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Climate-change impacts on water resources and hydropower potential in the Upper Colorado River Basin

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ABSTRACT

Study region: The Upper Colorado River Basin (UCRB), comprised of the Colorado and Gunnison River basins, is the prime water source for much of the western United States.

Study focus: Future climate change models were used to drive a hydrologic model of the UCRB to evaluate future water resources and hydropower potential of the basin, using three different climate projections. The Intergovernmental Panel on Climate Change (IPCC) emission scenarios, the A2-business as usual, and the B1-reduced emissions scenarios were evaluated. More than 4500 water diversions and 17 reservoirs were incorporated into the hydrologic model.

New hydrological insights for the region: Precipitation projections from climate models vary up to 16%; flow projections revealed greater differences, up to 50%. The climate models projected increase in temperature at low elevations with extreme seasonality at high elevations, although summer temperatures increased at all elevations. The models projected a 60% decline in precipitation at lower elevations and a 74% increase at high elevations, although precipitation declined during the summer months at all elevations. Using the A2 scenario an overall decrease in annual flow was predicted, attributed to a reduction in precipitation and increasing temperature trends; however, this was not consistent during the winter months,

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which showed an increase in precipitation at high elevations and a modest temperature increase during the winter and resulted in an increase in stream flow. The responses to climate change on reservoir levels varied basin-wide due to variability in precipitation, evapotranspiration, and stream flow. Simulations indicated that water levels in Blue Mesa Reservoir (the largest reservoir in the UCRB) would decline by more than 70% with increasing annual temperatures. Reservoirs with smaller surface areas to the volume ratio were not significantly impacted by evapotranspiration. Our results indicate that hydropower management strategies in the UCRB must adapt to potential climate change, but the required adaptations are dependent on several factors including reservoir size and location.

1. Introduction

Potential impacts of climate change on water resources are usually assessed by applying climate projections (temperature and precipitation) derived from global circulation models (GCM) using a hydrologic model. In this study we investigate the impact of global climate change on water resources and reservoir levels (as related to hydropower potential) on the Upper Colorado River Basin (UCRB) using state-of-the art climate projections and an integrated hydrologic model. The Colorado River is critical to the water resources of the southwestern United States. Already almost wholly allocated (Christensen et al., 2004), water management and supply issues of the basin are projected to be exacerbated by climate change (Nash and Gleick, 1991). Multiple studies have shown that the UCRB will respond to a temperature increase with an increase in the rain-to-snow ratio, increased winter runoff, and earlier spring snow melt. Although precipitation predictions vary, most studies agree in the overall reduction of runoff in the basin (Barnett and Pierce, 2009). A previous study on the basin by Christensen et al. (2004), demonstrated that there will be a 10–30% reduction in stream flow. These changes have already resulted in reduced storage levels of two significant reservoirs downstream, Lake Mead and Lake Powell, and are expected to impact the management of flow and reservoir regimes. Christensen et al. (2004) compared the impact of climate change on the Colorado River Basin using three 105-year future climate scenarios based on a “business-as-usual” (BAU) greenhouse gas (GHG) emission scenario to a static 1995 GHG simulation using the Variable Infiltration Capacity (VIC) model. The study concluded there would be a 0–10% increase in flow in the northwest portion of the river in Arizona. Christensen and Lettenmaier (2007) used an ensemble approach to characterize the hydrologic response to climate change using the Colorado River Reservoir Model (CRRM). They employed 11 GCMs and A2 and B1 climate scenarios. A2 is a business as usual (BAU) scenario that evaluates untamed CO_2 levels (850 parts per billion) until the year 2100, whereas B1 assumes a considerable effort to minimize emissions to achieve a moderate atmospheric carbon dioxide concentration of about 550 parts per billion. Although the authors used 11 GCMs, only 11 diversion points were considered to model the most critical junctures, in contrast to the over 4500 diversions considered in this study. The authors determined that an average increase in temperature of approximately 3–4 degrees Fahrenheit (°F), combined with a decrease in precipitation between 1% and 2%, resulted in a decrease in mean runoff to about 11%. Under the B1 scenario, it was predicted that there will be an average increase in temperature of approximately 2.52 °F, a change in precipitation between −1% and 1%, and a decrease in mean runoff up to 8%. McCabe and Wolock (2007) used a water balance model to describe streamflow changes and their impacts on long-term water sustainability of the Southwest. Only considering the warming effects of a changing climate, they concluded that the Colorado River Basin (CRB) will experience future water supply shortages. The United States Bureau of Reclamation (USBR) recently analyzed the basin under varying future scenarios, emphasizing the impact of evapotranspiration (ET). Using bias-corrected statistically downscaled data (BCSD) and changes in ET rates, they predicted a