IMPACTS OF CLIMATE CHANGE ON WATER SUPPLY OF OFF-STREAM RESERVOIR

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Abstract. Climate change is attracting more and more attention in recent years. In order to evaluate the impacts of climate change on future water supply, we developed HEC-5 model that can simulate the operation of off-stream reservoir under climate change scenarios. Our modeling results showed that with the coming climate changes, the yield of off-stream reservoir will decrease evidently, which might increase the risk of future water supply. However, these results are based on the predictions of climate change, which are highly uncertain at this stage.

INTRODUCTION

Climate change is attracting more and more attention in recent years because it affects almost all aspects of human life. Among these, water supply is one of the most vulnerable areas, and attracted many researchers. Palmer et al. (2004) evaluated the impacts of climate change on the Tualatin River Basin water supply. Barczak and Carroll (2007) investigated climate change implications for Georgia's water resources and energy future. Yao and Georgakakos (2011) assessed climate and demand change impacts and mitigation measures in ACF (Apalachicola-Chattahoochee-Flint) River Basin. Hay and Markstrom (2012) described Flint River response to climate change. All these studies shed some light on the impacts of climate changes on water supply.

As one of the measures to satisfy the growing demand for water resources in Georgia, more off-stream reservoirs are under consideration. Since the water of off-stream reservoir comes mainly from the pumping from Main River, the climate change will definitely affect the operation of the off-stream reservoirs by changing stream flow, precipitation, and evaporation. This study is conducted to demonstrate to what extent the off-stream reservoir might be affected by climate change.

METHOLOGY

The studied area is at Montezuma, located in the upper part of Flint River Basin in Georgia (Figure 1). This area has a drainage area of 2,920 square miles, which supplies water to the growing population in Atlanta and is a major recreational resources for the region (Hay and Markstrom, 2012). For this reason, we assumed an off-stream reservoir is to be built here to supply water to the nearby areas. The main parameters of this assumed reservoir is listed in Table 1.

Figure 1. The location of studied area

Table 1. Main parameters of off-stream reservoir

Area (acre)	471
Conservation storage (acre-feet)	15,911
Normal lake elevation (feet)	300
Pumping capacity (cfs)	200

The off-stream reservoir is located at Montezuma. Its water is pumped from Flint River according to an Interim Instream-flow Protection Policy of Georgia Department of Natural Resources (Georgia DNR, 2001). The policy calls for suspension of pumping from the main stem to the reservoirs if incoming flow to the pump station is less than a low-flow threshold. In this study if the stream flow in the river is above monthly 7Q10 (the lowest 7-day average flows in a month with a 10% probability of recurring), the surplus water (above 7Q10) will be pumped to the reservoir up to its pump capacity (If the reservoir elevation exceeds normal elevation, surplus water will be released). Otherwise, no water can be pumped. By this way, the minimum flow in the river can be protected. In order to realize this mechanism, a HEC-5 model was developed to simulate the operation of this off-stream reservoir. HEC-5 is a computer program developed at the Hydrologic Engineering Centre (HEC) of US Army Corps of Engineers to simulate reservoir operation (USACE, 1998). The detail of this model can be found in our previous paper (Jiang et al., 2009).

For projections of climate change, General Circulation Model (GCM) is one of the first models to evaluate climate change (Palmer et al., 2004). Here we utilized the results of Hay and Markstrom (2012), who studied the upper part of the Flint River Basin, and gave the change of monthly average of stream flow, precipitation, and evapotranspiration with climate change in three future periods (2025-2035, 2055-2065, and 2085-2095). With their ratio of monthly changes, we modified the current stream flow, precipitation, and evaporation to reflect their changes in future periods. The current stream flow data is from U.S. Geological Survey (USGS) stream flow gaging station 02349605. The current precipitation data is downloaded from Weather Warehouse, and the current evaporation data is estimated according to National Oceanic and Atmospheric Administration (NOAA) report (Farnsworth and Thompson, 1982).

RESULTS AND DISCUSSION

After developing the HEC-5 model, we utilized it to evaluate the safe yield of the off-stream reservoir under different scenarios. For the baseline scenario, we utilized the observed stream flow, precipitation, and estimated evaporation data during 1989-1999 periods. Here the safe yield is defined as the amount of water can be constantly provided during the whole period of interest. When the safe yield is withdrawn from the reservoir, the elevation will be close to the bottom during the critical years. The reservoir elevation in Figure 2 showed 1990 is a critical year. Besides 1990, the year of 1999 is also a drought year. If the simulation extends beyond 1999, the reservoir may approach its bottom again in 2000.

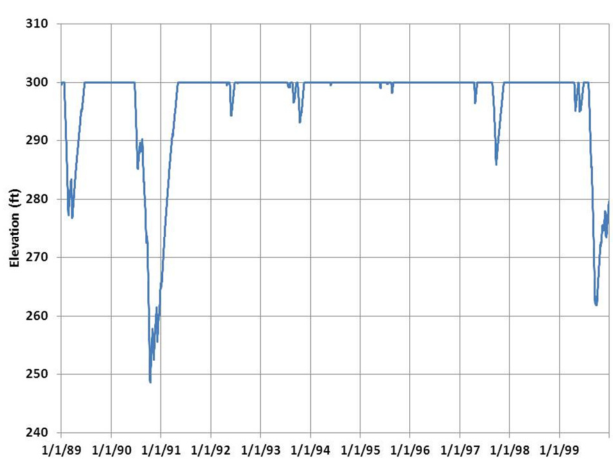

Figure 2. Reservoir elevation of the current scenario

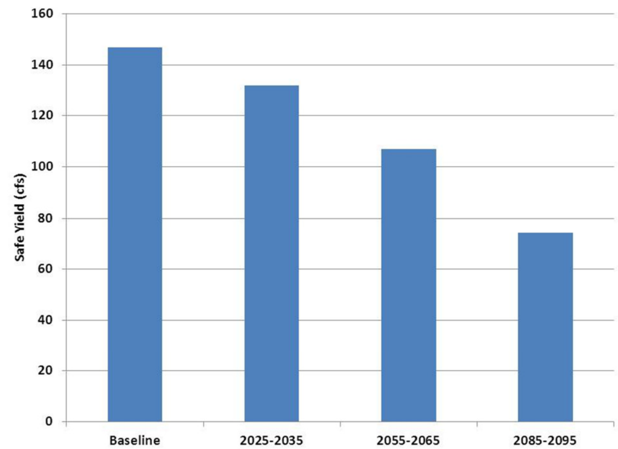

Figure 3. Safe yields under different scenarios

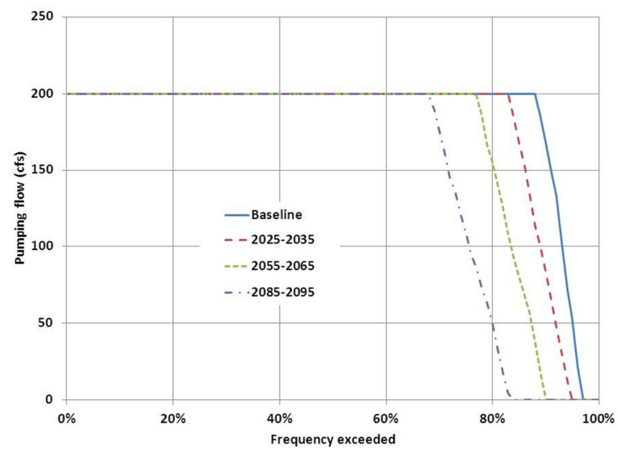

Figure 4. Duration curve of pumping flow

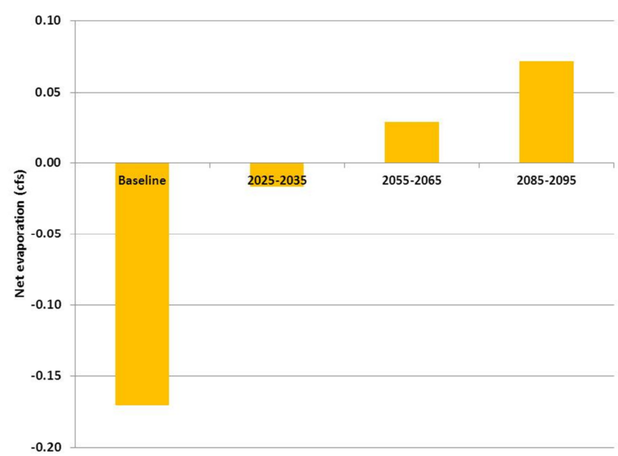

Figure 5. Net evaporation from the reservoir

For future climate change scenarios, we used predicted stream flow, precipitation, and evaporation values of 2025-2035, 2055-2065, and 2085-2095 periods. The safe yields under different scenarios are summarized in Figure

3, which demonstrated that with the progress of climate change, the safe yield of the off-stream reservoir will shrink dramatically. These findings are consistent with the results of Palmer et al. (2004), who concluded that climate change will consistently and significantly impact on the yield of water supply system. For the three future scenarios, the yield will decrease by 10%, 27%, and 50% respectively. The reason for the yield decrease is that less water can be pumped from the Flint River. The duration curve of the pumping flow is shown in Figure 4. For the baseline scenario, the pumping flow can reach its capacity for 88% of the time. For the three future scenarios, this ratio is reduced to 83%, 77%, and 68% respectively. Additionally, the pumping is stopped for only 3% of the time for the baseline scenario, while it will be stopped for 4%, 9%, and 15% of the time for future scenarios. Thus, less water will be pumped to the reservoir for the three future scenarios and the reliability of water supply from the off-stream reservoir will be compromised. Besides, climate change can impact water supply in various ways (Palmer et al., 2004). Another possible reason for the yield decrease is the increase of the evaporation from the reservoir surface. Because of the temperature rise, the evaporation rate will keep increasing. The results in Figure 5 are the simulated net evaporation from the reservoir surface, which equals to the evaporation minus precipitation. The positive value means water is losing from the reservoir, while the negative values means the reservoir gains water because precipitation exceeds evaporation. From Figure 5 it is found for the baseline scenario, the reservoir gains some water from precipitation. With the climate change, more and more water will evaporate from the reservoir, and the net evaporation turns into positive after 2035. However, from the angle of magnitude, the net evaporation from reservoir can be ignored compared with the pumping flow.

If we want to ensure water supply from off-stream reservoirs, we need to figure out some mitigation strategies. One possible mitigation measures to the impacts of climate change on water supply may be raising the dam of the off-stream reservoirs. If we can raise the height of the dam, the conservation storage will increase, which can compensate the impacts of climate change. With our HEC-5 model, we increased the conservation storage of the off-stream reservoir so that it can provide current yield under future climate change scenarios. The result is summarized in Figure 6, which clearly demonstrated that if we want to keep the current amount of water supply, the conservation storage needs to be increased by 35%, 107%, and 184% respectively for the three future scenarios. As a consequence, we need new investments to raise the current dam or build a new reservoir.

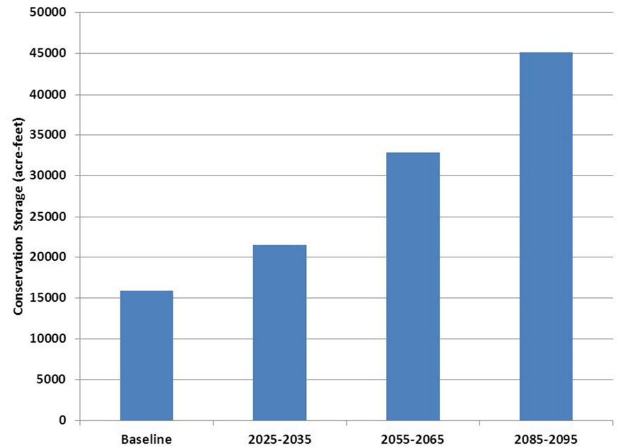

Figure 6. The necessary conservation storage of the off-stream reservoir to keep the current yield

Another way to mitigate the impacts of climate change is to increase the pumping capacity. For example, under the 2025-2035 scenario, the pumping capacity needs to be increased to 354 cfs in order to keep the current yield. As the largest pumping capacity of current off-stream reservoirs in Georgia is around 200 cfs, we think this option is not practical.

However, all these results rely on a series of models, all of which have simplifying assumptions and contribute uncertainty to our final results. On the one hand, the rate of future emissions is dependent upon complex variables, such as technological development, demographic shifts, and socio-economic forces, there are other emission scenarios that are better or worse than the three scenarios (A1B, B1, and A2) simulated here, and the recent downturn in the global economy has encouraged reevaluation of the best baseline scenario of climate changes (Palmer at al., 2004). Additionally, mitigation measures may slow down the pace of climate change. For example, the state of California has put a limit on the amount of greenhouse gases each business or utility is allowed to emit. If a company exceeds its limit, it needs to buy additional allowance. If its emission is below its cap, it can sell or trade its unused allowance. If such a trading policy can be implemented in the whole nation or world, the greenhouse emission will be reduced dramatically, which may reduce or even eliminate the impacts of the climate changes. On the other hand, GCM projections only show significant agreement on global scale, but show much less agreement on derived climatic variables such as precipitation (Palmer et al., 2004). The wide range in the precipitation projections indicates a large amount of uncertainty (Hay and Markstrom, 2012). Thus, currently we are not sure if the climate changes will happen exactly as GCM models predicted. These predictions need to be updated constantly according to future social and economic development and deeper understanding of climate change.

CONCLUSIONS

According to the predictions of climate changes by Hay and Markstrom (2012), we analyzed the impacts of climate change on water supply of an artificial off-stream reservoir. The results predicted significant decrease of the safe yield. In order to keep the current yield, the dam needs to be raised or more reservoirs need to be built. However, if the climate change does not happen as predicted, its impacts on water supply may be significantly different than those presented here and need to be re-evaluated.

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