Exploring Impacts of Future Climate Change on Dam Flood Risk Across the Western US

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Abstract

The Bureau of Reclamation (Reclamation) operates facilities across 17 western states that span a range of hydroclimates. The Safety of Dams Act, first implemented in 1978 in response to the failure of Teton Dam, authorized the Department of Interior to operate and maintain Federal Reclamation dams for safety of dam purposes. Reclamation uses risk guidance for decision-making at those facilities, with assessment of probabilistic flood risk being part of that process. Flood risk has typically been determined using past flood data; however, climate change brings uncertainty to the validity of those estimates. Discussions surrounding climate change generally focus on increasing precipitation and temperature, but the associated hydrologic response to those changes is not linear due to complex interactions between changing climate and watershed conditions. Further complicating the issue is large uncertainties in estimating characteristics of rare flood events (typically 10,000-year return periods and beyond). In order to better understand changing potential flood risk at facilities across the west under climate change scenarios, Reclamation is completing a number of different climate change research projects examining potential hydrologic responses to climate change for extreme events in different regions and hydroclimates. By completing a variety of projects focused on different scales (basin-specific to west-wide), different hydroclimatic regions, and different approaches, Reclamation is looking to gain insight into the complex interactions between climate change and hydrologic risk at our facilities.

Introduction

Management of large infrastructure, such as dams and nuclear power plants, has evolved over the years to include risk analyses, a study framework whereby responsible agencies, owners, and/or regulators identify potential failure modes, review structural performance, and identify adverse consequences. Specific loadings (hydrologic and seismic) that could initiate one or more potential failure mode are considered as part of a risk analysis process. Common hydrologic loads include flood peak and volume, maximum reservoir water surface elevation, spillway flow characteristics, and ice loadings (FERC, 2020). The flood load component sometimes involves estimating peak inflow magnitudes and volumes at return periods ranging from 5 to 10,000 years (and beyond). A variety of methods can be utilized to develop these flood frequency estimates, including statistical approaches applied to point streamflow observations, rainfall-runoff modeling, stochastic simulations, and paleoflood records.

While historical streamflow observations were considered sufficient for estimating flood magnitudes and associated return periods in the past (e.g., the assumption of stationarity), empirical evidence shows that the climate system is changing (Milly et al. 2008; IPCC 2013; IPCC 2021). For example, research shows that over the historical record, global mean surface air temperature has increased (Ji et al. 2014; Li et al. 2021), while the frequency and intensity of extreme precipitation events have also increased (Alexander et al. 2006; Westra et al. 2013; Easterling et al. 2017). Furthermore, there is clear evidence that these changes will continue into the future (Groisman et al. 2005; Barlow et al. 2019; IPCC 2021).

While changes in air temperature and extreme precipitation events are well documented in the observational record, evidence of widespread increases in extreme flood events is less clear (Sharma et al. 2018). The reason is that extreme precipitation does not always lead to an extreme streamflow response (Ivancic and Shaw 2015). Instead, flood response depends on the wetness of the catchment prior to precipitation, the location, duration, intensity, and spatial distribution of precipitation, and hydraulic characteristics of the basin (Sharma et al. 2018). Thus, future water management and adaptation strategies, including those related to dam safety, could benefit from combining local hydroclimate conditions with climate change projections to understand potential hydrologic responses during future extreme events.

Climate Change and Dam Safety

Potential impacts of climate change on dam safety include changes to reservoir water levels, flood characteristics, spillway performance, populations at risk, and dam operations (Herbozo et al. 2022). Studies exploring potential impacts of climate change on dam safety began popping up within the dam safety community during the 2010s (e.g., USACE 2014; Reclamation 2015; Reclamation 2016). These studies primarily focus on hydrologic loads, ignoring potential changes to other system components important to risk (e.g., future changes in population). Fluixá-Sanmartín et al. (2019) and Herbozo et al. (2022) take a different approach and develop workflows to explore how climate change may influence multiple aspects of dam safety risk. These studies demonstrate clear progress along with a call for continued research and development in this arena.

The Bureau of Reclamation (Reclamation) has identified a need for climate-informed flood frequency estimates that can be used to support site-specific risk analyses for dam safety. Reclamation's Dam Safety Office has responded to this need by funding two new projects aimed at developing these estimates using future climate projections. The first project, which will combine stochastic storm transposition and downscaled climate model output with a physics-based hydrology model, is underway with researchers from the University of Wisconsin-Madison. These tools will be applied on a basin-scale, with interest in two unique Reclamation watersheds. The spatial domain of the second project is much larger, the 17 western states, and is underway with researchers from the National Center for Atmospheric Research. The second project is developing an integrative approach for climate data selection (e.g., earth system model selection), dynamical downscaling, and an understanding of changes in event sequencing and basin-scale flood frequency estimates across Reclamation's western US domain. Project results will be transferred back to Reclamation for internal support of dam safety risk analyses. The two funded projects complement each other by focusing on different spatial scales and demonstrating alternative methods for exploring climate change impacts on flood frequency estimates. In this presentation, we will share results from these two projects with the broader dam safety community.

As our understanding of climate change continues to improve and evolve, so should our understanding of extreme flood events and the associated impacts to infrastructure safety and risk. Reclamation's current research projects described here are representative of collaboration between the scientific research community and an agency making decisions for important infrastructure in the face of a changing climate. Improving the understanding of extreme events and appropriate application of research-based results and products through collaboration is critical for a clear path forward to operate infrastructure safely and effectively into the future.

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