Upper Stillwater Reservoir Firm Yield Forecasting

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CEE 6440

Introduction

The Central Utah Water Conservancy District provides water to communities throughout Utah Valley. The populations of these communities have become so large, that local water sources are no longer able to provide adequate amounts of water for domestic uses, recreation, and agriculture. This lack of water has necessitated the use of other water sources for the valley's consumption. One such water source is the Upper Stillwater Reservoir located on Rock Creek in the Uinta Mountain Range.

The Upper Stillwater Dam, and other water similar water sources are essential to the continued growth of Utah Valley and the surrounding communities. Figure 1 below shows the route water from the Upper Stillwater Reservoir (highlighted in yellow) is carried to Strawberry Reservoir, through Diamond Fork, and to the Utah Valley communities of Provo and Orem.

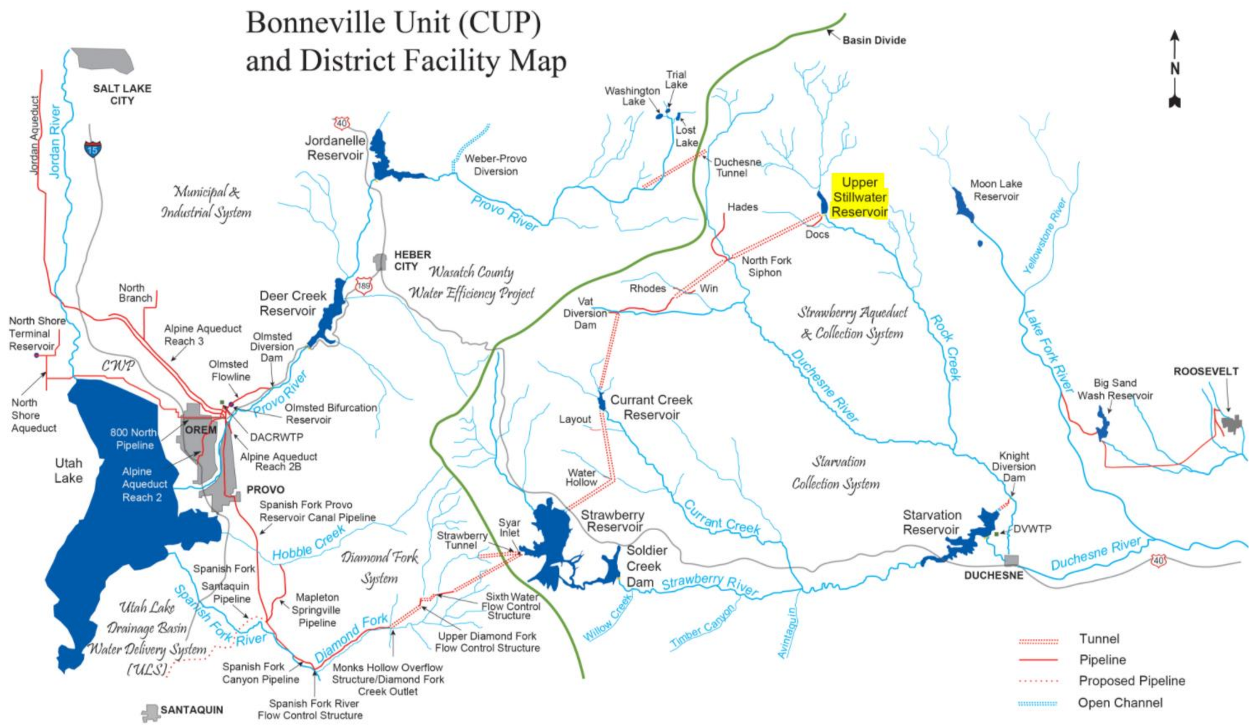

Figure 1. *Central Utah Water Conservancy District Facility Map. (Courtesy of the Central Utah Water Conservancy District)*

The communities serviced by the Central Utah Water Conservancy District are expected to grow significantly throughout the 21st century. This continued growth will place a large strain on the already minimal water supply. It will be extremely important for water managers to have access to accurate projections for the amount of water confidently supplied by the various sources throughout the district. This project focuses on Firm Yield projections for the Upper Stillwater Reservoir through the 21st century.

Objective

The overall aim of this project is to quantify accurate Firm Yield projections for the Upper Stillwater Reservoir. The key objectives to achieve this aim include determining climate projections for the region, calibrating those projections to match current climate trends, performing the firm yield analysis, and interpreting the results.

Hypothesis

It is hypothesized that due to climate change, average temperature will increase, causing a decrease in overall precipitation and an increase in evapotranspiration. The reasoning behind this hypothesis is the general idea that the Western United States is getting hotter and dryer due to climate change.

Methods and Assumptions

Due to the high importance of climate projection data on the results of this project, great care was taken to determine accurate information. The various sources of climate projection data were initially narrowed down to three possibilities; downscaled CMIP3 data, downscaled CMIP5 data, or USGS Dynamical Downscaled Regional Climate data. Due to the localized nature of the required data, it was determined that the USGS Downscaled Regional Climate data would provide the best information.

The USGS Dynamical Downscaled Regional Climate data utilized a regional climate model, RegCM3. This climate model is able to dynamically downscale global climate models to individual regions, providing a much more localized set of data. The data is produced in 15 kilometer grids.

The USGS has shown that the models are capable of producing accurate present day data and can be relied on for future projections. The models have been produced for several greenhouse gas emissions paths based on advancements in technology and governmental regulations, and a "middle of the road" analysis was chosen for this project.

The data requested from the USGS for this project included monthly mean daily precipitation rates, monthly mean daily evapotranspiration rates, and monthly mean max and min temperature.

Even though the data provided by the USGS is downscaled to model more localized conditions, the 15 kilometer grid did not provide data for the watershed without the inclusion of a significant amount of the surrounding area. In order to isolate the watershed, USGS Dynamical Downscaled Regional Climate data for the Uinta Mountain Range was acquired and compared with localized climate trends captured by SNOTEL stations in the area.

Six SNOTEL sites were used to calibrate the USGS climate projection data including the Trial Lake, Hayden Fork, Lily Lake, Rock Creek, Lakefork Basin, and Brown Duck sites. The locations of these sites can be seen in relation to the watershed in Figure 2 below.

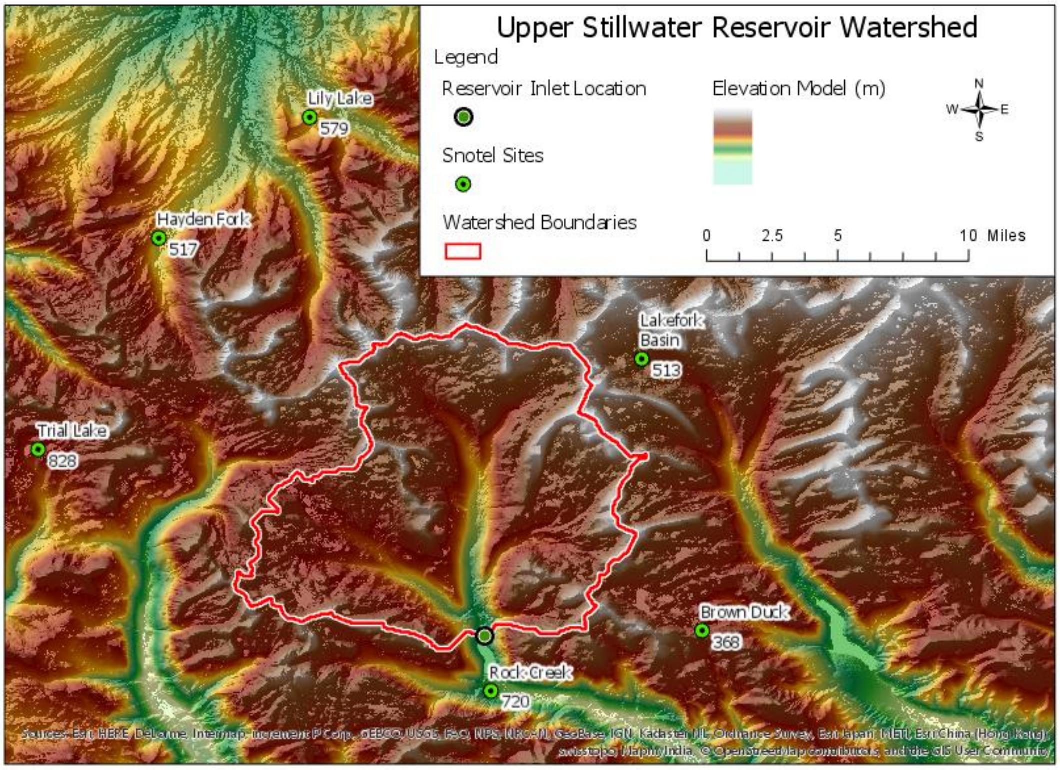

***Figure 2**. SNOTEL sites used in the calibration of the USGS downscaled climate projection data.*

Because of the impact of the variation in elevation on the precipitation in the watershed, it was determined that a standard Thiessen polygon method of determining the average basin precipitation would produce invalid results. An Inverse Distance Weighted (IDW) interpolation tool was used in ESRI ArcGIS Pro to determine the average precipitation within the basin from the years 1980 to 2000. This worked well as the SNOTEL sites were relatively evenly distributed throughout the watershed. A visual representation of the IDW interpolation for average annual precipitation results in millimeters can be seen in Figure 3 below.

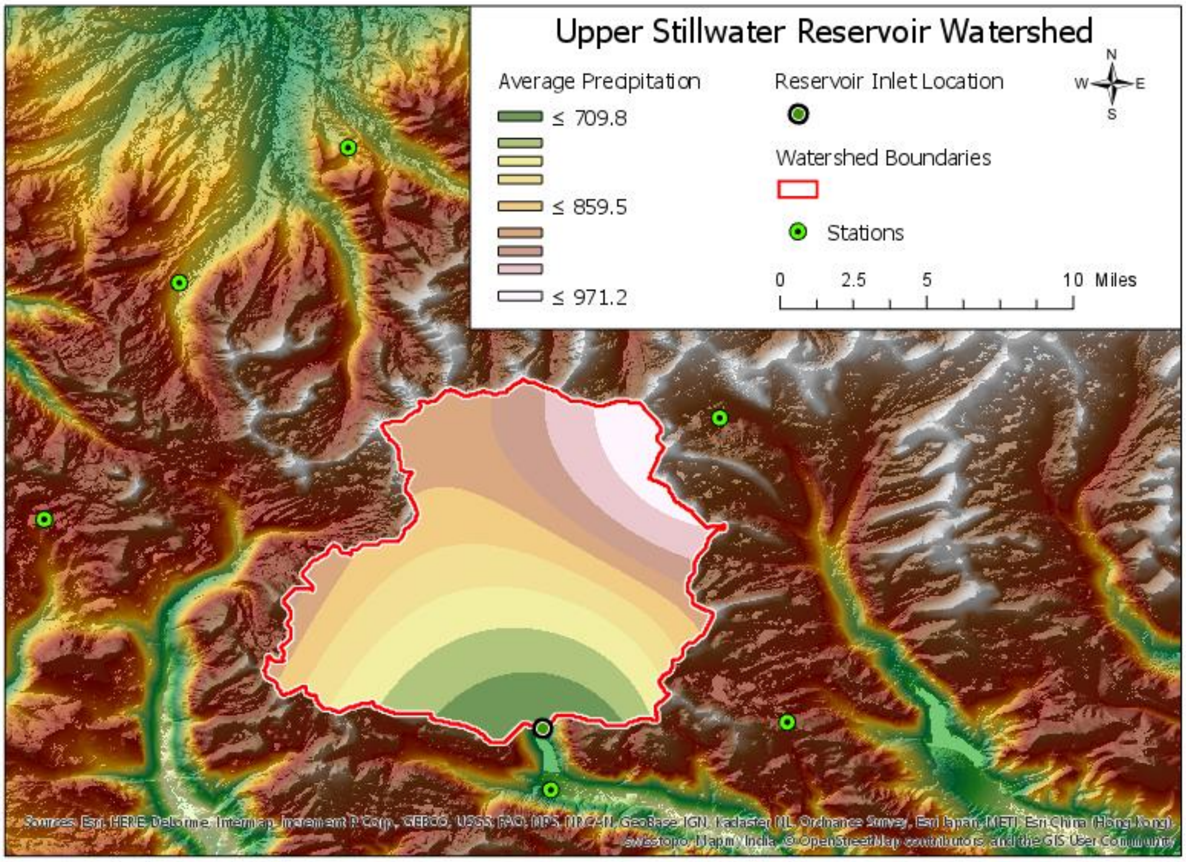

***Figure 3**. IDW Interpolation for precipitation results.*

In order to connect the recorded SNOTEL data with the USGS downscaled climate projection data, the average precipitation data calculated in ArcGIS using the SNOTEL data was compared with the average precipitation data from the same years from the USGS downscaled climate projection data. A ratio was calculated, representing the difference between the USGS downscaled data for the entire Uinta Mountain Range and the actual observed conditions within the watershed. This ratio was applied to the entire USGS downscaled dataset.

Evapotranspiration data was also gathered from the USGS downscaled dataset. The evapotranspiration data was assumed to be similar for the entire Uinta Mountain Range and no corrections were performed on the data. This assumption was made because of the relatively small amount of evapotranspiration shown in the data, and a general lack of information on observed evapotranspiration.

For the purposes of this project it was assumed that the amount of flow into the reservoir could be calculated by subtracting the evapotranspiration from the precipitation over the entire watershed area. This assumption was made because of a small chance of outside factors contributing to a gain or loss in storage. The watershed is located completely within a designated wilderness area, eliminating the chance of development or other significant changes to the ground cover, and the terrain limits the amount of groundwater storage that can be achieved.

It was originally planned that the calculated runoff could be compared with actual gauge data, but the only gauge in the area is located on the downstream end of the dam, and is impacted by water that is taken from the reservoir and periodic releases from the dam. This gauge was determined to be irrelevant to the purposes of this project.

Once the flow into the reservoir was calculated, a firm yield analysis on the reservoir could be performed using mass-balance and a sequent-peak analysis. A spreadsheet was created including the monthly mean daily precipitation and evapotranspiration values along with the volume of the reservoir to allow for the calculation of the firm yield in five year increments from 1980 to 2088. Five year increments were chosen to allow for the periodic drainage of the reservoir for dam maintenance and to demonstrate the change in firm yield over time.

Example calculations for the year 1980 can be seen in Table 1 below. The value for the column Precipitation minus Evapotranspiration was calculated as described above, following the calculation for monthly average inflow. The inflow is calculated using the precipitation minus evapotranspiration value over the entire watershed area.

The yield value represents the outflow value that can be confidently produced by the reservoir and was determined by an iterative process as follows. A yield value was chosen for the entire 5-year period; a negative number represents a positive value for output.

The deficit was then calculated for each month using a mass balance and sequent peak analysis. This includes the "roll over" of previous months deficits. In this case, a negative number indicates a deficit, while a positive number indicates an increase in storage. The maximum deficit value throughout each five year process was then recorded for further evaluation.

This process was repeated using different yield values until the calculated maximum deficit matched the actual storage value as reported by the Bureau of Reclamation of 15.76 m^3/s.

***Table 1**. Example Spreadsheet Firm Yield Calculations*

Month	Precip-Evap (mm)	Inflow (m^3/s)	Yield (m^3/s)	Deficit (m^/3)	Maximum Deficit (m^3/s)
Jan-80	20.02145	1.976584	-5.52	-3.54342	-15.7936
Feb-80	151.2154	14.92849	-5.52	5.865069	
Mar-80	153.3588	15.14008	-5.52	15.48515	
Apr-80	102.9586	10.16441	-5.52	20.12957	
May-80	65.02082	6.41907	-5.52	21.02864	
Jun-80	57.61142	5.68759	-5.52	21.19623	
Jul-80	1.842444	0.181892	-5.52	15.85812	
Aug-80	5.630739	0.555885	-5.52	10.894	
Sep-80	30.94622	3.055113	-5.52	8.429117	
Oct-80	33.77194	3.334078	-5.52	6.243194	
Nov-80	66.33074	6.54839	-5.52	7.271584	
Dec-80	73.88947	7.294612	-5.52	9.046196	

Calculation/Results

Results of the Firm Yield projection analysis can be seen in Figure 3 below. As was described in the previous section, the analysis was performed on five year blocks from 1980 to 2088. For each of the five year segments, the caculated firm yield is located at the time on the graph indicating the first year of the block. For example, the data point representing the calculated firm yield from 1980 to 1985 can be seen at the year 1980 on the graph.

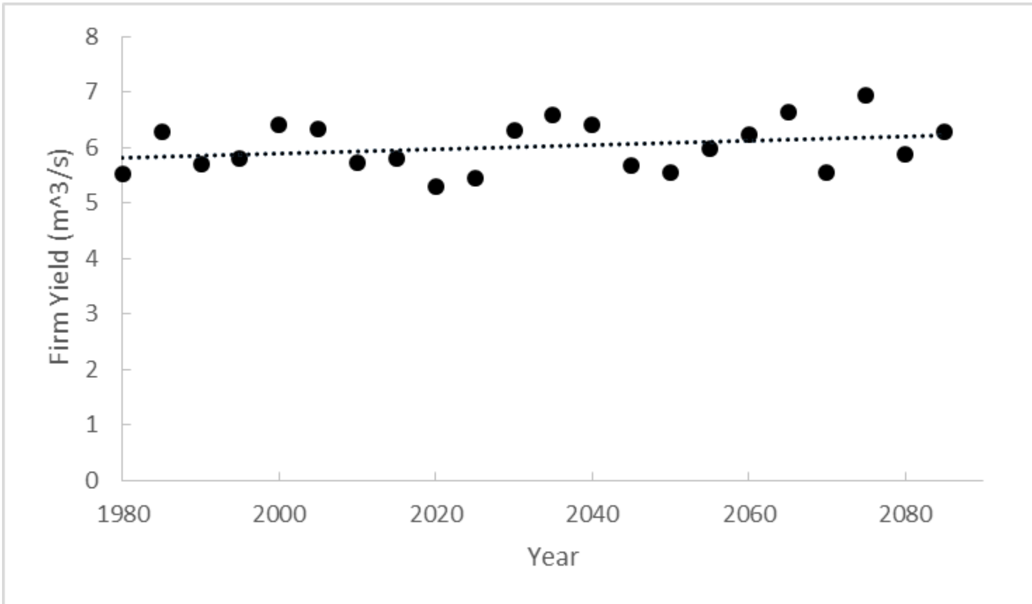

***Figure 4**. Calculated Firm Yield Projection*

Conclusions

The original hypothesis that the firm yield for the Upper Stillwater Reservoir would decrease over time was found to be incorrect. Based on the analysis of the available data, it appears that, if anything, the firm yield for the reservoir will experience a slight increase over time.

Based on the research that was conducted throughout the process of completing this project, it is not surprising that the initial hypothesis is incorrect. It appears that the future of the Upper Colorado River basin is in debate among climate scientists. According to some, the basin will experience an increase in precipitation, while others believe it will decrease.

This debate is especially evident in the difference between the downscaled CMIP3 and CMIP5 climate projection datasets. The CMIP3 datasets were calculated several years prior to the CMIP5 and does not include several recent climate trends and technological advancements. The CMIP3 data predicts a decrease in precipitation for the Upper Colorado River Basin, while the CMIP5 data predicts an increase in precipitation. The developers of these datasets are quick to note that one is not necessarily more accurate than the other.

Despite the uncertainty evident in this evaluation, potentially the safest takeaway from this project is that the future climate in and around the Upper Stillwater Watershed is uncertain and the data even indicates increasing variability in climate patterns.

References

Brekke, Levi; Thrasher, Bridget L; Maurer, Edwin P; Pruitt, Tom. (2017). 'Downscaled CMIP3 and CMIP5 Climate Projections'. Bureau of Reclamation, Climate Analytics Group, Climate Central, Lawrence Levermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, U.S. Geological Survey.

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