Bypassing the Uncertainty Question: Using Storylines to Describe Potential Hydrologic Futures for a Basin

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Introduction

This paper describes an approach for evaluation and modeling of potential responses to future water supply and demand challenges in a way that avoids describing the likelihood of potential future changes, and therefore avoids the need to characterize uncertainty associated with water supply and demand projections. This approach was used by the Bureau of Reclamation, and its partner the New Mexico Interstate Stream Commission (NMISC), for the Pecos River – New Mexico Basin Study

Background

Since the passage of the SECURE Water Act in 2009, the Bureau of Reclamation (Reclamation) has been developing state-of-the art methodologies for characterizing future climate and hydrology within the river basins of the Western US that are served by Reclamation water projects. These methodologies have been developed by Reclamation's West Wide Climate Risk Assessment Team and applied in Reclamation's Basin Studies, which are partnerships with local water-management entities to characterize potential future water supply and demand and develop and model adaptations to the projected system changes. Under the Basin Study Program, Reclamation has developed methodologies for ensembling forecasts of future water supply and demand based on large suites (compiled by the World Climate Research Programme's Coupled Model Intercomparison Project, or CMIP) of Global Climate Model (GCM) simulations, which have been bias-corrected and downscaled, and then run through hydrologic models in an attempt to capture the range of likely future water supply conditions. These ensembling methods are meant to help comprehend the results of the many GCM runs, and the range of variability of these results.

So far, these Basin Studies have primarily relied on two ensembling approaches: Transient Projections and Period-Change Projections. Transient projections are traces of the changes in climatic or hydrologic parameters over time (usually over the course of the 21st century). Transient projections are ensembled through the generation of statistics describing the full suite of these traces that are generated from a suite of GCMs. Period-change projections are projections of the likely range of climate and hydrology parameters at a specific future year. To develop ensemble period-change projections, Reclamation has clustered the hydrologic projections by the degree of change in temperature and precipitation, by the specified year, and then analyzed groups of projections according to their location in the precipitation-temperature space: central tendency, hot and wet, hot and dry, warm and wet, and warm and dry. Monthly change factors are applied to historic records for each of these groups, generating 5 sets of statistics characterizing the range of variability in the projections for the selected future year.

Both of these methods have in common an attempt to capture the degree of hydrologic change that we can expect in the future, both in terms of means and extremes, as well as the degree of uncertainty in the projection of future conditions, based on the range of variability within the ensembles. However, it is clear, based on the range of uncertainty within these projection sets that they come with considerable uncertainty, especially for precipitation. This uncertainty can complicate planning of adaptation measures by water managers and stakeholders.

In the Pecos Basin in New Mexico, the small portion of the basin's water supply that comes from snowpack, as well as the dominance of groundwater in the water supply, have made the Pecos Basin poorly suited for Reclamation's developed methodologies. Reclamation's Albuquerque Area Office therefore developed an alternative approach utilizing individual projections that tell particular stories about the way that the basin may develop. This approach has the added benefit that it avoids describing the likelihood of potential future changes, and therefore avoids the need to characterize uncertainty associated with water supply and demand projections. It also allowed Reclamation, its study partner, and basin stakeholders to play a game of "what if", which allowed consideration of different ways that the basin might change in the future. For example, we could contrast a future in which snowpack declines, but summer monsoonal precipitation increases with a future in which precipitation declines in both seasons, and another in which the seasonal distribution of precipitation doesn't change significantly. This provided a tool for visioning of different potential futures, which helped with the development of adaptation strategies, and also highlighted the adaptation strategies that are common between the different potential futures.

Methods

Modelling 930 traces (93 GCMs, 2 hydrologic models, and 4 bias-correction techniques plus raw output) takes high-end computing power and a large amount of time and effort for computation and analysis. What if, instead of trying to create a deterministic forecast that shows an envelope of many different traces, a selection of just a few statistically reasonable traces were chosen that describe varying futures for the basin? This is the thought process that was undertaken to narrow down the immense number of possible traces to analyze for the Pecos River Basin Study. The multistep process of narrowing down those 930 traces to a manageable number of storylines is shown in Figure 1.

The process of developing the storylines for the Pecos Basin in New Mexico began with the evaluation of 93 sets of climatic and hydrologic projections developed from the Coupled Model Comparison Project Phase 5 (CMIP5) suite of GCM simulations (https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/). The projections provided on this website have been bias corrected for climate parameters and spatially downscaled to 1/8th degree of latitude/longitude (through the statistical Bias Correction and Spatial Downscaling process BCSD (Wood et al., 2004)), and processed through two hydrologic modeling codes (the Variable Infiltration Capacity modeling code, or VIC (Liang et al., 1994), and the US Geological Survey's Precipitation Runoff Modeling System, or PRMS (Leavesley et al., 1983)).

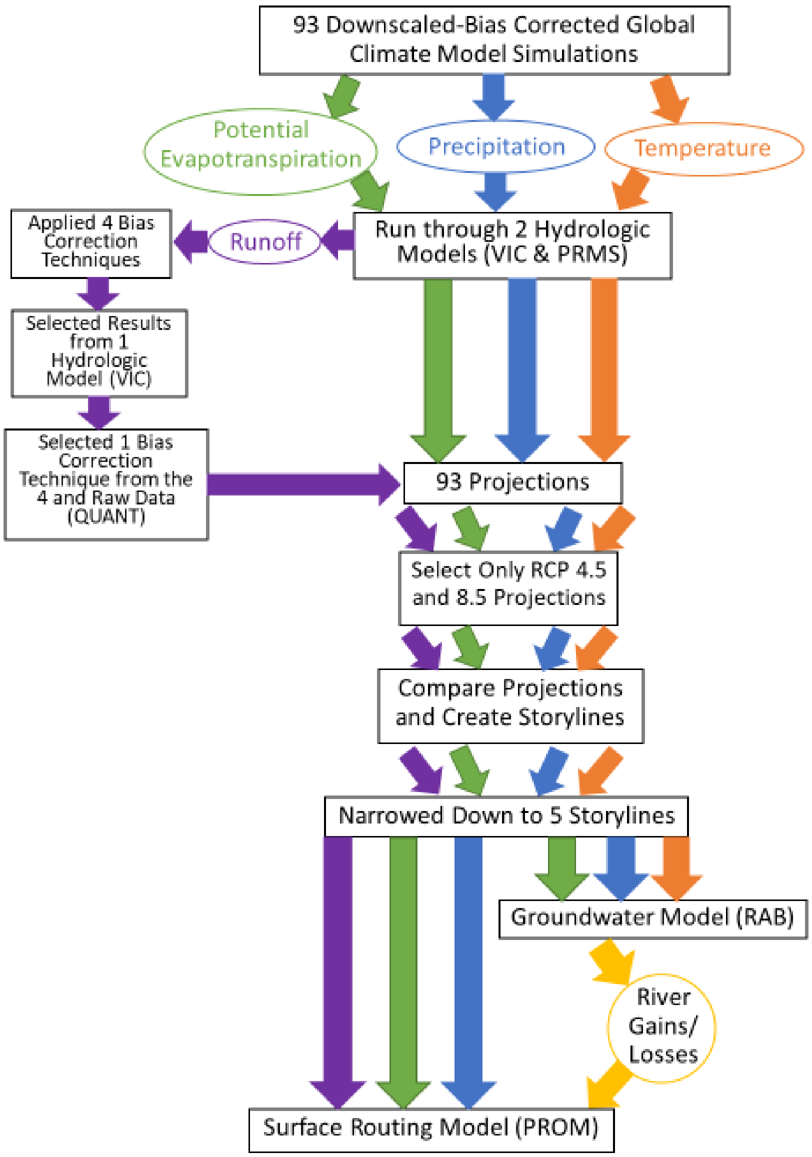

Figure 1. Simplified diagram depicting the steps that were taken to narrow the 930 traces to 5 Storylines.

The resulting hydrologic projections were then routed by the U. S. Army Corps of Engineers (USACE) using a hydrologic routing tool known as mizuRoute (Mizukami, et. al, 2016) to provide projections of streamflow at specific gage locations within the basin. This process provided a more complete projection set for the projections processed through the VIC model code (i.e. it provided hydrologic projections for each of the headwater locations in the operations model for the Pecos Basin in New Mexico), and for that reason, only projections processed through the VIC model code were carried forward in this study. USACE also performed bias correction on the routed streamflows using four bias correction techniques, and allowed us access to an in-house tool that compared the robustness of the routed streamflows using each technique for hindcast streamflows. Projections processed using the Quant streamflow bias correction technique were deemed the most robust and were carried forward in this study.

The processes described above provided 93 climate and hydrology projection traces for the 21st century. The number of projections under consideration in this study was then reduced through the selection of only the projections based on the greenhouse-gas emissions scenarios referred to as Representative Concentration Pathways 4.5 and 8.5. RCP 8.5 represents a "business as usual" future. In contrast, RCP 4.5 shows what would happen if our global society begins to strongly reduce greenhouse gas emissions. More conservative greenhouse-gas emissions groupings, including RCP 2.6, are broadly outside the projected range of future conditions considered by major climate assessments including those produced by the Intergovernmental Panel on Climate Change (Sun et al., 2015). Further, the Fourth National Climate Assessment (U.S. Global Change Research Program, 2018) which was underway at the time of this study, considers CMIP5 4.5 and CMIP5 8.5 projections only. This process narrowed the number of hydrologic projections under consideration to 48 (28 RCP 8.5 projections, and 30 RCP 4.5 projections).

A detailed comparative analysis was then performed on the remaining projection traces in order to characterize the story that each tells about the projected future climate and hydrology in the basin. Parameters characterized and compared included snowmelt runoff and timing, monsoon intensity, seasonal and spatial precipitation patterns, temperatures, evapotranspiration rates, and total streamflow in the mainstem and key tributaries. The stories were then evaluated by Reclamation and the NMISC, and presented to basin stakeholders as part of a collaborative decision-making process, which resulted in the selection of five stories to be carried forward in the study. Baseline characterizations of potential future conditions in the basin, especially related to the agricultural irrigation districts in the basin, were performed using the Pecos River Operations Model, PROM (Boroughs and Stockton, 2010) developed in RiverWare® (Zagona, et. al., 2001) as well as the Roswell Artesian Basin Groundwater Model (Daniel B. Stephens and Associates, 1995), developed in MODFLOW (Harbaugh, et. al. 2000). The final selected storylines were:

- <u>RCP 8.5 Moderate:</u> a Moderate Storyline that showed a mild amount of drying across the entire basin and was close to the median of all the RCP 8.5s that were analyzed,
- <u>RCP 8.5 Dry:</u> a Dry Storyline that showed extreme drying and increased temperatures across the basin,
- <u>RCP 8.5 High Monsoon, Low Snowpack</u>: a storyline that show an increase to the monsoon intensity great enough to make up for the decrease in snowpack,
- <u>RCP 4.5 Reduced Emissions Increased Monsoon:</u> a storyline that is around the average and median of the 4.5 projections and shows minor increases in monsoon activity and temperature and minor decreases in winter precipitation and snowpack over time,
- <u>RCP 4.5 Reduced Emissions Median:</u> a storyline that is close to the median of the 4.5 projections and shows minor decrease in precipitation and temperature over time.

Implications of this Work

This Storyline approach bypasses concerns about projection uncertainty – each projection is considered equally likely, but none are considered predictions of future conditions. Instead, they provide a picture of the range of variability in basin conditions, from which a variety of possible strategies can be developed. Having these different Storylines, allowed us to model different strategies for improving the basin water management for each of the Storylines and see which strategies worked the best for any specific Storyline, and even more importantly, which strategies worked well in all Storylines. This allowed us to address the stakeholders not only with strategies that will help water resource management in the basin for an average possible future, but from multiple, equally-likely, futures in which the basin's hydroclimate changes in different ways.

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