RECLAMATION
Managing Water in the West

ESTIMATING CLIMATIC CHANGE IMPACTS ON WATER RESOURCES IN ARID ENVIRONMENTS: THE ROLE OF DOWNSCALING METHODOLOGY

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I. Executive Summary

This study evaluates the impact of “downscaling” methods on two types of water resources assessments in arid environments under projected climate change. Downscaling is the process of translating Global Climate Model (GCM) projections with scales of one to two degrees latitude and longitude to a spatial resolution suitable for basin-scale hydrologic modeling. The approach compares an empirical method based on historical observations (statistical downscaling) to a physics-based method using GCM output as the input to a high-resolution Regional Climate Model (RCM) (dynamical downscaling).

The focus is the projected impact of changes in mid-21st century precipitation patterns on water resources management in two Arizona basins: The Upper Santa Cruz River (USCR) Basin, a binational (U.S. – Mexico) watershed where intermittent flows recharge the groundwater reservoirs serving the city of Nogales, Arizona and the Bill Williams River Basin upstream of Alamo Dam, in western Arizona. Alamo Dam regulates high flow events into Lake Havasu, where the Central Arizona Project (CAP) diverts Colorado River water for delivery to central and southern Arizona. Reclamation staff at the Boulder Canyon Operations Office expressed interest in evaluating potential changes in flood size and frequency for effects on downstream water quality, CAP diversions, and Lake Havasu reservoir regulation.

Both watersheds feature precipitation that is highly variable in space and time, which triggers highly variable streamflow events. In these areas, even small, nuanced changes in precipitation patterns may substantially impact water resources management and planning.

Precipitation simulations from three Global Climate Models (GCMs) were statistically and dynamically downscaled: 1) HadGEM2-ES (Global Environmental Model, Version 2 from the United Kingdom Meteorological Office, the Hadley Centre), 2) MPI-ESM-LR (Earth System Model) running on low resolution (LR) grid from the Max Planck Institute for Meteorology, and 3) GFDL-ESM2M (NOAA Geophysical Fluid Dynamic Laboratory – Earth System Model). The GCMs are derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) simulated with Representative Concentration Pathway 8.5 (RCP 8.5). The RCP 8.5 scenario assumes global greenhouse gas emissions will continue to increase through the 21st century. These GCMs were selected for their plausible representation of the historic climatology and prevailing precipitation-bearing synoptic conditions in the southwest United States.

The study incorporates statistically downscaled (SD) precipitation simulations from the Localized Constructed Analogs (LOCA) dataset produced by researchers at Scripps Institution of Oceanography at the University of California San Diego. The dynamically downscaled (DD) precipitation simulations are available from the North America Coordinated Regional Climate Downscaling Experiment (NA-CORDEX) program. These simulations, contributed to NA-CORDEX by the University of Arizona, used the

Advanced Research version of the Weather Research and Forecasting (WRF) model (Version 3.1) as the Regional Climate Model.

Our analysis of statistically and dynamically downscaled simulations for these three GCMs projects an increase in the frequency of dry winters and a weaker signal for a decrease in the frequency of wet winters during the mid-21st century (2020-2059). For summer precipitation, the GCMs are inconclusive and yielded contradicting projections. The most notable contradiction is between the dynamically downscaled HadGEM2 and MPI models. While the dynamically downscaled HadGEM2 projection (DD-HAD) projects wetter summers (decreasing frequency of dry summer and increasing frequency of wet summer), the DD-MPI projects drier summers (increasing frequency of dry summer and decreasing frequency of wet summers).

To evaluate the impact of the projected changes in precipitation on water resources, we developed a modeling framework for each watershed that includes the following components: 1) a weather generator (WG) that produces an ensemble of likely-to-occur hourly precipitation events; 2) a hydrologic model that simulates streamflow and 3) a water resources model that reproduces the operations of each facility.

Appropriately representing regional rainfall characteristics, including the natural variability and uncertainty associated with the observed record, requires that a WG produce a sufficiently large number of realizations. For these basins, an hourly time scale is necessary to accurately simulate input to the hydrologic models.

For the USCR Basin, we used a groundwater reservoir model to estimate recharge and water storage in conjunction with prescribed groundwater withdrawal management. For the Bill Williams River (BWR) Basin, we used a lake model based on the Army Corps of Engineers recommended operational rules to simulate the water levels and outflow from Alamo Lake.

The WGs were initially created to represent the variability of the observed historical precipitation record. They were then modified to simulate ensembles of likely-to-occur realizations of projected mid-21st century precipitation as inferred from the downscaled simulations. These modifications are based on analyses comparing the climate model simulations of the historic period (1950-2005) with the projected mid-21st century models (2020-2059) for key inter- and intra-seasonal characteristics. Seven ensembles were created, one representing the historic period and six representing the projected mid-21st century changes in precipitation, as inferred from the analysis of inter- and intra-seasonal characteristics. These hourly precipitation ensembles were used as input to the modeling framework described above.

For the USCR watershed, we analyzed the 40-year cumulative deficit of groundwater withdrawal for the City of Nogales' water supply. This is the volume of water required from an alternative source to fully satisfy the water demand for the city of Nogales under specified groundwater withdrawal conditions over a 40 year period. This index provides critical information for Reclamation's on-going Nogales Area Water Storage Study, which is evaluating future supply needs and developing alternatives for improving water storage.

For the BWR Basin, we estimated the cumulative time that projected water levels at Alamo Lake are projected to drop below the target operational and the recreation threshold level. We also examined the projected impact of climate change on large precipitation events and the chance for large releases or a spill over the dam's crest.

In both basins, the dynamically downscaled MPI and HAD simulations yield contradictory results. While the DD-HAD projects a wetter future, the DD-MPI projects a drier future. The statistically downscaled HAD projection also predicts a slightly wetter future in the BWR Basin. For both watersheds, the changes projected by the dynamically downscaled projections are larger than the statistically downscaled projections, for both wetter and drier futures.

The results provide important information for Reclamation planners concerned with estimating future water supplies. To evaluate the full range of future risks, available dynamically downscaled simulations should be considered in water resources analyses. Limiting studies to statistically downscaled projections that incorporate an assumption of stationarity may underestimate the actual range of uncertainty for future water resources.

In addition, the study demonstrates that small changes in rainfall patterns can be magnified as the precipitation is converted to streamflow and then to a stored water resource. Even a relatively minor change in projected precipitation may be of concern if the hydrologic system of interest resembles those described in this study.