Characterizing Historical, Current, and Future Hydrological Variability through the Development of Meteorological and Hydrological Ensemble-Based Datasets

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Extended Abstract

Current hydrological datasets used for long-term planning are based primarily on the historical period of observations, particularly for flood magnitude and flood frequency estimation. Supplementing these datasets with synthetic hydrology often relies on statistical scaling applied to historical events to match prescribed volumes corresponding to lower frequency events derived from statistical extrapolation of the historical record. This expands the representation of large events but does not change the representation of hydrological variability associated with the climate system such as spacing of extreme events in time or different sequences of wet and dry years. This approach also does not account for recent changes to the meteorology or hydrology of the basin. While development of these supplemental synthetically amplified historical events aids in extreme flood analyses, it does not increase the representation of hydrological variability significantly beyond what is available from the observational record, which is limited in time, and thus is unable to characterize the full range of possible variability (Deser et al. 2012). Often, sequences of events affecting the hydrological and reservoir system states are more important to system vulnerability than the impacts of individual events, even the more extreme events. Without a physically consistent strategy for representing a broader range of potential climate and hydrologic variability, even broad system-wide vulnerability analyses cannot fully represent hydroclimate and reservoir systems risk.

A combination of existing tools and datasets can be leveraged to broaden the representation of hydrological variability. This project uses numerical modeling of physical processes to produce a dataset that represents a large range of potential current and future hydrological conditions. The premise of the data development methodology is to simulate – in a physically consistent way – a wide range of plausible climate and hydrologic conditions that can be used as input to resource assessment models that can examine the coupled response of the vulnerability of water resource

systems. This is also a recommended approach to evaluate uncertainty in future climate projections (Clark et al. 2016). The project uses three types of process-based modeling to develop this dataset: Global Climate Modeling, Numerical Weather Modeling, and hydrological modeling.

Global Climate Models (GCM) simulate global weather patterns through interactions of the atmosphere with the ocean, sea ice, and land surface for periods of up to hundreds of years. GCM simulations for historical periods reflect weather patterns that are driven by the same general constraints (boundary conditions) inherent to the Earth's climate system, however, result in different evolutions of land surface and ocean states that lead to unique sequences of weather (internal variability). Future periods are based on several plausible pathways of greenhouse gas and aerosol emissions (emissions scenarios) and internal variability. While the physical process representation and spatial resolution of GCMs has become more detailed over time, the most recent simulations (Coupled Model Intercomparison Project, CMIP6) typically have grid spacings of 50-200 km, and refinement over regions of hydrologic interest is still required to adequately capture finer scale processes including local interactions of the atmosphere with land surface and terrain. Using more complex, finer-scale numerical weather models with the GCM simulations as boundary conditions is a robust means to provide a consistent, finer-scale solution of atmospheric fields for the region of interest. This level of physical representation in regional weather and climate is particularly relevant for the representation of extreme events.

Recently the U.S. Army Corps of Engineers (USACE) Climate Preparedness and Resilience program funded the development of a new form of regional climate model to dynamically downscale simulation output of GCMs. This model is called the Intermediate Complexity Atmospheric Research model (ICAR) and was developed by the National Center for Atmospheric Research (NCAR) (Gutmann et al. 2016). The objective of this model is to provide numerical process-based simulation of the atmosphere similar to the widely used Weather Research and Forecasting model (WRF) but with some simplifications for greater computational efficiency. Current versions of ICAR show it to be 100 to 1000 times faster than comparable WRF simulations for the same domain. The model has been validated against simulations using WRF and PRISM estimates of surface meteorology. This project uses ICAR to downscale a large ensemble of GCM simulations.

To assess the effect of changes in weather sequences on hydrological processes, it is necessary to run a hydrologic model to simulate streamflow magnitudes. This project uses a watershed-based implementation of a modeling framework centered on the Structure for Unifying Multiple Modeling Alternatives (SUMMA: Clark et al. 2015a; Clark et al. 2015b) and the MizuRoute channel routing model (Mizukami et al. 2015) that has been configured for the entire western U.S. on an intermediate USGS HUC-12 scale (about 100 km2 per watershed). The model implementation has been calibrated using unimpaired streamflow records for 225 sites in the Pacific Northwest region that are of interest to USACE, our partners, and regional stakeholders. The calibration of the hydrology model is a core component of this project. Calibration considers a suite of streamflow characteristics that are most relevant to water management operations (e.g., peak flow, snowmelt center of mass, long duration low flow). As necessary, structural errors in simulated streamflow will be bias-corrected using a technique called bmorph (Bennett et al. 2021; Bennett et al. 2022).

This development effort is producing a large set of plausible meteorological and hydrological conditions and responses of water resource systems to create a robust depiction of the hydrologic uncertainty and risk to management and planning of water resources in the Pacific Northwest region.

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