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Review Paper

Implications of projected climate change for groundwater recharge in the western United States

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SUMMARY

Existing studies on the impacts of climate change on groundwater recharge are either global or basin/location-specific. The global studies lack the specificity to inform decision making, while the local studies do little to clarify potential changes over large regions (major river basins, states, or groups of states), a scale often important in the development of water policy. An analysis of the potential impact of climate change on groundwater recharge across the western United States (west of 100° longitude) is presented synthesizing existing studies and applying current knowledge of recharge processes and amounts. Eight representative aquifers located across the region were evaluated. For each aquifer published recharge budget components were converted into four standard recharge mechanisms: diffuse, focused, irrigation, and mountain-systems recharge. Future changes in individual recharge mechanisms and total recharge were then estimated for each aquifer. Model-based studies of projected climate-change effects on recharge were available and utilized for half of the aquifers. For the remainder, forecasted changes in temperature and precipitation were logically propagated through each recharge mechanism producing qualitative estimates of direction of changes in recharge only (not magnitude). Several key patterns emerge from the analysis. First, the available estimates indicate average declines of 10–20% in total recharge across the southern aquifers, but with a wide range of uncertainty that includes no change. Second, the northern set of aquifers will likely incur little change to slight increases in total recharge. Third, mountain system recharge is expected to decline across much of the region due to decreased snowpack, with that impact lessening with higher elevation and latitude. Factors contributing the greatest uncertainty in the estimates include: (1) limited studies quantitatively coupling climate projections to recharge estimation methods using detailed, process-based numerical models; (2) a generally poor understanding of hydrologic flowpaths and processes in mountain systems; (3) difficulty predicting the response of focused recharge to potential changes in the frequency and intensity of extreme precipitation events; and (4) unconstrained feedbacks between climate, irrigation practices, and recharge in highly developed aquifer systems.

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Contents

1. Introduction

Existing studies of the potential impact of climate change on groundwater are either global-level or basin specific analyses. The global-level studies consist of generalized considerations of potential future recharge trends, or some form of coupling of coarse resolution climate models with groundwater models (e.g., Green et al., 2011; Taylor et al., 2013; Döll and Fiedler, 2007). The basin/location-specific studies connect climate and groundwater-flow models for a particular aquifer system to understand the impacts of climate change on groundwater in that system (e.g., Serrat-Capdevila et al., 2007; Hanson et al., 2012). These two study types provide valuable insights, but between them a knowledge gap exists. The global studies lack the specificity to inform decision making, while the local studies do little to clarify potential changes over large regions (major river basins, states, or groups of states), a scale often important in the development of water policy. This gap has led to a lack of consideration of how the impacts of climate change on a specific recharge mechanism may vary within a given region. Depending on the recharge mechanisms operating in a given aquifer system there may be increased or decreased sensitivity to climate change, and varying response to climate change by different recharge mechanisms (Flint and Flint, 2014; Ng et al., 2010). This gap is particularly problematic for transboundary and multi-jurisdictional aquifers where existing agreements on use of groundwater generally assume a degree of stationarity (Cooley et al., 2011).

Groundwater represents 25% of fresh water withdrawals in the United States (U.S.) (Maupin et al., 2014). However, research efforts on the impacts of climate change on water resources in the U.S. have focused predominantly on surface-water systems (Overpeck and Udall, 2010; Seager et al., 2013; Vano et al., 2014). This paper assesses the impacts of projected climate change on groundwater recharge across the western U.S. (west of 100° longitude). The western U.S. was selected because of the importance of groundwater in the region and because the region spans the transition between humid conditions favorable to recharge and arid conditions with little or no recharge. This region thus includes aquifer systems with diverse recharge rates and mechanisms, and provides examples of recharge responses to climate change that could be useful to investigators in a variety of settings. The following questions guided this study: (1) What generalizations can be made about how total recharge will change across the western U.S. under projected climate change? (2) How do projected climate changes interact with individual recharge mechanisms? (3) What are the most significant knowledge gaps that limit our ability to predict future changes in recharge?

We conducted the assessment as follows. First, eight representative aquifers were selected that (a) have recharge estimates for the current climate, (b) are economically significant, and (c) capture a diverse set of climates, geologic settings, and recharge mechanisms. We converted published recharge budget components for these aquifers into four standard recharge mechanisms: diffuse, focused, mountain system, and irrigation. We analyzed available climate-change projections to determine likely changes in temperature and precipitation in the sub-regions containing the eight representative aquifers. Next, we predicted the direction of change for each recharge mechanism and for total recharge in each aquifer using either compiled prior model-based estimates (available for four of the eight aquifers) or careful consideration of how changes in temperature and precipitation will likely impact and propagate through specific processes controlling each mechanism. Finally, we assigned a confidence level (high, medium, or low) to predicted recharge changes. This structured approach provides a template for how large scale regional assessments of the response of groundwater recharge to climate change might be conducted in other regions. Our assessment represents a way in which the global scale process of climate change will modulate recharge processes in a specific region. While climate change is a global process, its impacts must be assessed in a specific place and time to understand how society may need to respond considering socio-economic factors.