecosystems, and represent the dynamic nature of water demand (Carey et al., 2014). In our research, we developed a socially coupled water resource model for residential landscapes in the Okanagan Basin of British Columbia, Canada. The model demonstrates the effects that residents' preferences concerning their lawns under various scenarios will have on water use.

The coupled socio-hydrological model (the "Okanagan coupled model") is designed for use as a decision support tool to inform policies for managing water demand in the Okanagan Basin. The model uses the Water Evaluation and Planning System (WEAP – a water management and allocation system developed by Raskin et al. (1992) and the Stockholm Environment Institute) and a discrete choice model derived from a discrete choice experiment to examine the influence of residential landscape choices on regional water supplies. We applied the Okanagan coupled model in a subwatershed within the Okanagan Basin for alternative lawn scenarios to investigate changes in water demand. In this paper, we describe the process we developed for coupling the discrete choice model with WEAP and the resulting information provided to decision makers. To our knowledge this paper presents the first application of a discrete choice model being fully coupled with a water resource model, moving beyond the simple linking of outputs from separated models or frameworks. The results illustrate how the Okanagan coupled model provides water demand simulations based on hydrological and behavioural modelling, including empirical evidence of the preferences of water users, allowing for more informed policymaking.

This paper is organized as follows: An overview of the study area is given in the remainder of Section 1. Section 2 discusses the parameterization of the WEAP software with water supply and demand data in the Okanagan Basin. We include a description of the theory and calculations underlying the preference data and how the data were used to estimate the behavioural parameters in the Okanagan coupled model. In Section 3 we demonstrate how the Okanagan coupled model can be used for behaviourally realistic scenario analysis. Section 4 provides a discussion of the results and assesses the usefulness of the approach.

1.1. Study area

The Okanagan Basin covers 8046 km^2 in British Columbia, Canada (Fig. 1) and is unique in that it has the highest ratio of population to annual surface water yields of any basin in Canada (Statistics Canada, 2010). The semi-arid Okanagan Basin has a small water catchment, receives an annual average of only 300 mm of precipitation in the lower basin, analogous to other semi-arid regions like the southwest United States and parts of Australia, and is undergoing rapid population growth in a changing climate (Cohen et al., 2004; Merritt et al., 2003; Taylor and Barton, 2004). Surface water is major supply source, meeting 67% of the region's water demand (Summit Environmental, 2010a). Historically, water managers have mainly used surface water storage to meet growing water demand (McNeill, 2004); however, future scenario modelling suggests that existing surface water storage systems will be unable to meet municipal and instream flow needs by 2050 (Harma et al., 2012).

To study these issues, in 2007 the Okanagan Basin Water Board (a regional water governance body whose board is comprised of local governments, water suppliers and First Nations) initiated the development of two regional planning models for water and land use in the region. The first, the Okanagan Water Demand Model, estimated water needs for residential, agricultural, and industrial and commercial uses, based on land survey data, GIS and cadastral mapping of crop types – including turfgrass, irrigation system types, soil properties, and climatic data (Summit Environmental, 2010b). The second model, the Okanagan Water Accounting Model (OWAM), estimated natural streamflows and the effects of water storage and extractions on streamflows and lake levels in the Okanagan Basin (DHI Water and Environment, 2010). Neither of these models included a coupled social component. These models did, however, provide the hydrologic basis for our study as well as a foundation for considering water management strategies and policies in the Okanagan Basin.

In 2010, the Okanagan Basin Water Board had initiated a new phase of work to increase the availability of data, refine modelling tools, and improve public consultation in policy development. This timing presented a window of opportunity to evaluate methods for increasing the predictive capacity of water resource models of the Okanagan Basin, by including a representation of water user behaviour. A key point of interest for water providers in the Okanagan Basin is the impact population growth will have on water supplies as rural landscapes transition to residential land uses.

The population of the Okanagan basin grew by 46% during the period 1990–2010, from 235,793 to 345,831 (BCStats, n.d.). Accompanying this growth was the expansion of single family residential development, with large lawns that require more water to maintain compared to higher density developments (Maurer, 2010). Irrigating these residential lawns accounts for 24% of all water use in the Okanagan Basin; the second largest use of water after agricultural irrigation (Summit Environmental, 2010a). Reoccurring droughts have had a moderate impact on water conservation attitudes suggesting residents are open to consider options for reducing outdoor water use (Brandes and Kriwoken, 2006; Conrad, 2012a). Unfortunately, in choosing options for managing water use water managers often have little empirical information about the preferences of water users concerning these options. Instead, water managers often formulate strategies based on their own uncertain and sometimes inaccurate assumptions about the perceptions and preferences of water users. Therefore, predicting how residential consumers will respond to water demand management strategies and policies targeting residential landscapes is critical in decision making about water management in the Okanagan.

2. The Okanagan coupled model

In addition to the previously mentioned WEAP, there exist many possible basin wide water modelling systems, including RIBASIM (Hydraulics, 2004), MIKE BASIN (DHI Water and Environment, 2009), AQUATOOL (Andreu et al., 1996), and MODSIM (Labadie, 1995). We selected WEAP as the modelling platform because of its broad use as a decision support tool and because the Okanagan Basin Water Board was planning to adopt WEAP as a water management tool. Also, WEAP is a platform that provides flexibility in structuring water demand data by various measures of social and economic activities (e.g. water use rates per household, water use rates, number of households with lawns) (Yates et al., 2005).

The WEAP platform is a water management and allocation tool that has a graphical user interface to guide model parameterization. WEAP uses a mass balance accounting framework to calculate a monthly water balance of flows, changes in reservoir and groundwater storages, and water supply allocations to water demands and outflows (Yates et al., 2005). WEAP uses a linear programming heuristics approach to consider demand priorities and supply preferences to simulate both natural processes and human influences. Key assumptions may be built into the accounting to represent policies, costs and other factors that affect demand, supply, and the overall hydrologic cycle. A scenario feature allows the user to explore the effect of changes in climate and water management strategies on water systems, making WEAP well suited for evaluating human influences on water systems and informing water policymaking (Yates et al., 2005).

As a decision support tool, WEAP has been used to explore human-water interactions in a number of case studies. Swiech et al. (2012), for example, analyzed the impacts of a reservoir for improved agricultural production in the Yarabamba region, Peru with a WEAP model application. In another WEAP modelling application for Benin, Höllermann et al. (2010) applied different scenarios of socio-economic development