The effect of uncertainty in evaporation rate on predictions of water availability in the Savannah River basin

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ABSTRACT. We examine the impact of uncertainty in estimates of lake evaporation on the uncertainty in water availability estimates in the Savanah River Basin. Remotely sensed lake surface temperature measurements were used as inputs to three mass transfer models to estimate daily evaporation rates. These estimates, along with traditional pan based estimates, were used to generate four water availability estimates of the Savannah River Basin. The four models were implemented within the USACE HEC-ResSim water availability simulation model. Historical water availability simulations were run for 57 years of data and future availability estimates based on water use growth scenarios were simulated 70 years into the future. The simulations were run using extant water management and drought plans. The total available water, defined as the volume of water above the lake critical intake, was used as a comparative measure and was computed for drought and normal flow conditions. Results show significant variability in the predicted available water during periods of drought. Return periods were calculated for an event where the lake and basin storage volumes went below 50% of capacity. The calculated return periods indicate that the variability in predicted water availability is greater than the overall estimates of availability of individual models for both historical and future water use scenarios. For example, the estimates of return period for a basin wide 50% full event ranged from 9 to 31 years depending on the choice of evaporation parameterization.

INTRODUCTION

Economic growth, population growth, and land use changes will combine to stress water resources along the Savannah River Basin (SRB). This will result in increased periods of time where low lake levels will require careful water management and potentially force the introduction of water use restrictions. Such circumstances require improved modeling of water availability along the SRB. A key component of the water cycle that influences water availability is lake evaporation. This paper reports findings of a study into the sensitivity of modelled water availability along the SRB to the choice of evaporation model. The US Army Corps of Engineers (USACE) HEC-RES Sim model for the SRB was used with four different models of lake evaporation.

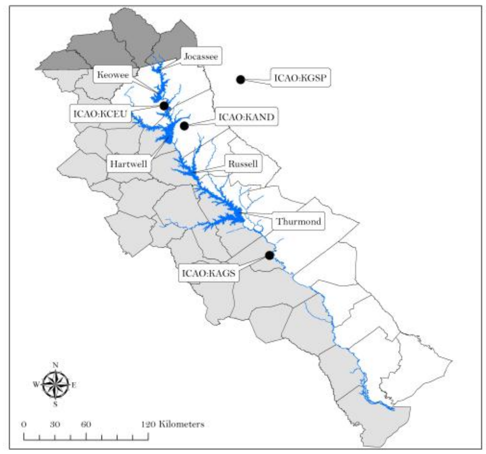

Figure 1: Map showing the major lakes of the Savannah River basin and the ASOS stations used for collecting weather data.

MODEL

The model consisted of two main components a hydrologic model of the SRB, and a set of evaporation models.

The hydrologic model of the SRB was developed by HDR Engineering and provided to the authors by USACE. The model was built within the HEC-RES Sim framework and contained historical data for rainfall, stream flow, and water usage as well as lake geometric data and operational and environmental rule sets. The model is capable of generating unimpaired flow (UIF)

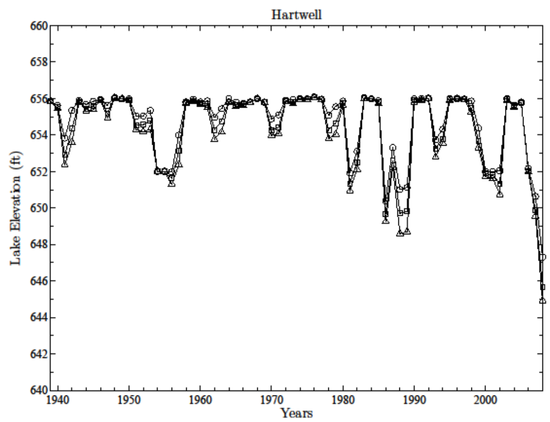

Figure 2: Plot of the maximum, mean, and minimum predictions for annual minimum water elevation for Lake Hartwell based on four different evaporation estimates.

predictions as well as simulations of the lake levels along the SRB.

Four evaporation estimates were used. Pan data from the Clemson Class A pan was used for all the lakes along the SRB with monthly varying, lake specific pan coefficients. The other three evaporation estimates were calculated using different mass transfer models. The mass transfer models calculate evaporation based on the vertical gradient of specific humidity just above the lake. To calculate this, satellite measurements of lake surface temperature (from the MODIS sensor on the Terra and Aqua satellites) were combined with land based measurements of atmospheric temperature, wind speed, and humidity from the ASOS system. The three mass transfer models are based on turbulent boundary layer models (TBL), the general aerodynamic method (AERO), and heat transfer correlations (HT). All three have been used to estimate evaporation from lakes (Brutsaert 1982, Dalton 1802, Gupta 2001, Sartori 2000, and Sweers 1976). See Phillips et al. (2014) for more details on the evaporation methods used.

Simulations were run using historical data for stream flow, rainfall, evaporation, and water usage. Simulations were also run based on the same historical hydrologic data, but with future projections of water usage developed by HDR Engineering (2013).

RESULTS

The four evaporation data sets were used to estimate the change in lake level over time for the five major lakes of the SRB. Due to page limitations, data is presented primarily for Lake Hartwell; summary data is presented for all five lakes.

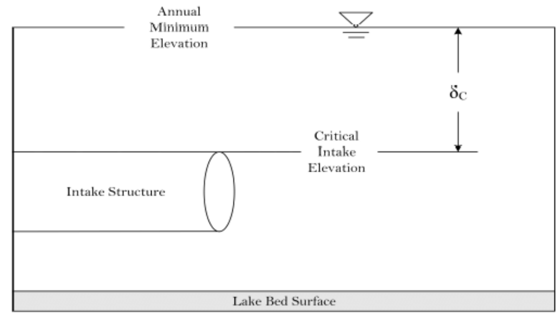

Figure 3: Sketch illustrating the definition of the annual minimum distance to critical intake δ_c.

All of the lakes, with the exception of Russell, along the SRB have management plans governing outflows that raise and lower the lake levels over the course of the year with each lake having an annual target maximum and minimum elevation. Figure 2 shows the minimum annual lake level estimates for Lake Hartwell. The plot shows the maximum, minimum, and average annual minimum lake level estimates using the four evaporation data sets. The figure shows that in most years the annual minimum is the lake target minimum of 656 feet and that each of the evaporation data-sets produce the same result. However, in periods of drought there is a divergence of estimates on annual minimum lake elevation.

The focus of this paper is on water availability, which we define as the depth of water above the critical intake structure for a given lake (lake availability), or, the total volume of water above all the critical intakes for the entire basin (basin availability). For a given lake and evaporation data set, the annual minimum availability is defined as the minimum depth of water above the critical intake and is denoted by δ_c (see figure 3 for a definition sketch). Figure 4 shows a plot of the range of predicted values of δ_c (denoted as $\Delta\delta_c$) as a function of δ_c. The plot shows more clearly the result seen in figure 2, namely that the uncertainty in lake level prediction due to variability in estimates of lake evaporation increases during periods of drought. That is, the greatest uncertainty in water availability occurs during periods where accurate predictions are most needed.

Another way of analyzing the data is in terms of a predicted return period for specific events. Figure 5 shows the estimated return period for an event in which the annual minimum available depth is less than half the annual target minimum. For Lake Hartwell this represents δ_c=2.74 m. Data in figure 5 is shown for all four evaporation data sets and for both historical and future water use projections. The different methods for estimating evaporation result in return period predictions ranging from 46 years to 71 years.

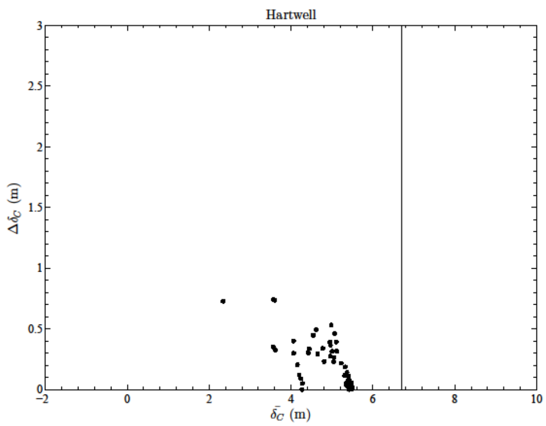

Figure 4: Plot of the spread in predictions for δ_c (denoted as $\Delta\delta_c$) versus δ_c.

Future projections of water availability based on historical rainfall and stream flow data and using projected water usage exhibit a large decrease in the δ_c=2.74 m return period. For the four evaporation data sets the return period is projected to be somewhere between 26 and 35 years.

The five major lakes within the SRB are managed as a system and, as such, the lake elevation and availability in each lake is somewhat balanced. We therefore examined the total volume of available water in the system of the five lakes. The total availability is taken to be the total volume of water above the five critical intakes for the five lakes. The annual minimum system availability was calculated using each evaporation data set and for both historical and projected water usage. A plot of the estimated return period for an event in which the annual minimum system availability is less than half the target minimum (based on the target minimum elevation for each lake) is shown in figure 6. At a system level, there is less variability for the historical water usage with the return period varying between 32 and 41 years. However, there is substantial variability in the return period predictions for future water usage. For this scenario, the return period for a 50% target minimum event ranges from 9 to 31 years.

The predicted return periods for a 50% availability event based on forecast usage are dramatically shorter than those based on historical water usage. The average return period based on historical usage is 35.5 years compared to 17.3 years when simulations are run using projected water usage for the SRB.

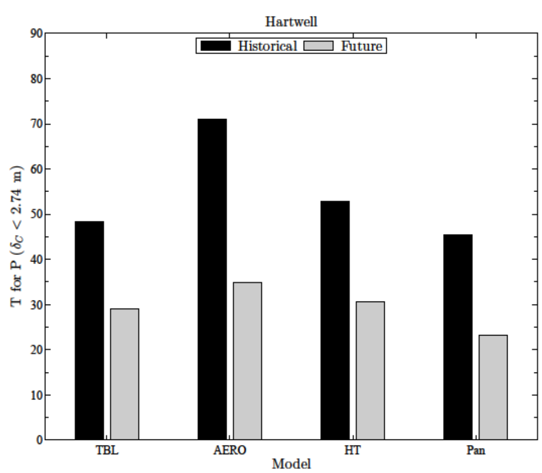

Figure 5: Historical and future projections of Lake Hartwell predicted return period for δ_c being less than half the distance the annual target minimum value of δ_c for each evaporation data set.

DISCUSSION

Results of a series of simulations of the SRB reservoir network have been presented that examine the role of variability in predictions of lake surface evaporation on uncertainty in predictions of water availability. Two sets of simulations were run; one using historical water usage data and a second using a projection of future water usage. The simulations were run using four different estimates of lake surface evaporation based on pan measurements and three different mass transfer models which incorporated satellite measurements of lake surface temperature. Three main results were observed.

1. Variability in predicted evaporation rates can lead to uncertainty in estimated availability and that this uncertainty increases during periods of drought when accurate estimates of availability are most needed

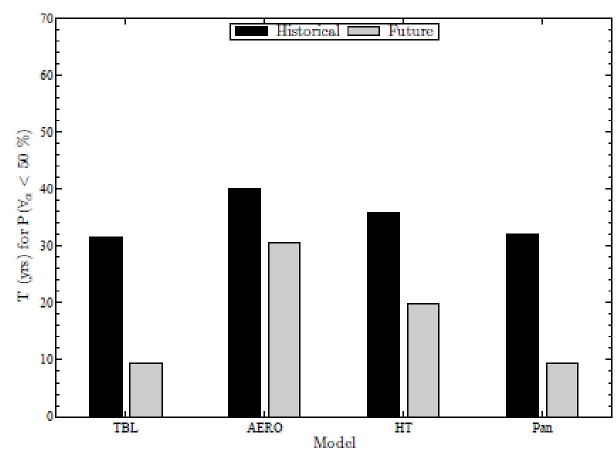

Figure 6: Historical and future predictions of the return period of an event in which the total water availability in the SRB is less than half the target annual minimum.

2. This variability in estimated availability can lead to a broad range of predictions for the return period for particular water scarcity events.
3. Projected future water usage along the SRB will dramatically reduce the return period for water scarcity events.

The results presented herein suggest that there is a need for accurate estimates of lake evaporation along the SRB in order to manage its water resources during periods of low water availability. This need is growing over time as increases in water usage will lead to more frequent periods of reduced availability.

More work is also needed to improve the accuracy of the future projections. The future availability projections are based on running simulations using historical rainfall and stream flow data with projections for future usage. However, such an approach assumes that the climate is statistically stationary, whereas there is evidence that this is not the case; specifically, the Southeast US will become wetter over the remainder of this century. Developing models for rainfall and stream flows based on global climate models, as well as improved evaporation estimates, will improve the accuracy of the future projections of water availability along the SRB.

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