UNCERTAINTY ANALYSIS OF UNIMPAIRED FLOW AND MONTHLY 7Q10

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Abstract. The basic hydrologic inputs to the surface water availability assessment of Statewide Water management Plan, unimpaired flow (UIF) and monthly 7Q10, were developed with USGS flow data, water use data, reservoir operation data, etc. Uncertainties exist in all these input data and are propagated into the resulting UIF and monthly 7Q10 through the development process. The magnitude of uncertainty in all input data was determined and the amount of uncertainty in each step of the development process was analyzed. Monte Carlo simulations were conducted to quantify the uncertainty in all input data and resulting UIF and monthly 7Q10. Our initial analyses indicate that the amount of uncertainty in both development of the UIF data and the development of monthly 7Q10's is very small, and has no significant influence on modeling results of surface water availability assessment. The largest uncertainty in UIF and 7Q10 was contributed by stream flow data filling process.

INTRODUCTION

Unimpaired flow (UIF) and monthly 7Q10 (the lowest seven-day flow rate expected once in a 10 year period) developed from UIF data are the basic hydrologic inputs to the surface water availability assessment of Statewide Water management Plan. UIF was developed with USGS stream flow data, water use data, reservoir operation data, etc. Uncertainties exist in all these input data and are propagated into the resulting UIF and monthly 7Q10 through the development process.

The objective of this study is to take account of the uncertainties involved in the State Water Plan's Surface Water Availability Resource Assessment. By determining the magnitude of uncertainty in all input data and the amount of uncertainty in each step of the development process, the uncertainty associated with UIF and 7Q10 can be quantified. Through this work, the key or most sensitive sources of uncertainty can be identified. In subsequent data collection, compilation, analyses, and modeling, more attention can be directed toward these sources and associated processes to reduce the amount of uncertainty.

APPORACH

The general approach is to determine the uncertainties in all inputs and capture propagations of uncertainty through steps of the UIF and monthly 7Q10 development, and quantify the amount of uncertainty in the products of UIF data and monthly 7Q10s. We also try to quantify the uncertainty in the Resource Assessment (RA) modeling results.

This study focuses on unregulated nodes. For an unregulated node, UIF was developed from stream flow data and water use data over the entire period of assessment (from January 01, 1939 to December 31, 2007). Stream flow data were obtained from USGS gage readings. If the target USGS gage record contains missing periods, one or multiple reference gage records were used to fill the missing periods. Data filling was done by using either annual liner regression (LRG) or monthly MOVE2 method through TSTool program (Georgia EPD, 2010 and Riverside Technology, 2009). Data filling methods were selected based on multiple criteria (Georgia DNR, 2010).

If there are upstream nodes above the target node, stream flow at upstream nodes was routed downstream using Variable Lag & K method through TSTool program (Georgia EPD, 2010). The routed flow then was used to calculate the local incremental flow (LIF) and UIF at the downstream target node. A schematic of physical locations of upstream/downstream nodes is shown in Figure 1. The observed or filled flow and the water use are denoted as $Q_{obs,fill}^{up}$ and WU^{up} for upstream node and $Q_{obs,fill}^{down}$ and WU^{down} for upstream node.

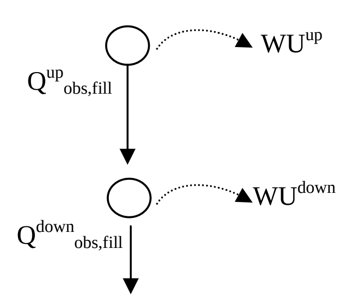

Figure 1. Schematic of upstream/downstream nodes.

The calculation of UIF at the upstream node, UIF^{up}, is shown in Equation (1). The calculations of LIF and cumulative UIF at downstream node, LIF^{down} and $CUIF^{down}$, are shown in Equations (2) and (3).

$$\mathrm{UIF}^{\mathrm{up}} = \mathrm{Q}^{\mathrm{up}}_{\mathrm{obs,fill}} + \mathrm{WU}^{\mathrm{up}} \quad (1)$$

$$\mathrm{LIF}^{\mathrm{down}} = \mathrm{Q}^{\mathrm{down}}_{\mathrm{obs,fill}} - \mathrm{Rtd}(\mathrm{Q}^{\mathrm{up}}_{\mathrm{obs,fill}}) + \mathrm{WU}^{\mathrm{down}} \quad (2)$$

$$\mathrm{CUIF}^{\mathrm{down}} = \mathrm{Rtd}(\mathrm{UIF}^{\mathrm{up}}) + \mathrm{LIF} \quad (3)$$

where $Rtd(Q^{up}_{obs,fill})$ and $Rtd(UIF^{up})$ are the upstream flow and the upstream UIF routed down respectively.

Substitute Equations (1) and (2) into (3), obtain

$$\mathrm{CUIF}^{\mathrm{dwon}} = \mathrm{Rtd}\left(\mathrm{Q}^{\mathrm{up}}_{\mathrm{obs,fill}} + \mathrm{WU}^{\mathrm{up}}\right) + \mathrm{Q}^{\mathrm{down}}_{\mathrm{obs,fill}} - \mathrm{Rtd}(\mathrm{Q}^{\mathrm{up}}_{\mathrm{obs,fill}}) + \mathrm{WU}^{\mathrm{down}} \quad (4)$$

Equation (4) is the general form of UIF at a downstream node. If there is no water use at upstream node, upstream flow (observed and/or filled) will cancel out, consequently will not affect the UIF at downstream node.

Uncertainty in UIF at an unregulated node arises from stream flow data and water use data as well as stream flow data filling and routing processes. By assuming all stream flow data and water use data are uncorrelated with each other, uncertainties in these input data were determined and propagated into resulting UIF and monthly 7Q10 through Monte Carlo simulations. The flow chart in Figure 2 shows the logical steps of the simulation. The first step is to determine the statistical distributions of observed stream flow and water use data. The second step is to randomly sample a single observed flow and use it for stream flow data filling if necessary. The third step is to route downstream the filled stream flow if necessary. After multiple realizations of step 2 and 3, possible outcomes and distributions of filled flow and routed flow are obtained. The next step is to randomly sample stream flow data and water use data to compute the UIF and monthly 7Q10. After multiple realizations, possible outcomes of UIF and monthly 7Q10 are obtained. The last step is to quantify the uncertainty in RA modeling results. Details of these steps are described in the following paragraphs.

The magnitude of uncertainty in USGS observed stream flow data was determined based on its field Measurements Quality Code (http://waterdata.usgs.gov/nwis/help?codes_help#rated) and USGS report [Sauer and Meyer, 1992]. Stream flow measurement quality information and error coefficient (EC) are shown in Table 1. For a single stream flow observation (a daily number), its upper bound (UB) and lower bound (LB) were determined as *UB = Q_obs * (1+EC)* and *LB = Q_obs * (1-EC)*. This single stream flow was assumed to be uniformly distributed between its UB and LB (Figure 3) after the discussion with USGS staff.

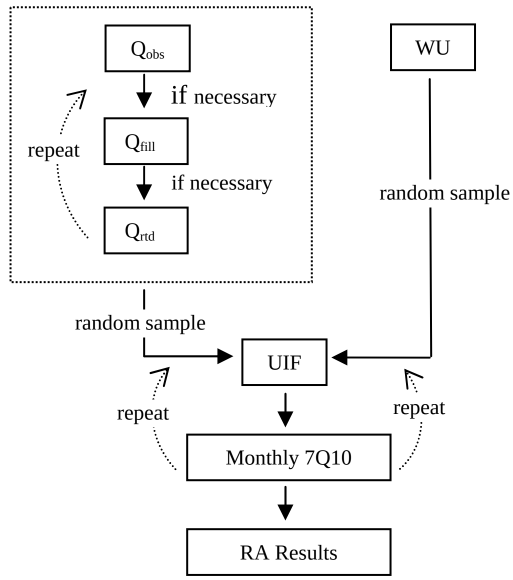

Figure 2. Flow chart of Monte Carlo simulations.

Table 1. USGS field Measurements Quality Code and EC.

Rating	Description	EC
EXCL	The data is within 2% of the actual flow	2%*
GOOD	The data is within 5% of the actual flow	5%*
FAIR	The data is within 8% of the actual flow	8%*
POOR	The data are >8% of the actual flow	20%**
UNSP	Unsepcified	20%**

*based on USGS Field Measurement Quality Code

**based on USGS report by Sauer and Meyer [1992]

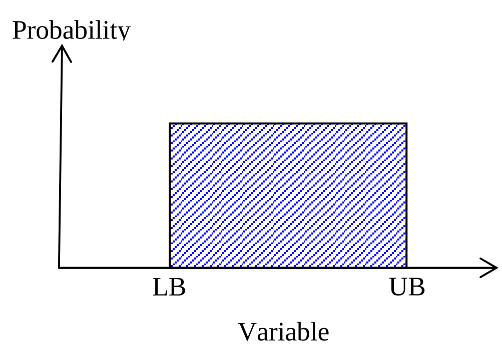

Figure 3. Schematic of variable distribution.

The magnitude of uncertainty in water use data could be determined from withdrawal and return data as recorded and reported by water and wastewater utilities. However, such information is not available at this point. We assumed that water use data has an error of 10%. The UB of water use is 10% more than recorded value and LB is 10% less. Water use was assumed to be uniformly distributed between its UB and LB (Figure 3).

The magnitude of uncertainties in stream flow data filling and routing was determined by Monte Carlo simulations. Once the UBs and LBs of observed flow at target and reference gages were determined, flow data for each gage was sampled randomly and a single realization of regression and filling was run to generate a single result of filled flow. This single set of filled flow was then routed downstream. After multiple realizations were finished, possible outcomes of filled and routed flow were obtained.. The ensemble of the multiple different filled stream flow data reflects the uncertainties in observed flow and regression/filling process. Here, the uncertainties in the regression coefficient and parameters are lumped together instead of separate from each other. The ensemble of the multiple different routed stream flow data reflects the uncertainties in observed flow and routing process. However, same routing equations were used during the multiple realizations. So the uncertainties in the routing coefficient and parameters might be underestimated in some degree.

The magnitude of uncertainties in UIF and monthly 7Q10 were assessed by Monte Carlo simulations. Once the possible ranges of all observed flow data, filled flow data, routed flow data and water use data were determined, multiple realizations of UIF computation and monthly 7Q10 were conducted using MATLAB program (The MathWorks, 2008). It was assumed that each input variable has a uniform distribution and a single value was randomly sampled during each realization. After multiple realizations were finished, possible outcomes of UIF and monthly 7Q10 were obtained given the uncertainties in flow data, water use data, filling and routing processes.

In this study, a Planning Node Pinetta in Ochlocknee, Suwannee, Satilla and St. Mary's (OSSS) River Basins in south George is selected. Two upstream nodes, Bemiss and Quitman, are above Pinetta (Figure 4). Both upstream nodes are headwater nodes. The major water use at Pinetta, Bemiss and Quitman nodes is caused by agriculture activities.

The UIF at Pinetta was developed based on the stream flow data and the water use data at these three nodes. Stream flow record at Pinetta is full over the entire period of assessment, while flow records are missing from January 01, 1939 to June 10, 1988 at Bemiss and from January 01, 1939 to December 20, 1979 and from September 30, 2007 to December 31, 2007 at Quitman. Stream flow data filling was conducted to both upstream nodes. Filled flow

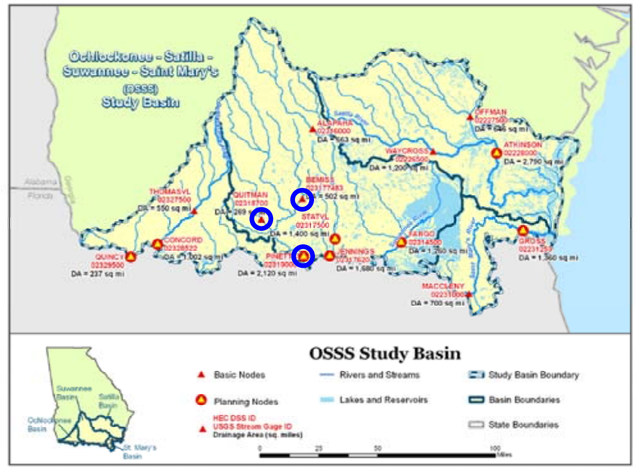

Figure 4. OSSS River Basin map.

at Bemiss and Quitman were then routed downstream separately to Pinetta to compute accumulative UIF at Pinetta as shown in following equation (5):

$$\mathrm{CUIF}^{\mathrm{Pinetta}} = \mathrm{Rtd}\left(\mathrm{Q}_{\mathrm{fill}}^{\mathrm{Bemiss}} + \mathrm{WU}^{\mathrm{Bemiss}}\right) - \mathrm{Rtd}\left(\mathrm{Q}_{\mathrm{fill}}^{\mathrm{Bemiss}}\right) + \mathrm{Rtd}\left(\mathrm{Q}_{\mathrm{fill}}^{\mathrm{Quitman}} + \mathrm{WU}^{\mathrm{Quitman}}\right) - \mathrm{Rtd}(\mathrm{Q}_{\mathrm{fill}}^{\mathrm{Quitman}}) + \mathrm{Q}_{\mathrm{obs}}^{\mathrm{Pinetta}} + \mathrm{WU}^{\mathrm{Pinetta}} \quad (5)$$

Following above approach, uncertainties in stream flow data and water use data at Pinetta, Bemiss and Quitman as well as stream flow data filling and routing processes were determined and propagated into the resulting UIF and monthly 7Q10. The effects of uncertainties associated with UIF and monthly 7Q10 on modeling results of surface water availability assessment were also evaluated. Analysis results are presented in the next section.

RESULTS AND DISCUSSIONS

The stream flow data of a chosen period with UBs and LBs under 2007 hydrological condition at Pinetta, Bemiss and Quitman are shown in Figure 5a through Figure 5c, respectively. Generally, the range of low stream flow is narrower than that of high flow. Water use data with UBs and LBs under 2007 hydrological condition at Pinetta, Bemiss and Quitman are shown in Figure 6a through Figure 6c, respectively.

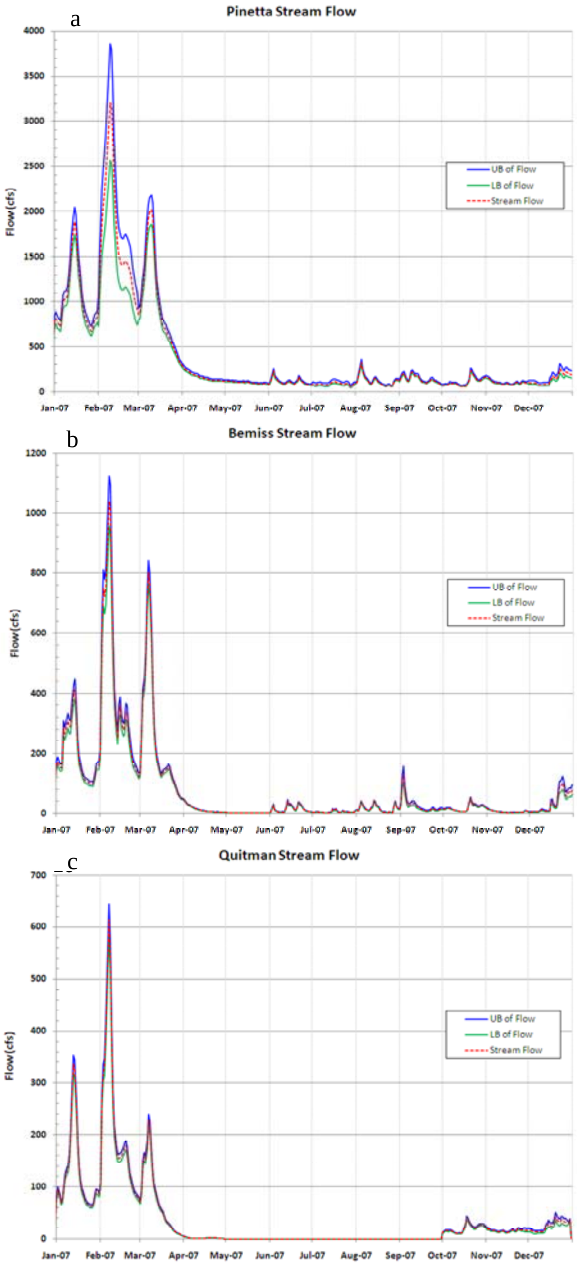

Figure 5. Stream flow with UB/LB under 2007 hydrological condition. a. Pinetta; b. Bemiss; c. Quitman

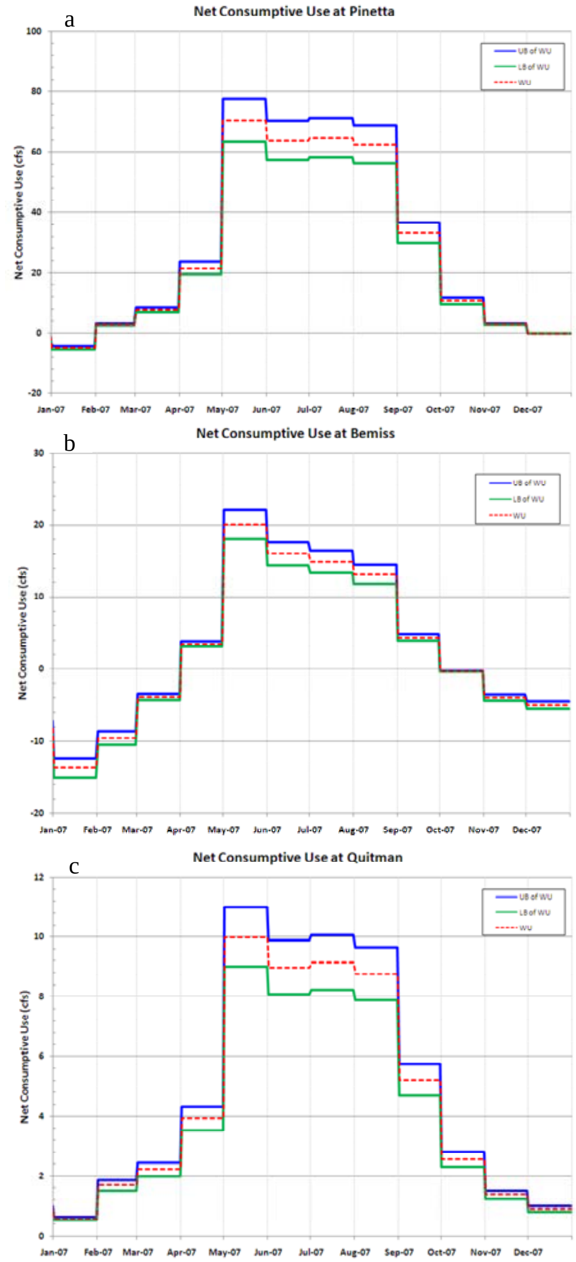

Figure 6. Water use data with UB/LB under 2007 hydrological condition. a. Pinetta; b. Bemiss; c. Quitman.

The newly developed developed UIF values under 2007 hydrological condition at Pinetta are show in Figure 7. The overall spread between the 97.5th percentile (P97.5) and the 2.5th percentile (P2.5) of the potential UIF values is fairly narrow, indicating small amount of uncertainty in the UIF product. The spread of low UIF is much narrower than that of high UIF.

The newly developed monthly 7Q10 values at Pinetta are show in Figure 8. The overall spread between P97.5 and P2.5 of the potential monthly7Q10 is very narrow, indicating small amount of uncertainty in the monthly 7Q10 product. The widest spread of monthly 7Q10 occurs in April, with a value of 18 cubic feet per second (cfs), which is about 6% of the mean April 7Q10 value.

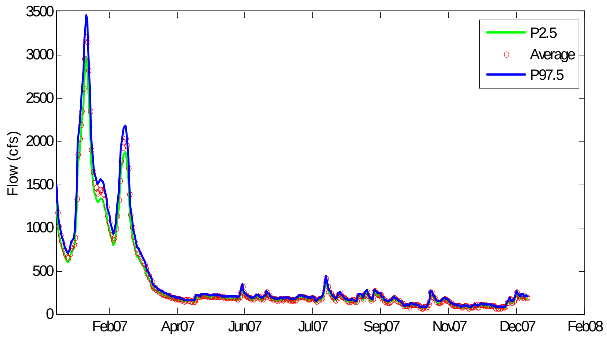

Figure 7. Potential UIF values under 2007 hydrological condition at Pinetta.

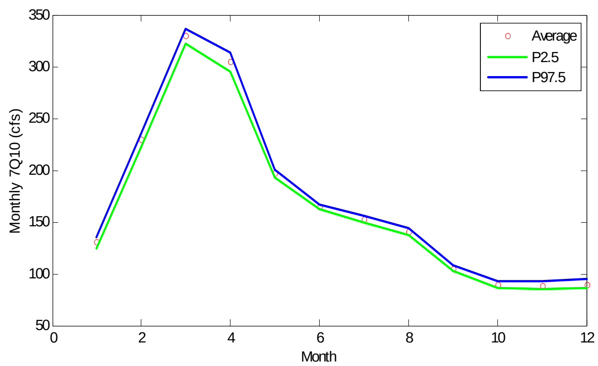

Figure 8. Potential monthly7Q10 values at Pinetta.

Three sets of monthly 7Q10 values, the originally developed monthly 7Q10 values, the newly developed P97.5 and P2.5 of the potential monthly 7Q10 values were used to evaluate the uncertainty in RA modeling results. The important RA results are the length of flow gap (percentage of time that flow gap occurs) and the depth of flow gap (average value of the flow gap). The comparisons of the length and depth of flow gaps using three different sets of monthly 7Q10 values under both current and 2050 non-management practice (NMP) water use conditions are shown in Table 2.

Under current condition, the length of flow gap at Pinetta is 11.21% and the depth of flow gap is 43.09 cfs based on the originally developed monthly 7Q10. In Synopsis Report Surface Water Availability Assessment (Georiga EPD, 2010), these numbers are rounded up to the integer level for explicitness purpose after the discussions with the Regional Council members and Planning Contractors. Using P2.5 and P97.5 of the potential monthly 7Q10 values resulted in a narrow spread of the flow gap length (from 10.09% to 11.19%) and a narrow spread of the flow gap depth that is less than 1% of the original gap depth (from 42.62 cfs to 42.95 cfs). The narrow spreads in both length and depth of flow gap under current condition indicate small amount of uncertainty in the RA modeling results.

Under 2050-NMP condition, the length of flow gap is 12.05% and the depth of flow gap is 66.81 cfs using originally developed monthly 7Q10. Similarly for the explicitness purpose, these numbers are rounded up to the integer level and shown to the Regional Council members and Planning Contractors. Using P2.5 and P97.5 of potential monthly 7Q10 resulted in a narrow spread of flow gap length (from 11.48% to 12.05%) and a narrow spread of flow gap depth that is less than 3% of the original gap depth (from 64.46 cfs to 66.21 cfs). The narrow spreads in both length and depth of flow gap under 2050-NMP condition indicate small amount of uncertainty in the RA modeling results.

Table 2. Comparison of RA results using three sets of 7Q10s.

	Current		**2050-NMP**	
	Length of shortage	**Average shortage (cfs)**	**Length of shortage**	**Average shortage (cfs)**
7Q10 (Original)	11.21%	43.09	12.05%	66.81
7Q10 (P97.5)	11.19%	42.62	12.05%	66.21
7Q10 (P2.5)	10.09%	42.95	11.48%	64.46

CONCLUSION

The uncertainty involved in the State Water Plan's Surface Water Availability Resource Assessment has been evaluated by quantifying the magnitude of uncertainty in all input data and the amount of uncertainty in each step of UIF and monthly 7Q10 development process. Given the uncertainties in stream flow data, water use data, flow data filling and routing processes, the preliminary results show very close range of both UIF and monthly 7Q10's as well as insignificant changes to the length and depth of resulting flow gaps, indicating limited amount of uncertainty in the modeling results of surface water availability assessment. The largest uncertainty in UIF and 7Q10 was contributed by stream flow data filling process.

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