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Application of synthetic scenarios to address water resource concerns: A management-guided case study from the Upper Colorado River Basin

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ABSTRACT

Water managers are increasingly interested in better understanding and planning for projected resource impacts from climate change. In this management-guided study, we use a very large suite of synthetic climate scenarios in a statistical modeling framework to simultaneously evaluate how (1) average temperature and precipitation changes, (2) initial basin conditions, and (3) temporal characteristics of the input climate data influence water-year flow in the Upper Colorado River. The results here suggest that existing studies may underestimate the degree of uncertainty in future streamflow, particularly under moderate temperature and precipitation changes. However, we also find that the relative severity of future flow projections within a given climate scenario can be estimated with simple metrics that characterize the input climate data and basin conditions. These results suggest that simple testing, like the analyses presented in this paper, may be helpful in understanding differences between existing studies or in identifying specific conditions for physically based mechanistic modeling. Both options could reduce overall cost and improve the efficiency of conducting climate change impacts studies.

Practical Implications

The results here suggest that both initial conditions within the basin and differences in the timing and duration of wet, dry, warm, or cool periods in the driving climate data are important sources of uncertainty in streamflow simulations that should be considered in evaluating projections of future flows. These results also underscore the importance of using multiple approaches to evaluate the impacts of climate changes. Top-down study designs, where climate model data is selected, downscaled and used to drive an impacts model, provide valuable information, but they have the potential to integrate multiple influences on streamflow because model-derived climate scenarios may differ in many ways (e.g., mean change, seasonality of change, temporal characteristics of the data, spatial pattern of change), and initial basin conditions are not always well characterized because of the need for model spin-up. Different studies use different years of climate data to initialize hydrological models, leading to slightly different initial conditions. The approach used here is capable of deconstructing the influence of initial basin conditions, mean climate change, and differences in the pattern and timing of climate change in a way that a top-down study cannot. Moreover, the methods used in this study, which make it easy to evaluate the effects of mean climate changes and initial conditions, provide a framework for evaluating and prioritizing more intensive hydrological modeling efforts. A synthetic scenario strategy like the one used here facilitates using a bottom-up research approach that allows for a more comprehensive assessment of the types and ranges of hydrological and climatic conditions that can impact future flows.

1. Introduction

1.1. Colorado River flow projections

The Colorado River provides water for most of the major metropolitan areas and agricultural producing regions in the southwestern U.S., with the Upper Colorado River Basin generating the vast majority of the flow (about 90% according to Christensen et al., 2004) (UCRB,

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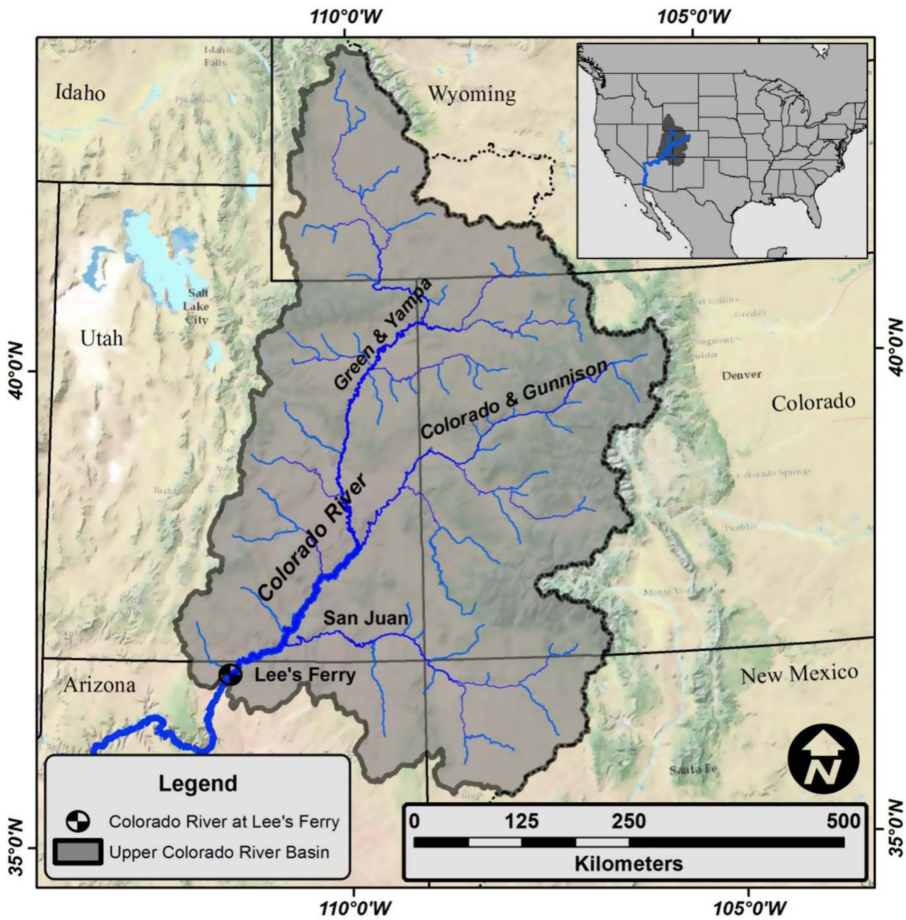

Fig. 1. Map of the Upper Colorado River Basin. The location of the Lees Ferry gauge is indicated.

Fig. 1). Proxy-based streamflow reconstructions have documented long duration low-flow periods in the distant past (e.g., Meko et al., 2007; Gangopadhyay et al., 2015) that would have significantly impacted municipal, industrial, and economic activities in the region. Projections for warmer and possibly drier conditions in the coming century (IPCC, 2013; Ayers et al., 2016; Udall and Overpeck, 2017) have raised concern about future flows in the basin, and the fate of Colorado River has been the focus of numerous streamflow projection studies. These have ranged from statistical estimates of flow, such as Hoerling and Eischeid's (2007) estimates based on projected values of the Palmer Drought Severity Index, to complex studies that use downscaled projections of future temperature and precipitation with a range of hydrological models (Vano et al., 2014).

Results have ranged from predictions of minimal storage in Lake Mead by 2021 (Barnett and Pierce, 2008), to more modest decreases in flow (Christensen et al., 2004; Cook et al., 2004; Milly et al., 2005; Christensen and Lettenmaier, 2007; Hoerling and Eischeid, 2007; McCabe and Wolock, 2007; Seager et al., 2007; Gao et al., 2011; Rasmussen et al., 2011; USBR, 2011a, b; Gao et al., 2012; Seager et al., 2013; Udall and Overpeck, 2017), to projections of little to no change (Harding et al., 2012), with the potential for increases in flow volumes when more recent climate projections are used (Ayers et al., 2016).

1.2. Sources of uncertainty in flow projections

The diversity of flow projections has been largely attributed to the choice of climate scenarios (Harding et al., 2012; Vano et al., 2014), downscaling methods (Vano et al., 2014; Mendoza et al., 2016), and hydrological model parameters (Vano et al., 2014; Mizukami et al., 2016). Other potential sources of uncertainty in flow projections have also been assessed in other contexts. For example, forecast models are regularly run using the best estimate of initial basin conditions (i.e., soil moisture, snowpack or groundwater storage) or with ranges of initial basin conditions to provide better seasonal projections (Harpold et al., 2016; Franz et al., 2003). Starting longer term climate projection-based hydrological simulations under different climatic regimes (i.e., wet or dry and hot or cold periods) can also result in different outcomes (Koczot et al., 2011), yet it is not always clear how comparable initial basin conditions are, given the need for hydrological model spin-up (see Vano et al., 2012; Mizukami et al., 2016 for two initialization strategies).

In addition, the timing and duration of wet/dry/cool/warm periods in input climate data can vary substantially. Clark et al. (2016) suggest that this is an important source of uncertainty to consider (see their Fig.1). Within climate models, climatic persistence can derive from initial atmospheric or oceanic conditions and/or from unforced variability within the model itself, and these two sources of uncertainty are not entirely independent (Hawkins et al., 2016; Deser et al., 2014). Over multi-decadal periods, internal variability can influence the direction of trends (Deser et al., 2012a), and at regional scales, internal variability contributes to projection uncertainty for up to a century (Hawkins and Sutton, 2009). Moreover, many climate models do not skillfully simulate all of the processes that influence multi-annual to multi-decadal variability (Ault et al., 2012, 2014; Deser et al., 2012b), adding a further layer of complication.

1.3. Addressing water manager concerns

Thus, despite the large and growing suite of studies evaluating changes in Colorado River flow, planning for the impacts of climate change on the UCRB is still a significant challenge for water resource managers (Clark et al., 2016). Identifying a way to assess the potential