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3.2.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.2.6.** The figure shows that the M&I net withdrawals are generally low (±10 cfs), but there are discrepancies between the USACE and EPD datasets. Both datasets are also subject to abrupt, unexplained changes in demand magnitude. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that sizable relative uncertainties (up to 80%) are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.2.5 Agricultural Withdrawals

Agricultural withdrawals are not modeled for this reach in the derivation of the unimpaired flows.

3.2.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the derivation of the unimpaired flows.

3.2.7 Discussion

There is a significant rise in the unimpaired flows after the mid-1950s that quadruples the average unimpaired flow magnitude. Such a change appears unnatural because it does not correspond with precipitation trends. Since the change occurs right after the construction of Buford Dam it is possible that some flows in and out of this reach were neglected or not properly estimated either before or after the construction of the dam. Another potential explanation for the change could be leakage from the dam or incorrectly specified observed streamflow measurements for part of the study period. The reasons behind the UIF rise should be identified and this systematic discrepancy should be corrected.

Furthermore, the Buford observed streamflows used by the USACE and EPD datasets are not identical after 2002. The inconsistency results from the fact that the two datasets are based on measurements recorded at different streamflow gages. The appropriate measurement location that best represents the Buford node streamflows should be determined and be used to re-compute the unimpaired flows for the Norcross and Buford reaches.

The daily USACE and EPD unimpaired flows can be significantly different even when the same streamflow measurements are used. These differences may amount to up to 1,000 cfs and are caused by the fact that USACE and EPD employed different flow adjustment techniques. The filled in observed streamflow values in this reach also add significant daily uncertainties. Alternative estimation procedures of missing values could mitigate these errors.

Additional short term uncertainties are introduced by the routing model. Particularly during periods of higher flows, the routing model developed for this reach does not properly translate flows from the Buford node to the Norcross node. The improperly routed flows result in large daily errors of the unimpaired flows including large negative values.

There are significant inconsistences between the USACE and EPD municipal & industrial withdrawals in this reach. Both datasets are also subject to abrupt magnitude changes that should be corrected.

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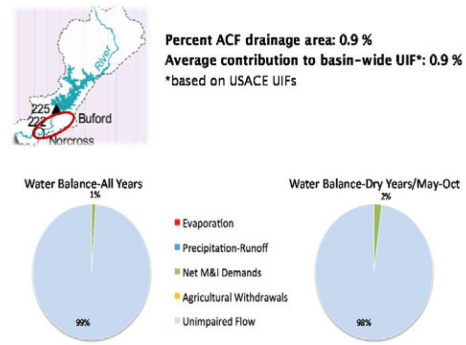

Figure 3.2.1: Norcross reach overview.

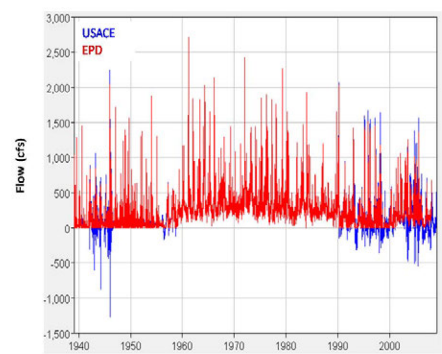

Figure 3.2.2: Norcross reach daily unimpaired flows.

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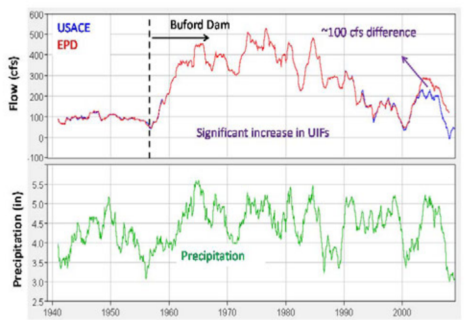

Figure 3.2.3: Two year moving averages of unimpaired flows and precipitation in the Norcross reach.

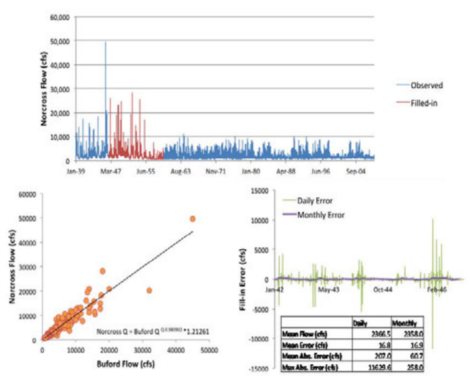

Figure 3.2.4: Estimation of Norcross node streamflows.

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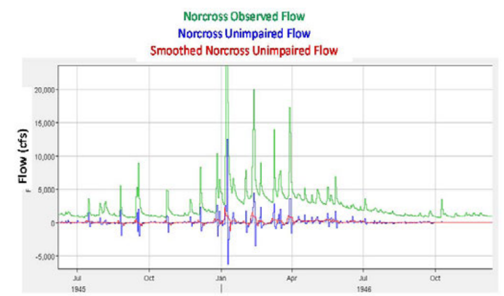

Figure 3.2.5: Negative unimpaired flows resulting during periods of high streamflow.

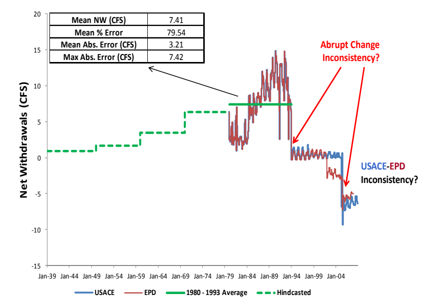

Figure 3.2.6: Norcross reach net municipal & industrial withdrawals.

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3.3 Morgan Falls and Atlanta

The Morgan Falls and Atlanta reaches are located between the Norcross and Atlanta nodes. The Morgan Falls reach is defined as the catchment between the Norcross node and Morgan Falls Dam, while the Atlanta reach spans from Morgan Falls Dam to the Atlanta node. Even though the early USACE datasets derived unimpaired flows for these two reaches separately, the latest USACE and the EPD datasets treat them as one reach because observations at Morgan Falls Dam were deemed to be unreliable. USACE does however compute individual local unimpaired flows for each reach by scaling the larger reach results according to drainage area ratios. Summary information for the Buford reach is shown in **Figure 3.3.1**. This reach contributes only about 1.6% to the basin-wide UIF volume. The largest component of the water budget is the unimpaired flows. However, the net municipal & industrial withdrawals are also substantial, especially during dry periods when they amount to about 38% of the total reach flows.

3.3.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.3.2**. Both USACE and EPD used 7 day centered moving averages to smooth the unimpaired flows. The USACE data still contain negative values of up to 1000 cfs. EPD made additional annual adjustments to remove any negative unimpaired flow values. Since these adjustments are made annually, the overall annual water balance over each individual year is maintained, and the two year moving averages shown in **Figure 3.3.3** are similar for most of the study period. However, there are some systematic differences between the unimpaired flows from 1993 through 2001 of up to 100 cfs.

The unimpaired flows show some correspondence with precipitation data, though high/low precipitation periods do not always consistently correspond to high/low unimpaired flows.

3.3.2 Observed Streamflow Filling

Observed streamflows at the Atlanta node were available over the whole study period. The streamflows at the upstream Norcross node were not complete over the whole study period and are discussed in the section pertaining to the Norcross reach.

3.3.3 Streamflow Routing

A simplified Muskingum model with only two parameters was used to route observed streamflows from Norcross to Atlanta. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.3.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.3.4** and reach a maximum level of 300 cfs in recent years. The figure indicates that there are significant discrepancies between the USACE and EPD datasets. These discrepancies are the reason why the USACE and EPD unimpaired flows in **Figure 3.3.3** are different between 1993 and 2001. Besides these discrepancies, both datasets experience abrupt changes in net withdrawals during several years of the study period. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveals that sizable uncertainties are introduced by hindcasts that keep withdrawals constant on a decadal basis. As **Figure 3.3.4** indicates, these errors could be larger than the mean net withdrawals.

3.3.5 Agricultural Withdrawals

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Agricultural withdrawals are not modeled for this reach in the derivation of the unimpaired flows.

3.3.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the derivation of the USACE and EPD unimpaired flows, despite the presence of a small reservoir (Morgan Falls).

3.3.7 Discussion

The daily USACE and EPD unimpaired flows can be significantly different (up to 1,000 cfs) even when the same streamflow measurements are used. The filled in observed streamflow values in this reach also add significant daily uncertainties. Alternative estimation procedures of missing values could mitigate these errors.

Additional daily errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

There are significant discrepancies between the EPD and USACE net municipal & industrial withdrawals. An effort to reconcile the differences and determine the appropriate withdrawals should be made since these withdrawals can account for a sizeable portion of the water budget, especially during dry years.

The net evaporation losses in this reach are not explicitly considered during the unimpaired flow derivation. Further discrepancies arise from the use of these UIFs in river basin simulation studies using the ResSim. In modeling the reservoirs in this reach, all recent studies explicitly consider evaporation losses using rates applicable to Buford. Evaporation losses are therefore subtracted twice, one time indirectly through the UIFs and a second time directly in the simulation.

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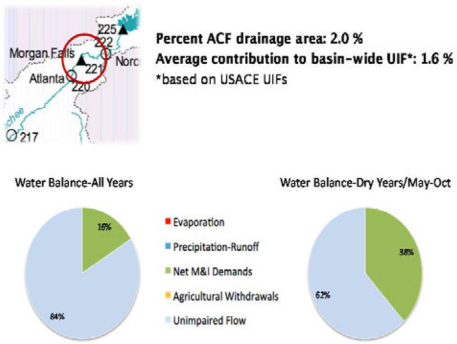

Figure 3.3.1: Atlanta/Morgan Falls reach overview.

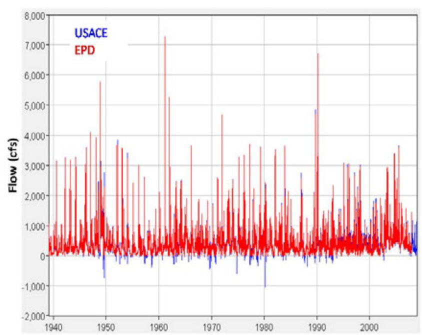

Figure 3.3.2: Atlanta/Morgan Falls reach daily unimpaired flows.

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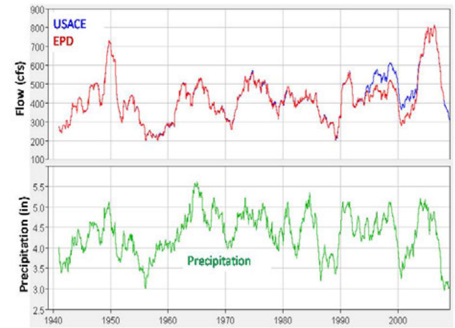

Figure 3.3.3: Two-year moving averages of unimpaired flows and precipitation in the Atlanta/Morgan Falls reach.

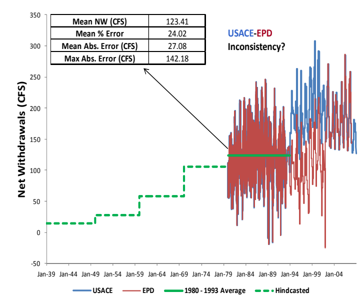

Figure 3.3.4: Atlanta/Morgan Falls reach net municipal & industrial withdrawals.

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3.4 Whitesburg

The Whitesburg reach is located between the Atlanta and Whitesburg nodes. Summary information for the reach is shown in **Figure 3.4.1** which indicates that the average reach contribution to the total ACF flows is approximately 5%. The water budget is largely made up of unimpaired flows and has some contribution from municipal & industrial withdrawals which reach up to 12% of the total during dry years. Agricultural withdrawals are also made within this reach but are only a small portion of the water budget.

3.4.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.4.2**. There are large discrepancies (of up to 15,000 cfs) between the USACE and EPD datasets on a daily basis since the USACE dataset was smoothed with 7 day centered moving averages while the EPD dataset was left unsmoothed and only had negative values removed on an annual basis. The differences disappear when averaging the flows over two years, as shown in **Figure 3.4.3**. The two-year moving averages of unimpaired flows generally follow similar trends as the two-year moving averages of mean aerial precipitation over the watershed that drains this reach.

3.4.2 Observed Streamflow Filling

Observed streamflows over the whole study period were available for the Atlanta node and are discussed in the section pertaining to the Atlanta reach. The Whitesburg streamflow records were not complete over the entire study period, and the flows at several time periods were filled in using relationships developed with the streamflow at the West Point Gage node, as shown in **Figure 3.4.4**. The period from 1939 to mid-1954 was used to calibrate the relationship, which was then used to estimate the streamflows from mid-1954 through the end of 1964. The errors between the predicted and observed streamflows during the calibration period reveal that there can be large daily errors (up to 25,000 cfs). However, the errors decrease (down to 2,000 cfs) when considering a monthly time resolution.

3.4.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from Atlanta to Whitesburg. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.4.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.4.5**. The flow magnitudes are mostly negative, indicating a net return of water to the river in this reach. The daily returns reach up to 300 cfs. There are some discrepancies between the data used by USACE and EPD. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that sizable uncertainties (in excess of 200 cfs) are introduced by hindcasts that are constant over the span of a decade.

3.4.5 Agricultural Withdrawals

The agricultural withdrawals are shown in **Figure 3.4.6**. There are large discrepancies between the USACE and EPD datasets, though the absolute withdrawals are generally less than 20 cfs.

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3.4.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the derivation of the unimpaired flows.

3.4.7 Discussion

The daily USACE and EPD unimpaired flows can be significantly different (up to 15,000 cfs) even when the same streamflow measurements are used. The filled in observed streamflow values in this reach also add significant daily uncertainties. Alternative estimation procedures of missing values could mitigate these errors. Additional daily errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

There are significant inconsistences between the USACE and EPD agricultural withdrawals in this reach. Additionally, municipal & industrial withdrawals are different at times and are also subject to abrupt magnitude changes. Further investigations could be carried out to reconcile the two datasets and identify the reasons for abrupt changes in withdrawals.

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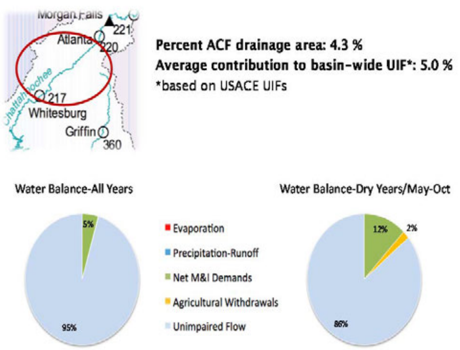

Figure 3.4.1: Whitesburg reach overview.

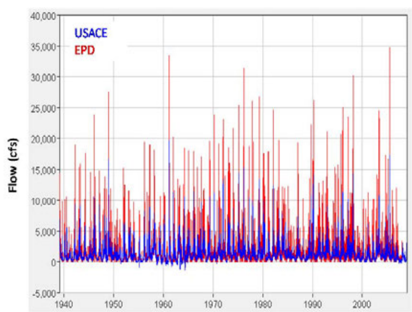

Figure 3.4.2: Whitesburg reach daily unimpaired flows.

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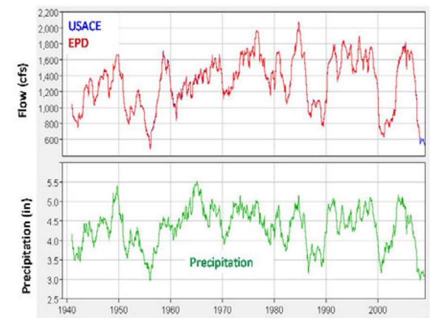

Figure 3.4.3: Two year moving averages of unimpaired flows and precipitation in the Whitesburg reach.

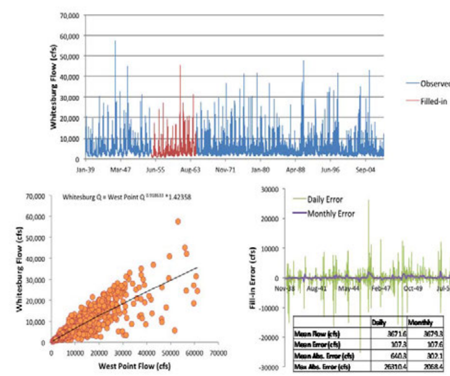

Figure 3.4.4: Estimation of Whitesburg node streamflows.

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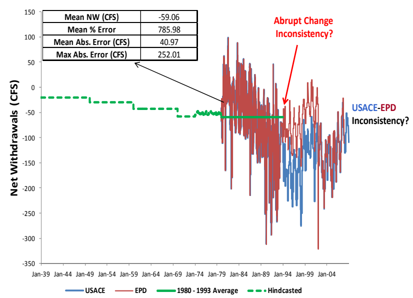

Figure 3.4.5: Whitesburg reach net municipal & industrial withdrawals.

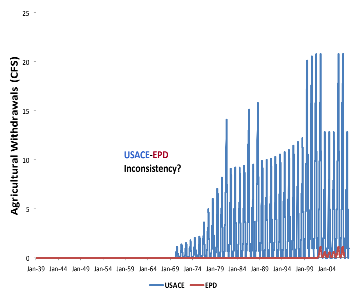

Figure 3.4.6: Whitesburg reach agricultural withdrawals.

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3.5 West Point Reservoir

The West Point Reservoir reach is located between the Whitesburg and West Point Reservoir nodes. Summary information for the reach is shown in **Figure 3.5.1**, with an average reach contribution of 5% to the basinwide flows. Unimpaired flows are the major portion of the water budget. However, the contribution of net evaporation and municipal & industrial terms increase significantly during dry periods accounting for up to 26% of the water budget.

3.5.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.5.2**. There are large discrepancies between the USACE and EPD datasets on a daily basis (up to 50,000 cfs) since the USACE dataset was smoothed with 7-day centered moving averages while the EPD dataset was left unsmoothed. Negative unimpaired flows still remain in the USACE dataset but were removed from the EPD dataset through annual adjustments. The differences disappear for most of the period of study when averaging the flows over two years, as shown in **Figure 3.5.3**. However, from 2001 onward there are significant and systematic differences (of up to 750 cfs) between the USACE and EPD datasets.

Both datasets show declines in the unimpaired flows after the mid-1970s. While the average precipitation over the West Point Reservoir reach also declines during that time, the relative decreases in the unimpaired flows appear to be more pronounced than the precipitation decreases (**Figure 3.5.3**).

The previous analysis indicates that large and systematic errors exist in the UIF datasets, especially after 2001.

3.5.2 Observed Streamflow Filling

The observed streamflows for the Whitesburg node were not complete over the whole study period and are discussed in the section pertaining to the Whitesburg reach. The observed streamflows at West Point Reservoir were also incomplete over the study period and had to be filled in. Prior to the construction of West Point reservoir in the mid-1970s, no measurements at the location of the reservoir outlet existed and the observed streamflows at West Point Gage node were used instead. Measurements of streamflows at the reservoir outlet were available after the construction of West Point reservoir.

3.5.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from Whitesburg to West Point Reservoir. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.5.4 Municipal & Industrial Withdrawals

The municipal & industrial withdrawals at West Point Reservoir are shown in **Figure 3.5.4**. There are significant differences (up to 70 cfs) between the USACE and EPD datasets for portions of the study period. Additionally, both datasets exhibit abrupt changes in withdrawals. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that sizable uncertainties are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.5.5 Agricultural Withdrawals

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The agricultural withdrawals at West Point Reservoir are shown in **Figure 3.5.5**. While the absolute magnitude of the agricultural withdrawals is less than 20 cfs, there are significant relative differences between the USACE and EPD datasets.

3.5.6 Net Evaporation

The different datasets used to compute the net evaporation from West Point Lake are shown in **Figures 3.5.6** to **3.5.9**. It should be noted that prior to 2001 the EPD dataset is based on the same net evaporation rates as the USACE dataset. However, in order to facilitate comparison between the USACE and EPD net evaporation estimation approaches, the EPD results depict the quantities that would have been computed if the EPD approach had also been used prior to 2001.

The USACE and EPD evaporation rates are shown in **Figure 3.5.6** and are relatively similar, though the EPD rates tend to be higher during the months with high evaporation rates. The average GWRI rates are larger than the USACE and EPD rates. The GWRI rates also show wider intra-annual fluctuations, though they are usually smaller than the USACE and EPD rates during the low evaporation months. The precipitation data used by USACE, EPD, and GWRI are shown in **Figure 3.5.7** and are generally similar in magnitude. The constant runoff coefficients used by USACE and EPD are depicted in **Figure 3.5.8**, with the USACE coefficient being 0.5 and the EPD coefficient being 0.33. The GWRI coefficients are not constant and reveal that runoff coefficients can exhibit significant variation. The final net evaporation timeseries computed by combining the evaporation, precipitation, and runoff datasets are shown in **Figure 3.5.9**. The EPD net evaporation flows are consistently higher than those computed by USACE by about 30 to 40 cfs or by an average factor of 1.5. When averaged over a year, the GWRI net evaporation flows tend to be in between the USACE and EPD rates. However, the instantaneous net evaporation flows fluctuate more strongly within each year and are lower and higher than the USACE and EPD rates during periods of low and high evaporation, respectively.

The USACE dataset also contains an unexplained abrupt spike on September 30, 2000. The net evaporation losses on that day are about 30 times larger in magnitude than the net losses during the preceding days.

3.5.7 Discussion

The daily USACE and EPD unimpaired flows can be significantly different (up to 50,000 cfs) even when the same streamflow measurements are used. The filled in observed streamflow values in this reach also add significant daily uncertainties. Alternative estimation procedures of missing values could be considered to mitigate these errors. Additional daily errors and uncertainties are introduced by the routing model used in the unimpaired flow derivation.

Both the USACE and EPD unimpaired flows exhibit declines in unimpaired flows starting in the mid-1970s that are not fully consistent with the average precipitation trends. These inconsistencies were found to be the result of the observed streamflow filling procedures used to estimate West Point Reservoir streamflows before the existence of West Point reservoir. Before the construction of the reservoir, the West Point Gage streamflows were directly used as the West Point Reservoir node streamflows. The unimpaired flows are therefore unusually high because they are computed for a watershed the includes the West Point Reservoir reach as well as the next downstream reach, West Point Gage. The decline in unimpaired flows in the mid-1970s is caused by the fact that only the smaller watershed consisting solely of the West Point Reservoir reach is considered after the construction of the reservoir. The discrepancy between the USACE and EPD unimpaired flows after 2001 is also the result of including contributions of the West Point Gage reach. While USACE

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correctly separates the West Point Reservoir and West Point Gage reaches, the EPD dataset reverts to using the West Point Gage measurements as the downstream observed streamflows. The inclusion of the West Point Gage reach during the computation of the unimpaired flows before the construction of West Point Reservoir (and also after 2001 for the EPD dataset) should be corrected since more flows are assumed to enter West Point Reservoir than in reality.

There are significant differences between the net evaporation flows computed by USACE and EPD. On average, the EPD losses are 1.5 times higher than the USACE losses. These differences are unexpected since the individual USACE and EPD datasets (evaporation rate, precipitation, runoff coefficients) used to calculate the net evaporation flows are relatively similar. Additionally, the USACE and EPD documentation mention similar derivation procedures. Closer analysis of the results indicates that the EPD derivation deviates from the procedure and values discussed in the EPD documentation. For example, the runoff factor used in the derivation was not 0.33 as shown in **Figure 3.5.8**, but rather 0.4. The precipitation data was also multiplied by a factor of 0.5. Most likely, these adjustments were motivated by the need to improve on the USACE net evaporation rates, but they do not follow a consistent climatological approach. The alternative net evaporation losses that were computed by GWRI for informational purposes are between the USACE and EPD flows on average and exhibit wider fluctuations intra-annually. Further investigation into developing the best estimates of net evaporation from the reservoir surface is recommended.

There are relative inconsistences between the USACE and EPD agricultural withdrawals in this reach, though the actual absolute magnitude of these withdrawals is relatively small. Similarly, net municipal & industrial withdrawals are different at times and are also subject to abrupt magnitude changes. Efforts should be undertaken to reconcile the two datasets and identify the reasons for abrupt changes in withdrawals.

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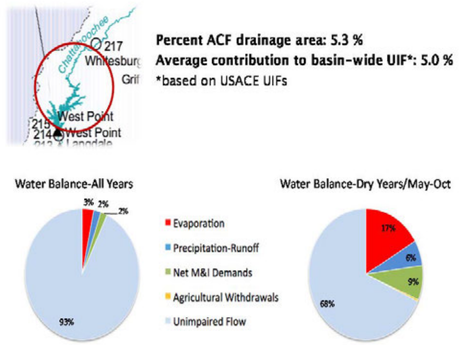

Figure 3.5.1: West Point Reservoir reach overview.

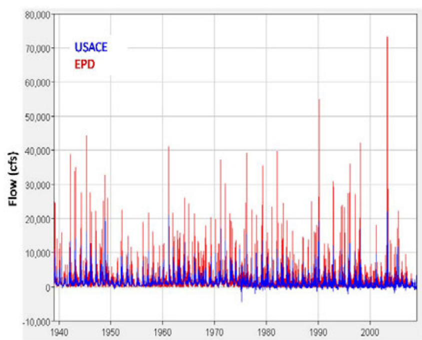

Figure 3.5.2: West Point Reservoir reach daily unimpaired flows.

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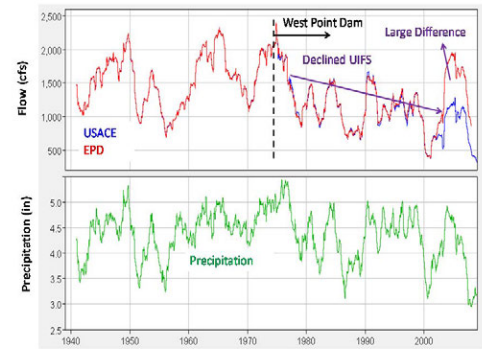

Figure 3.5.3: Two year moving averages of unimpaired flows and precipitation in the West Point Reservoir reach.

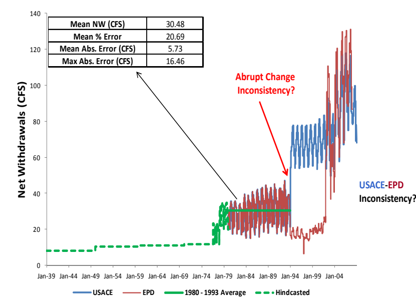

Figure 3.5.4: West Point Reservoir reach net municipal & industrial withdrawals.

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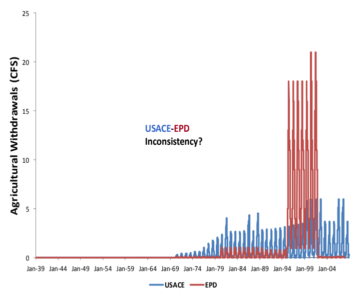

Figure 3.5.5: West Point Reservoir reach agricultural withdrawals.

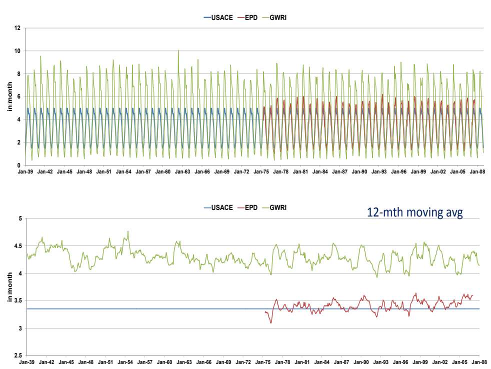

Figure 3.5.6: West Point Lake evaporation rates.

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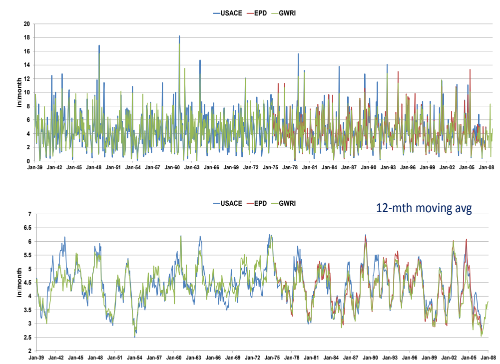

Figure 3.5.7: Mean aerial precipitation over West Point Lake.

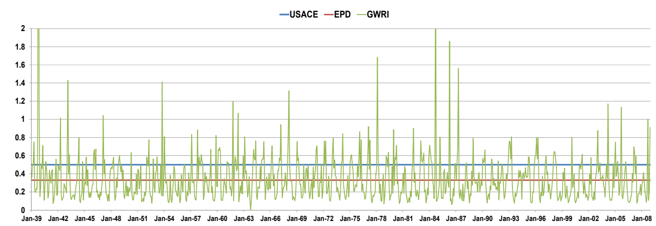

Figure 3.5.8: Runoff coefficients in the vicinity of West Point Lake.

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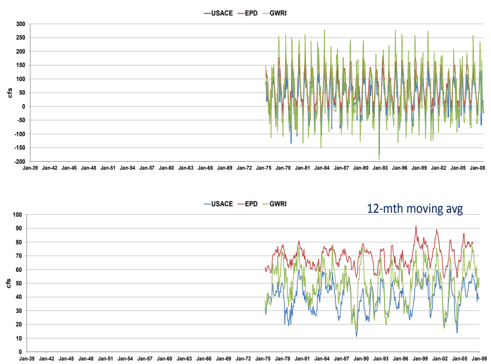

Figure 3.5.9: Net evaporation flows out of West Point Lake.

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3.6 West Point Gage

The West Point Gage reach is located between the West Point Reservoir and West Point Gage nodes. Summary information for the reach is shown in **Figure 3.6.1**. The reach is very small and makes a minor (less than 1%) contribution to the basin-wide flows. The water budget is heavily dominated by the unimpaired flows, even during dry periods. EPD does not consider the West Point Gage reach as a separate location, choosing instead to add the associated unimpaired flows either to the West Point Reservoir reach or the combined Bartlett's Ferry, Goat Rock, Oliver, North Highlands, and Columbus reach.

3.6.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.6.2**. The flow magnitudes prior to the mid-1970s are zero because the West Point Gage unimpaired flows are included in the West Point Reservoir reach for that time period.

Two-year moving averages of the unimpaired flows and average reach precipitation are shown in **Figure 3.6.3**. While the two quantities have similar peaks and valleys, there are large changes in the unimpaired flows that do not correspond to similar trends in precipitation.

3.6.2 Observed Streamflow Filling

The streamflow observations at the West Point Reservoir node are discussed in the section for the West Point Reservoir reach. The observations at West Point Gage were complete over the whole period of study.

3.6.3 Streamflow Routing

No streamflow routing was used since the travel time between the upstream and downstream nodes is very small.

3.6.4 Municipal & Industrial Withdrawals

The municipal & industrial withdrawals are shown in **Figure 3.6.4**. There are some abrupt changes, though the withdrawal magnitudes are relatively small.

3.6.5 Agricultural Withdrawals

Agricultural withdrawals are not modeled for this reach in the derivation of the unimpaired flows.

3.6.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the derivation of the unimpaired flows.

3.6.7 Discussion

The unimpaired flows for this reach are subject to the same, but reverse, errors as the West Point Reservoir reach. Prior to the construction of West Point reservoir (and also after 2001 for the EPD dataset), the West Point Gage unimpaired flows are erroneously included in the West Point Reservoir reach. This error should be corrected to ensure that the amounts of unimpaired flows occurring below and above the West Point Reservoir node are estimated and allocated correctly.

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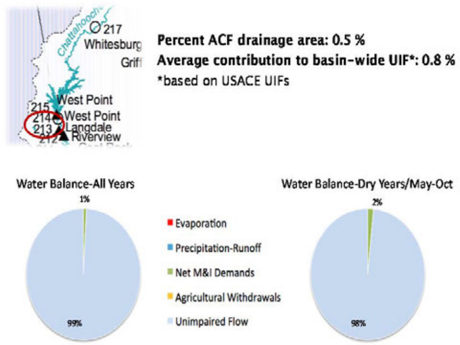

Figure 3.6.1: West Point Gage reach overview.

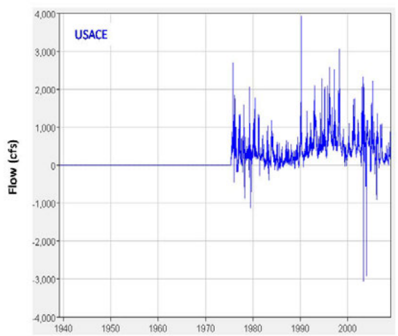

Figure 3.6.2: West Point Gage reach daily unimpaired flows.

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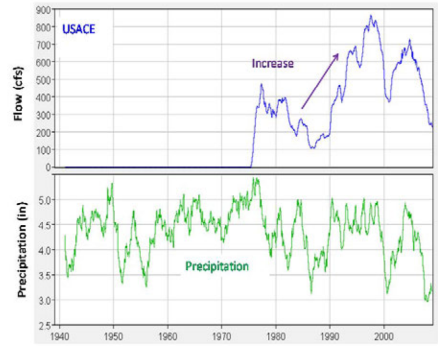

Figure 3.6.3: Two year moving averages of unimpaired flows and precipitation in the West Point Gage reach.

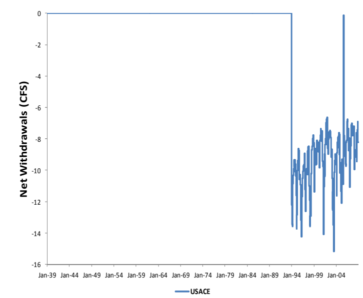

Figure 3.6.4: West Point Gage reach net municipal & industrial withdrawals.

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3.7 Bartlett's Ferry, Goat Rock, Oliver, North Highland, Columbus

The Bartlett's Ferry, Goat Rock, Oliver, North Highlands, and Columbus reaches are treated as individual reaches in most water management studies. However, due to the lack of streamflow measurements at these reaches, the development of their unimpaired flows is based on the same dataset and will not be discussed individually.

The reaches are located between the upstream West Point Gage and the downstream Columbus nodes. The Bartlett's Ferry reach is located between the West Point Gage and Columbus nodes, the Goat Rock reach is located between the Bartlett's Ferry and Goat Rock nodes, the Oliver reach is located between the Goat Rock and Oliver nodes, the North Highlands reach is located between the Oliver and North Highlands nodes, and the Columbus reach is located between the North Highlands and Columbus nodes. Summary information for the combined reaches is shown in **Figure 3.7.1**. The water budget primarily consists of unimpaired flows with net M&I amounting up to 8% during dry years. Evaporation from the impoundments in these reaches is not explicitly considered in the UIF derivation performed by the USACE.

3.7.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.7.2**. The EPD dataset is based on a slightly different spatial aggregation and is not shown. The daily USACE flows were smoothed using 7-day centered moving averages but some negative values remain starting in the late 1990s.

Two-year moving average sequences of precipitation and unimpaired flows are shown in **Figure 3.7.3**. The two variables generally exhibit similar trends.

3.7.2 Observed Streamflow Filling

Observed streamflows were not available at the Bartlett's Ferry, Goat Rock, Oliver, and North Highlands nodes. As a result, the streamflows at those locations were estimated using drainage area ratios and the observed streamflows at the West Point Gage and Columbus nodes. The streamflows at the West Point Gage node are discussed in the section pertaining to the West Point Gage reach. Streamflow records at the Columbus node were available during the whole period of study.

3.7.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from West Point Gage to Bartlett's Ferry. No routing was employed for the other nodes. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.7.4 Municipal & Industrial Withdrawals

Municipal & industrial withdrawals for the entire combined reach between West Point Gage and Columbus are shown in **Figure 3.7.4**. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that sizable uncertainties (on the order of 30 to 50 cfs) are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.7.5 Agricultural Withdrawals

Agricultural withdrawals for the entire combined reach between West Point Gage and Columbus are shown in **Figure 3.7.5**. The withdrawals are small (less than 5 cfs).

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3.7.6 Net Evaporation

Net evaporation losses are not explicitly modeled for any of the reaches in the derivation of the UIFs even though a number of Georgia Power reservoirs are situated in these reaches. However, such losses are indirectly accounted for by the streamflow observations.

3.7.7 Discussion

Since streamflow measurements are not available and had to be estimated at the Bartlett's Ferry, Goat Rock, Oliver, and North Highlands nodes, the unimpaired flows computed at each individual reach defined by these nodes are subject to errors. The individual UIFs were computed based on relative drainage ratios, but a more accurate procedure would have been to apportion the cumulative reach flow based on relative *precipitation* volume ratios. Furthermore, the withdrawals for this entire area (i.e., the cumulative reach) are all taken out in the Columbus reach, even though some of the abstractions in reality occur further upstream. However, while the individual UIFs are subject to errors, the combined unimpaired flows occurring between West Point Gage and Columbus are expected to be more reliable.

Daily errors and uncertainties can also be introduced by the routing model used in the unimpaired flow derivation.

The USACE dataset does not explicitly consider the net evaporation losses during the unimpaired flow derivation. Further discrepancies arise from the use of these UIFs in river basin simulation studies using the ResSim. In modeling the reservoirs in this reach, recent studies explicitly consider evaporation losses using rates applicable to West Point Lake. Evaporation losses are therefore subtracted twice, one time indirectly through the UIFs and a second time directly in the simulation.

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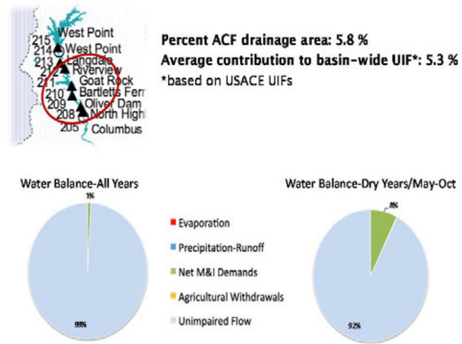

Figure 3.7.1: Combined Bartlett's Ferry, Goat Rock, Oliver, North Highland, and Columbus reach overview.

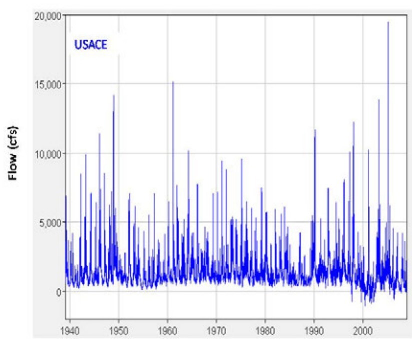

Figure 3.7.2: Combined Bartlett's Ferry, Goat Rock, Oliver, North Highland, Columbus reach daily unimpaired flows.

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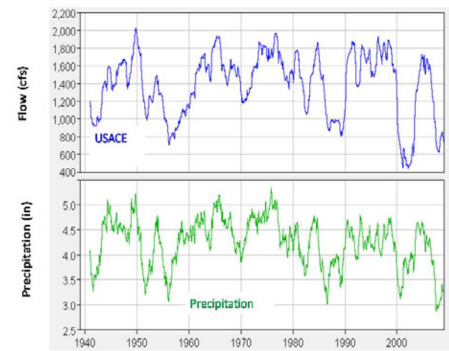

Figure 3.7.3: Two-year moving averages of unimpaired flows and precipitation in the combined Bartlett's Ferry, Goat Rock, Oliver, North Highland, and Columbus reach.

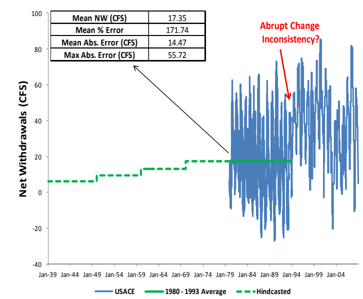

Figure 3.7.4: Combined Bartlett's Ferry, Goat Rock, Oliver, North Highland, and Columbus reach net municipal & industrial withdrawals.

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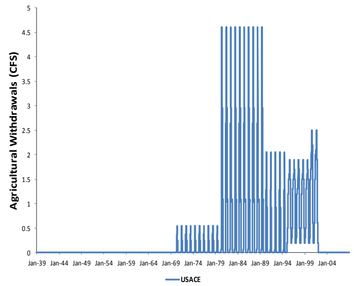

Figure 3.7.5: Combined Bartlett's Ferry, Goat Rock, Oliver, North Highland, and Columbus reach agricultural withdrawals.

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3.8 W.F. George

The W.F. George reach is located between the Columbus and W.F. George nodes. Summary information is shown in **Figure 3.8.1** indicating that this reach contributes an average of 10.7% to the basinwide flows. The unimpaired flows constitute a sizeable portion of the water budget, though the evaporation losses (from Lake W.F. George) can be significant (up to 17%) during dry periods.

3.8.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.8.2**. There are very large differences between the USACE and EPD datasets (up to several thousand cfs) since the USACE flows are smoothed using 7 day centered moving averages. The EPD flows are unsmoothed, though negatives were removed on an annual basis.

The two-year moving averages of unimpaired flows and average precipitation are shown in **Figure 3.8.3**. At this resolution, the USACE and EPD datasets show no significant discrepancies. However, both unimpaired flow datasets exhibit a declining trend over time that is not corroborated by the historical precipitation pattern. While average precipitation also decreases, its decline is not as steep as that of the unimpaired flows.

3.8.2 Observed Streamflow Filling

The observed streamflows at the Columbus node were discussed in the section pertaining to the Columbus reach. Streamflow measurements at W.F. George were only available after the construction of W.F. George reservoir in the early 1960s. Prior to that, the streamflows were estimated as a function of streamflows in Columbia using drainage area ratios. Such a coarse estimation approach can introduce large errors on a daily basis and may even result in systematic errors over longer time periods. As indicated earlier, this approach could be improved by the use of time-varying precipitation volume ratios over the respective basins.

3.8.3 Streamflow Routing

A modified Muskingum model was used to route flows from Columbus to W.F. George. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.8.4 Municipal & Industrial Withdrawals

Municipal & industrial withdrawals are shown in **Figure 3.8.4** and, while they are overall relatively low, they exhibit inconsistencies between the USACE and EPD datasets. Both datasets also sometimes exhibit abrupt changes in withdrawals. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that some uncertainties (up to ±40 cfs) are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.8.5 Agricultural Withdrawals

Agricultural withdrawals are shown in **Figure 3.8.5**, showing discrepancies (of up to 60 cfs) between the USACE and EPD datasets.

3.8.6 Net Evaporation

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The different datasets used to compute the net evaporation from W.F. George reservoir are shown in **Figures 3.8.6** to **3.8.9**. It should be noted that prior to 2001 the EPD dataset is based on the same net evaporation rates as the USACE dataset. However, in order to facilitate comparison between the USACE and EPD net evaporation estimation approaches, the EPD results depict the quantities that would have been computed if the EPD approach had also been used prior to 2001.

The USACE and EPD evaporation rates are shown in **Figure 3.8.6** and are relatively similar, though the EPD rates tend to be higher during the months with high evaporation rates. The average GWRI rates are significantly larger than the USACE and EPD rates and show wider intra-annual fluctuations, though they are usually smaller than the USACE and EPD rates during the low evaporation months. The precipitation data used by USACE, EPD, and GWRI are shown in **Figure 3.8.7** and are generally similar in magnitude. The constant runoff coefficients used by USACE and EPD are depicted in **Figure 3.8.8**, with the USACE coefficient being 0.4 and the EPD coefficient being 0.33. The GWRI coefficients are based on a calibrated physically-based hydrologic model and reveal that runoff coefficients can exhibit significant monthly variation. The final net evaporation timeseries computed by combining the evaporation, precipitation, and runoff datasets are shown in **Figure 3.8.9**. The EPD net evaporation flows are consistently higher than those computed by USACE, on average by about a factor of 2. The difference reaches up to 100 cfs. When averaged over a year, the GWRI net evaporation flows tend to be close to the EPD flows. However, the instantaneous net evaporation flows fluctuate more widely within each year.

The USACE dataset also contains an unexplained abrupt spike on September 30, 2000. The net evaporation losses on that day are about 30 times larger in magnitude than the net losses during the preceding days.

3.8.7 Discussion

The daily USACE and EPD unimpaired flows can be significantly different (up to several thousand cfs) even when the same streamflow measurements are used. Significant errors and uncertainties may also be present prior to the construction of W.F. George reservoir in the early 1960s since a drainage area ratio approach was used to estimate the W.F. George streamflows. Additional daily errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

The final unimpaired flows exhibit a declining trend over time. While there are also declines in average precipitation, the unimpaired flows seem to decline at a faster rate. One reason for the possible decline is the fact that the W.F. George streamflows had to be estimated from Columbia flows before the construction of W.F. George reservoir in the early 1960s. However, the unimpaired flows still continue to decline significantly after the construction of W.F. George reservoir. A hydrological model (described in Georgakakos and Zhang, 2011) was calibrated for this reach to test if these declines could be explained by natural drivers such a precipitation, evapotranspiration, and soil moisture. **Figure 3.8.10** shows monthly flows and two year moving averages of the USACE unimpaired flows and the unimpaired flows calculated by the hydrological model[2]. While these two unimpaired flow sequences exhibit good correspondence and similar trends in the early decades, after around 1980 the USACE unimpaired flows begin to be consistently lower than the flows estimated by the hydrologic model, especially during dry periods. Specifically, during the 1998-2002 drought, the hydrologic UIFs are higher by up to 2,500 cfs compared to the USACE "observed" UIFs. The implication of this analysis is that some factor other than the precipitation decline (that

[2] The period before 1960 was used to calibrate the hydrologic model.

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has been accounted for in the hydrologic model) is responsible for the steep UIF decline in this reach. The previous conclusion was also corroborated by a double mass streamflow investigation.

There are three potential causes that may underlie the UIF decline in this reach. The first may be systematic errors in the streamflow gage measurements. Based on USGS practices and input, however, there is no basis to assume that streamflow measurements are unreliable. The second is that municipal & industrial and/or agricultural withdrawals may not have been properly considered in the unimpaired flow derivation. However, this possibility is also unlikely because the magnitude of these withdrawals (**Figures 3.8.4** and **3.8.5**) is relatively small and cannot explain the flow decline which is 1.5 to 2 orders of magnitude higher than these withdrawals. It is also unlikely that surface water withdrawals of that magnitude exist and were not accounted for during the data collection phase.

The third potential cause for the observed UIF decline is that there may have been a change in the net groundwater flux out of this reach. Such a change can occur if (a) the reach experiences significant leakage in recent decades due to the presence of the reservoir, or (b) the regional groundwater table has experienced significant decline leading to lower contributions to the surface water system. While these two possibilities would have the same volumetric effect on the UIFs, they would have opposite regional groundwater signatures, with the leakage supporting higher groundwater levels in recent decades, as opposed to a regional groundwater level decline. To investigate these possibilities, well water level information in the area surrounding this reach were analyzed in collaboration with USGS staff in Atlanta. The wells showed a steep and consistent decline starting in the 1980s, coinciding with the timing of the divergence between the hydrologic and observed UIFs in **Figure 3.8.10**. **Figure 3.8.11** depicts the water level variation from 1950 to the present (as depth from the surface to the water level) at USGS well 06S001 screened in the Cretaceous aquifer unit which outcrops south of the Fall Line in Georgia and Alabama and interacts hydraulically with the surface system in the area of this reach. The graph is typical of the drastic water level decline in this aquifer unit over this time period, now exceeding 50 feet. The decline is particularly steep in the 1980s. Based on these assessments, the substantial UIF reductions in this reach in recent decades are most likely attributed to the significant regional groundwater level decline. This decline can result from reduced aquifer recharge (due to declining precipitation) and/or increased groundwater pumping in the lower Chattahoochee and Flint basins. Both reasons are likely contributing to the groundwater decline, but a quantitative characterization of their individual effects is not possible without the use of a regional groundwater model for this aquifer system. Unfortunately, no such model for this aquifer unit presently exists.

There are also significant differences between the net evaporation flows computed by USACE and EPD. On average, the EPD flows are twice as high (by 100 cfs) than the USACE flows. These differences are unexpected since the individual USACE and EPD datasets (evaporation rate, precipitation, runoff coefficients) used to calculate the net evaporation flows are relatively similar. Additionally, the USACE and EPD documentation mention similar derivation procedures. Closer analysis of the results indicates that the EPD derivation deviates from the procedure and values discussed in the EPD documentation. The runoff factor used in the derivation is not 0.32 as shown in **Figure 3.8.8**, but rather 0.4. The precipitation data was also multiplied by a factor of 0.5. While these adjustments may have been motivated by the need to improve on the USACE net evaporation rates, they do not follow a consistent climatological approach. The alternative net evaporation flows that were computed by GWRI for informational purposes are on the same order of magnitude as the EPD flows on average but are subject to wider fluctuations intra-annually. The GWRI estimates, however, are methodologically consistent throughout the basin. There is a need to develop and use better and more unified estimates of net reservoir evaporation.

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Lastly, there are inconsistences between the USACE and EPD agricultural withdrawals in this reach of up to 60 cfs. Additionally, municipal & industrial withdrawals are different at times and are also subject to abrupt magnitude changes. There is a need to reconcile the two datasets and identify the reasons for the abrupt changes in the withdrawals.

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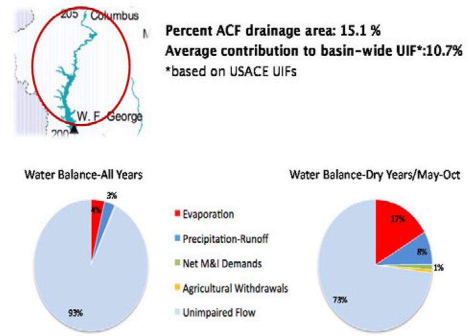

Figure 3.8.1: W.F. George reach overview.

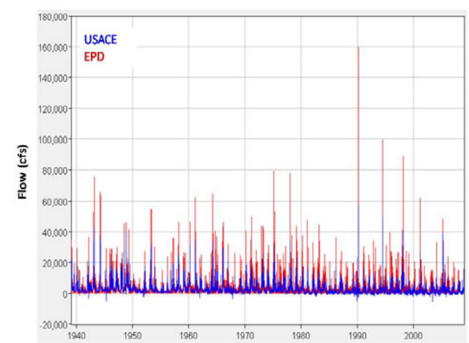

Figure 3.8.2: W.F. George reach daily unimpaired flows.

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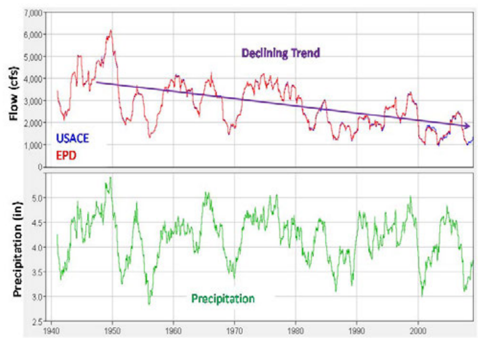

Figure 3.8.3: Two year moving averages of unimpaired flows and precipitation in the W.F. George reach.

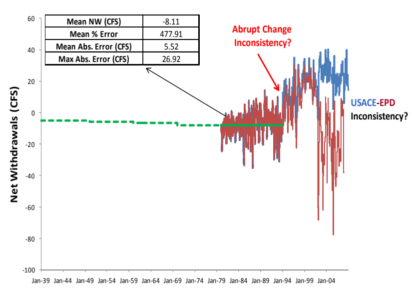

Figure 3.8.4: W.F. George reach net municipal & industrial withdrawals.

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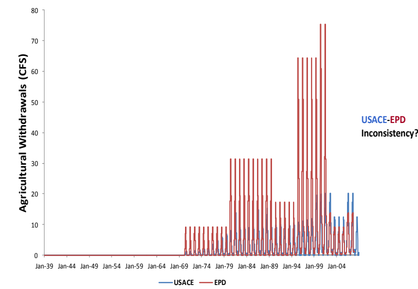

Figure 3.8.5: W.F. George reach agricultural withdrawals.

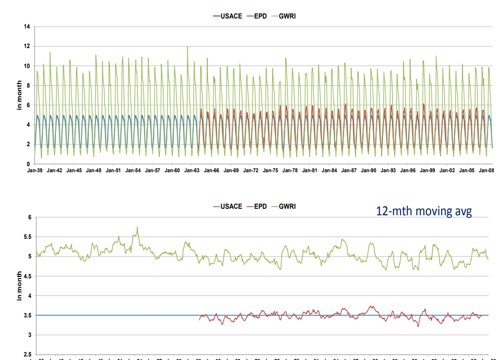

Figure 3.8.6: W.F. George reservoir evaporation rates.

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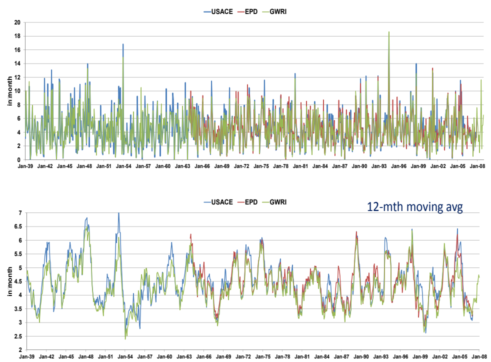

Figure 3.8.7: Mean aerial precipitation over W.F. George reservoir.

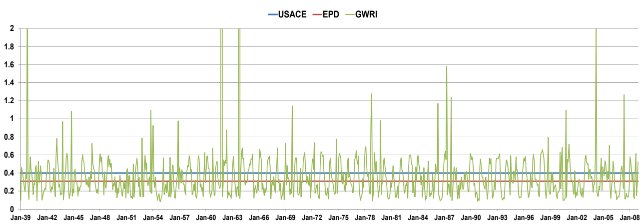

Figure 3.8.8: Runoff coefficients in the vicinity of W.F. George reservoir.

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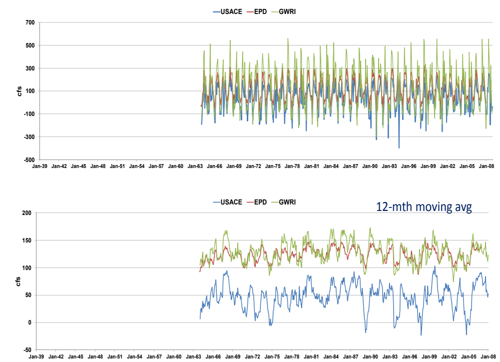

Figure 3.8.9: Net evaporation flows out of W.F. George reservoir.

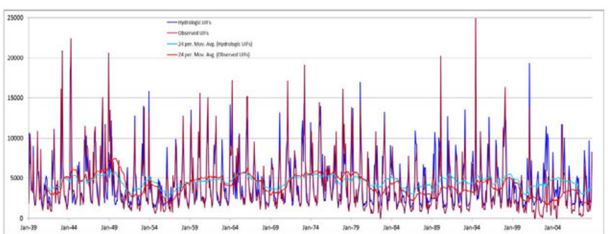

Figure 3.8.10: Hydrologic model results comparing USACE (observed; red) and hydrologic (based on the GWRI hydrologic model; blue) unimpaired flows. Starting in the 1980s, the observed UIFs are increasingly drier (up to 2,500 cfs) than the hydrologic UIFs, with low flows more severely affected.

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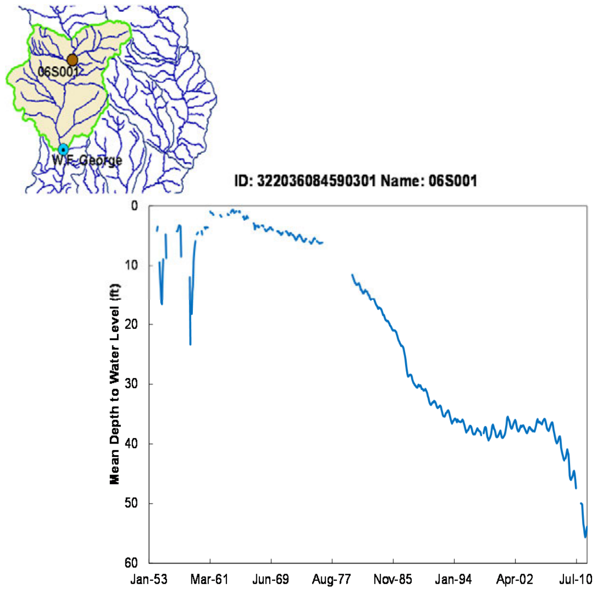

Figure 3.8.11: Typical water level decline in the Cretaceous aquifer unit at the W.F. George reach. (Site 322036084590301, at Fort Benning in Chattahoochee County, Georgia, just south of Columbus.)

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3.9 George Andrews (Columbia)

The George Andrews reach is located between the W.F. George and George Andrews nodes for the USACE dataset. The EPD dataset includes a similar reach named Columbia that is located between the W.F. George and Columbia nodes. Direct comparisons between the two datasets are possible since the Columbia and George Andrews nodes are at the same spatial location. Summary information for the reach is shown in **Figure 3.9.1**. The reach supplies 3.6% of the basinwide flows. The water budget is heavily dominated by the unimpaired flows, even during dry periods.

3.9.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.9.2**. The USACE and EPD unimpaired flows are significantly different since the USACE dataset was smoothed using 7 day central moving averages. The EPD unimpaired flows were not smoothed, but local adjustments were made to remove negative flows. As a result, the daily UIFs exhibit several thousand cfs of difference in high flows, and a consistent difference in low flows after the mid-1960s when the W.F. George reservoir came on line.

Two-year moving averages of unimpaired flows and average precipitation over the reach are shown in **Figure 3.9.3**. The USACE and EPD datasets show close agreement until 2002 when the average EPD flows start to be significantly higher (by 300 to 400 cfs) than the USACE flows. The unimpaired flow averages follow similar general trends as the precipitation data.

3.9.2 Observed Streamflow Filling

The observed streamflows at the W.F. George node are discussed in the section pertaining to the W.F. George reach. The streamflows at the George Andrews were incomplete and had to be estimated. In the USACE dataset, the George Andrews streamflows were estimated to be 1.1 times the W.F. George streamflows for the entire study period. The EPD dataset used the same estimation procedure until 2001. After 2001, observed streamflows measured at a USGS gage at the outlet of George Andrews Dam were used. This is the reason why the unimpaired flows from the USACE and EPD datasets are significantly different after 2001.

3.9.3 Streamflow Routing

No routing was used to translate the upstream flows to the downstream location of this reach.

3.9.4 Municipal & Industrial Withdrawals

Municipal & industrial withdrawals made in this reach are shown in **Figure 3.9.4**. The withdrawals are generally small, but there are some discrepancies between the USACE and EPD datasets. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal that hindcasts that keep withdrawals constant on a decadal basis introduce errors on the order of 5 to 10 cfs.

3.9.5 Agricultural Withdrawals

The agricultural withdrawals of this reach are shown in **Figure 3.9.5**. The two datasets coincide, but there is an abrupt reduction (of about 30 cfs) in the early 1990s, and a total cessation in the early 2000s.

3.9.6 Net Evaporation

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Net evaporation losses are not modeled for this reach in the derivation of the unimpaired flows by the USACE, despite the presence of George Andrews reservoir. EPD does consider evaporation losses in this reach.

3.9.7 Discussion

The daily USACE and EPD unimpaired flows can be significantly different (up to a few thousand cfs) even when the same streamflow measurements are used.

The estimation of observed streamflows could be improved for this reach. For the USACE dataset, the streamflows at the downstream George Andrews node were estimated as a 10% scaled up version of the flows at the upstream W.F. George node during the entire period of study. As a result, the unimpaired flows are themselves just a factor of the W.F George node flows, safe for a few adjustments due to the withdrawals made in the reach. The unimpaired flows for the USACE dataset therefore may contain significant errors and uncertainties (in magnitude and timing), especially after the construction of W.F. George Dam because the observed streamflows at the W.F. George node correspond to the reservoir releases and are not natural flows. The EPD dataset is subject to the same potential errors up until 2001. After 2001, measured streamflows at the Columbia gage were used to specify the George Andrews observed streamflows instead and are expected to give a more accurate representation of the actual flows. In fact, the differences between the two data sets after 2001 exemplify the potential UIF errors for the earlier study period from 1939 to 2000. It is recommended that the USACE and EPD flows be recomputed using the gage information instead of the estimated streamflows, since measurements at this gage are available for several decades prior to 2001.

The USACE dataset does not explicitly consider net evaporation losses in this reach during the unimpaired flow derivation. Further discrepancies arise from the use of these UIFs in river basin simulation studies using the ResSim. In modeling the reservoirs in this reach, all recent studies explicitly consider evaporation losses using rates applicable to W.F. George reservoir. Evaporation losses are therefore subtracted twice, one time indirectly through the UIFs and a second time directly in the simulation.

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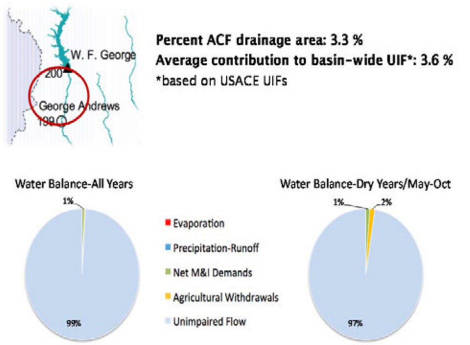

Figure 3.9.1: George Andrews reach overview.

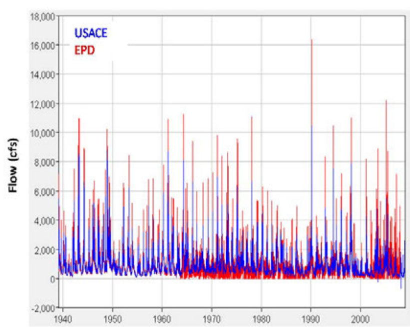

Figure 3.9.2: George Andrews reach daily unimpaired flows.

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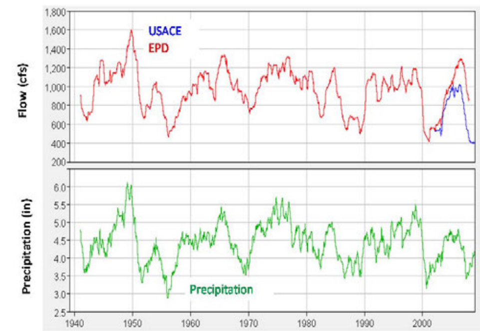

Figure 3.9.3: Two year moving averages of unimpaired flows and precipitation in the George Andrews reach.

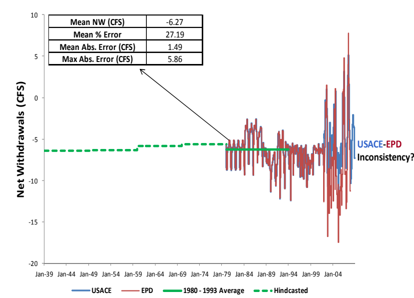

Figure 3.9.4: George Andrews reach net municipal & industrial withdrawals.

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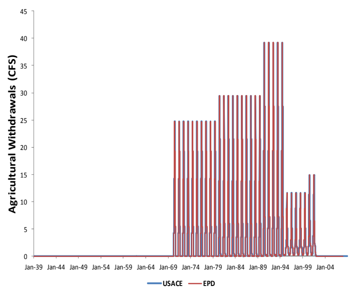

Figure 3.9.5: George Andrews reach agricultural withdrawals.

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3.10 Griffin

The Griffin reach is a headwater basin located above the Griffin node. Summary information for the reach is shown in **Figure 3.10.1**. The basinwide flow contribution of this reach is 1.3%. The water budget is primarily dominated by the unimpaired flows, though the withdrawals can account for a sizeable fraction during dry periods (of up to 19%). EPD does not separately compute unimpaired flows for this reach, and no comparisons between the USACE and EPD datasets can be made.

3.10.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.10.2**. The flows were left unsmoothed. Two year moving averages of the unimpaired flows and average precipitation are shown in **Figure 3.10.3** and follow the same general trends.

3.10.2 Observed Streamflow Filling

The observed streamflow records at the Griffin node were complete.

3.10.3 Streamflow Routing

Routing was not required since Griffin is a headwater reach.

3.10.4 Municipal & Industrial Withdrawals

The municipal & industrial withdrawals are shown in **Figure 3.10.4**. The withdrawals reach up to 45 cfs, and exhibit an abrupt increase in the mid 1990s. Analysis of the differences between measured and averaged flows from 1980 to 1993 shows that uncertainties as large as 10-15 cfs may be introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.10.5 Agricultural Withdrawals

Agricultural withdrawals are not considered for this reach in the derivation of the unimpaired flows.

3.10.6 Net Evaporation

Net evaporation losses are not considered for this reach in the derivation of the unimpaired flows.

3.10.7 Discussion

Overall, the UIFs in this reach appear to be consistent, and can be readily incorporated in the EPD dataset. Some UIF improvements can be made through better estimation of the net M&I withdrawals.

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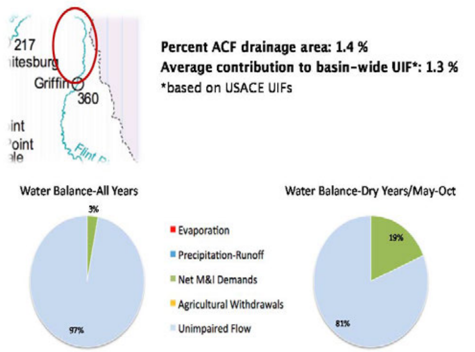

Figure 3.10.1: Griffin reach overview.

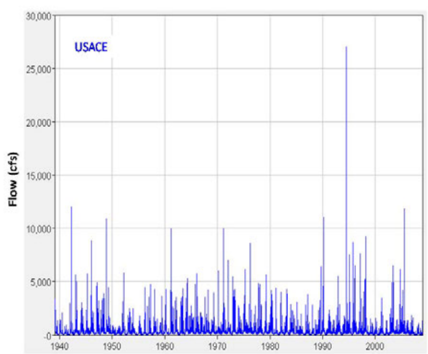

Figure 3.10.2: Griffin reach daily unimpaired flows.

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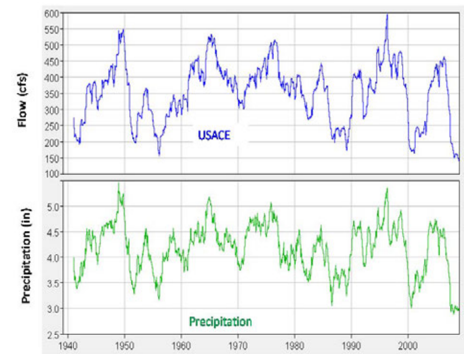

Figure 3.10.3: Two year moving averages of unimpaired flows and precipitation in the Griffin reach.

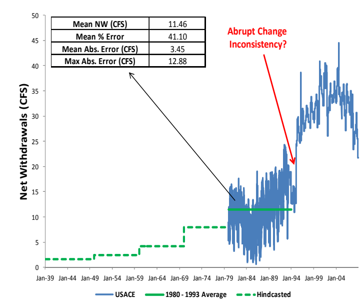

Figure 3.10.4: Griffin reach net municipal & industrial withdrawals.

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3.11 Montezuma

The Montezuma reach is located between the Griffin and Montezuma nodes. Summary information for the reach is shown in **Figure 3.11.1**, indicating a 12% contribution to the basinwide flows. The water budget is heavily dominated by the unimpaired flows, even during dry periods. EPD does not compute unimpaired flows for this reach separately, and no comparisons between the USACE and EPD datasets can be made.

3.11.1 Final Unimpaired Flows

The USACE daily unimpaired flows are shown in **Figure 3.11.2**. The flows were left unsmoothed. Two year moving averages of the unimpaired flows and average precipitation are shown in **Figure 3.11.3** and follow the same general trends.

3.11.2 Observed Streamflow Filling

Observed streamflow measurements at the Griffin and Montezuma nodes existed over the entire period of study.

3.11.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from the upstream Griffin node to the Montezuma node. Daily errors can result from the routing model since it is an approximation of the true hydraulics. The model was also calibrated without full knowledge of the local inflows to the reach. This is a major problem, because the local flow contributions are much larger than the upstream streamflows in this particular reach.

3.11.4 Municipal & Industrial Withdrawals

The municipal & industrial withdrawals are shown in **Figure 3.11.4**. There are some abrupt changes in the average withdrawal magnitudes starting from the mid 1990s. Analysis of the differences between measured and averaged flows from 1980 to 1993 show that errors up to 15 cfs are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.11.5 Agricultural Withdrawals

The agricultural withdrawals are shown in **Figure 3.11.5** and are fairly consistent in the two datasets.

3.11.6 Net Evaporation

Net evaporation losses are not considered for this reach in the derivation of the unimpaired flows.

3.11.7 Discussion

Daily errors and uncertainties can be introduced by the routing model and smoothing technique used in the unimpaired flow derivation.

The UIFs can be further improved by a more accurate representation of the net M&I withdrawals.

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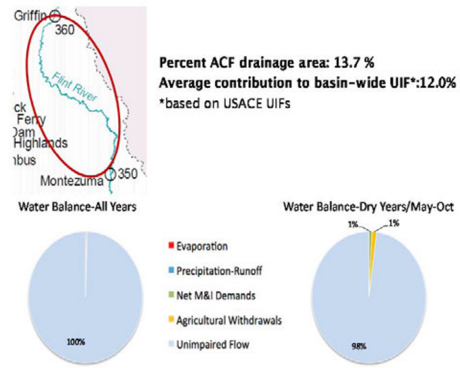

Figure 3.11.1: Montezuma reach overview.

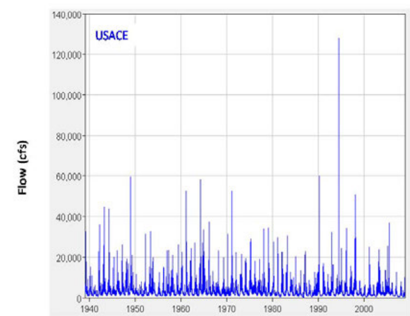

Figure 3.11.2: Montezuma reach daily unimpaired flows.

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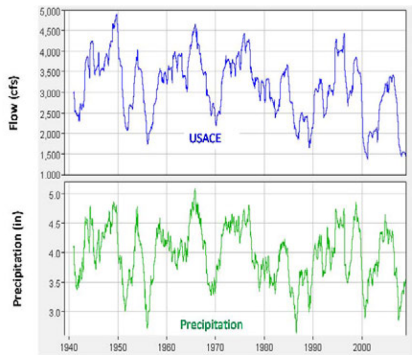

Figure 3.11.3: Two year moving averages of unimpaired flows and precipitation in the Montezuma reach.

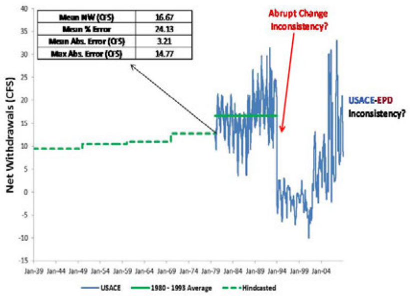

Figure 3.11.4: Montezuma reach net municipal & industrial withdrawals.

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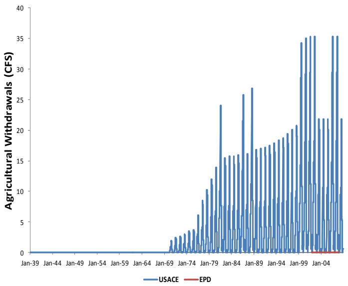

Figure 3.11.5: Montezuma reach agricultural withdrawals.

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3.12 Albany

The Albany reach is located between the Montezuma and Albany nodes. Summary information for the reach is shown in **Figure 3.12.1** indicating a 9.3% contribution to basinwide flows. The water budget primarily consists of the unimpaired flows, though the agricultural withdrawals can account for a significant percentage (18%) during dry years.

3.12.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.12.2**. The USACE data was smoothed using 5 day moving averages. The EPD flows were not smoothed but local adjustments were made to remove negative values. Significant differences exist in the daily UIFs ranging up to 25,000 cfs.

Two-year moving averages of the unimpaired flows and the average precipitation over the watershed that drains the Albany reach are shown in **Figure 3.12.3**. The USACE and EPD unimpaired flows are similar and both exhibit the same general trends as the precipitation averages.

3.12.2 Observed Streamflow Filling

Observed streamflows at Montezuma (upstream node) and Albany (downstream node) exist over the entire study period.

3.12.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from the upstream Montezuma node to the Albany node. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.12.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.12.4**. The total withdrawals are estimated to be less than 20 cfs, but there are differences between the USACE and EPD datasets, both of which exhibit some abrupt changes in the average withdrawal magnitudes. Analysis of the differences between measured and averaged flows from 1980 to 1993 shows that uncertainties of up to 20 cfs are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.12.5 Agricultural Withdrawals

The agricultural withdrawals are shown in **Figure 3.12.5** and amount to 350 cfs during droughts. For certain periods, there are significant differences of up to 150 cfs between the USACE and EPD datasets.

3.12.6 Net Evaporation

Net evaporation losses are not considered for this reach in the derivation of the unimpaired flows.

3.12.7 Discussion

The daily UIFs contain errors of up to 25,000 cfs, while the two-year moving average sequences are similar and exhibit the same general trends as the precipitation averages. Additional daily

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errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

The UIFs can be improved by a more consistent and representative consideration of the net M&I and agricultural withdrawals to eliminate the differences between the USACE and EPD datasets as well as some unaccounted for abrupt changes.

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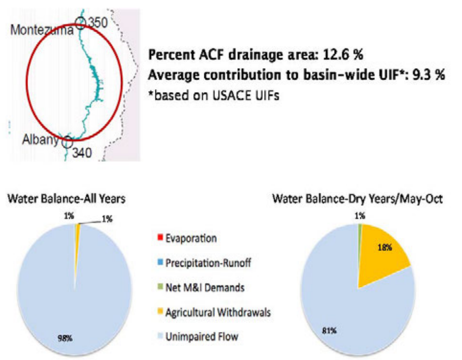

Figure 3.12.1: Albany reach overview.

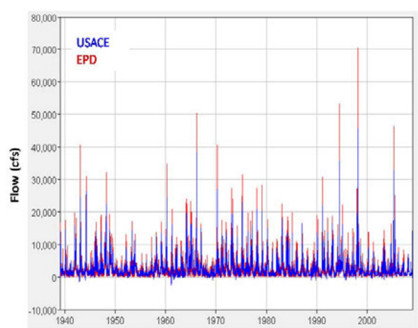

Figure 3.12.2: Albany reach daily unimpaired flows.

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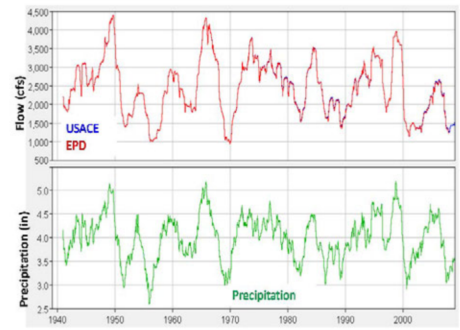

Figure 3.12.3: Two-year moving averages of unimpaired flows and precipitation in the Albany reach.

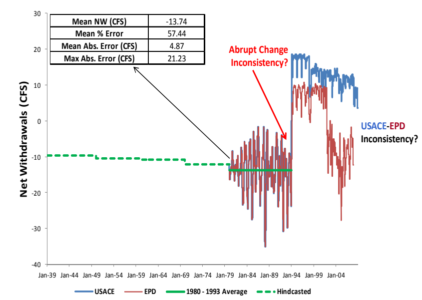

Figure 3.12.4: Albany reach net municipal & industrial withdrawals.

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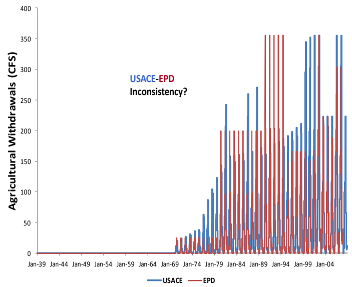

Figure 3.12.5: Albany reach agricultural withdrawals.

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3.13 Newton

The Newton reach is located between the Albany and Newton nodes. Summary information for the reach is shown in **Figure 3.13.1** indicating that the basinwide flow contribution is 2%. The unimpaired flows constitute the largest portion of the water budget, though the municipal & industrial and agricultural withdrawals are also significant during dry periods accounting for up to 18%.

3.13.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.13.2** and reveal that there are large differences between the USACE and EPD datasets (by several thousand cfs). The USACE data was smoothed using 5 day centered moving averages, though frequent and often large negative flows remain. The EPD data was not smoothed, but adjusted to remove negative values by redistributing flows over the entire period of record. Such adjustments are unfortunate as they perturb the UIFs away from their natural interannual, seasonal, weekly, and daily patterns (Chapter 2).

Two-year moving averages of unimpaired flows and precipitation in the Newton reach are shown in **Figure 3.13.3**. As expected, there are significant differences between the USACE and EPD datasets of up to 200 cfs over several years due to the fact that the EPD flows were adjusted using a technique that adds water to negative flows and removes water from positive flows. While both datasets sometimes follow the same general trends as the precipitation data, there are other periods where dips in precipitation are not accompanied by reduced unimpaired flows, and vice versa.

3.13.2 Observed Streamflow Filling

Observed streamflows at Albany (upstream node) were available for the entire study period. The Newton streamflow records were incomplete, and the flows at several time periods were filled in using relationships developed based on Albany streamflow data, as shown in **Figure 3.13.4**. Streamflows between 1939 and 1946 were used to calibrate the relationship, which was then used to estimate the streamflows from 1947 to 1956. The errors between the predicted and observed streamflows during the calibration period reveal that there can be large errors (up to 20,000 cfs) on a daily basis. However, the errors decrease when considering a monthly time resolution.

3.13.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from the upstream Albany node to the Newton node. Significant daily errors, including large and frequent negative flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.13.4 Municipal & Industrial Withdrawals

The municipal & industrial withdrawals are shown in **Figure 3.13.5**. The net withdrawals are mostly negative (up to -50 cfs), indicating that water returns to the river in this reach on average. There are differences between the USACE and EPD datasets and both exhibit some abrupt changes in the average withdrawal magnitudes. Analysis of the differences between measured and averaged flows from 1980 to 1993 indicates that uncertainties as high as 15 cfs are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.13.5 Agricultural Withdrawals

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The agricultural withdrawals are shown in **Figure 3.13.6**. There are significant differences between the USACE and EPD datasets of up to 250 cfs.

3.13.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the derivation of the unimpaired flows.

3.13.7 Discussion

The Newton reach is subject to frequent and large negative unimpaired flows, even after smoothing techniques were applied. The flow adjustment techniques employed in the development of the USACE and EPD unimpaired flows also result in significant differences between the datasets on the order of several thousand cfs. While the 5 day central moving averages applied by USACE change the appearance of the daily flows, they should not significantly affect flows on larger (decadal, annual, seasonal, and weekly) time scales. On the hand, the EPD adjustments applied to remove negative values significantly affect the hydrographs over the whole period of record since water is added to periods with negative unimpaired flows and taken from periods with positive unimpaired flows that may be weeks, months, or years apart. This compromises the hydrologic consistency of the UIFs which essentially represent the watershed response to precipitation and evapotranspiration.

The filled in observed streamflow values in this reach also add significant uncertainties on a daily basis. Alternative estimation procedures of missing values could mitigate these errors. Additional daily errors and uncertainties are introduced by the routing model used in the unimpaired flow derivation.

There are also significant differences between the USACE and EPD withdrawal data. The abrupt changes in the average municipal & industrial withdrawals should be corrected, and the agricultural withdrawal discrepancies should be resolved.

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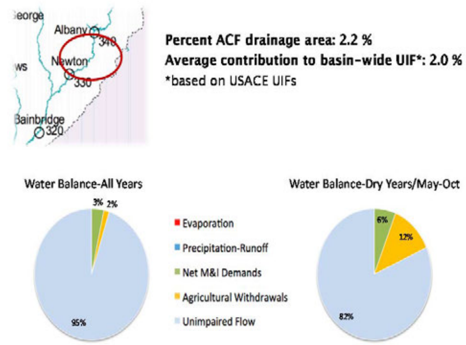

Figure 3.13.1: Newton reach overview.

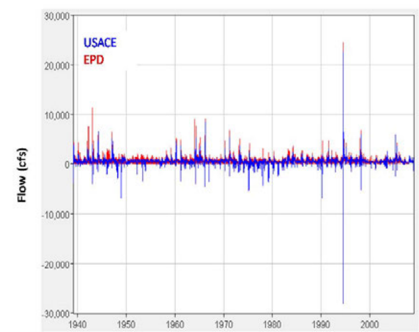

Figure 3.13.2: Newton reach daily unimpaired flows.

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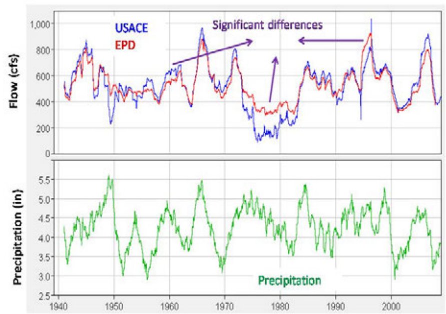
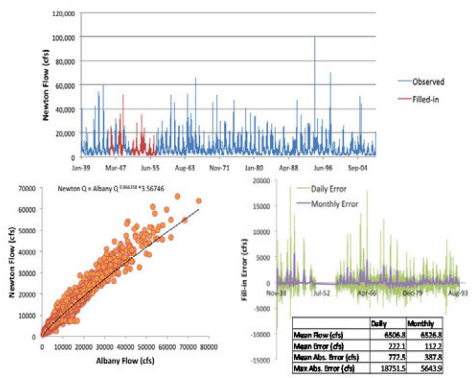


Figure 3.13.3: Two year moving averages of unimpaired flows and precipitation in the Newton reach.



	Daily	Monthly
Mean Flow (cfs)	6506.8	6526.8
Mean Error (cfs)	222.1	112.2
Mean Abs. Error (cfs)	777.5	387.8
Max Abs. Error (cfs)	18751.5	5643.9

Figure 3.13.4: Estimation of Newton node streamflows.

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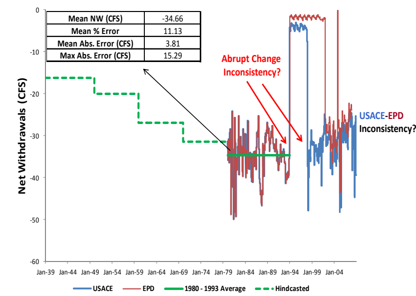

Mean NW (CFS)	-34.66
Mean % Error	11.13
Mean Abs. Error (CFS)	3.81
Max Abs. Error (CFS)	15.29

Figure 3.13.5: Newton reach net municipal & industrial withdrawals.

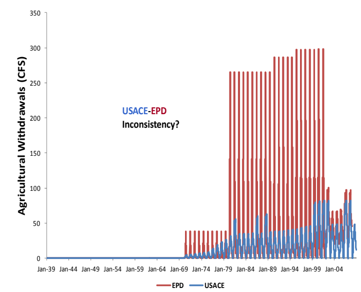

Figure 3.13.6: Newton reach agricultural withdrawals.

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3.14 Bainbridge

The Bainbridge reach is located between the Newton and Bainbridge nodes. Summary information for the reach is shown in **Figure 3.14.1**, indicating a basinwide flow contribution of 7.2%. The unimpaired flows constitute the largest portion of the water budget, but agricultural withdrawals become significant during dry periods amounting up to 19%. Data from the EPD dataset was derived by summing the unimpaired flows from the Milford and Bainbridge reaches to create a UIF series compatible with that of the USACE reach configuration.

3.14.1 Final Unimpaired Flows

The unimpaired flows are shown in **Figure 3.14.2** and show significant differences between the USACE and EPD datasets (of up to 10,000 cfs) on a daily timescale. The USACE flows were smoothed using 5 day averages with some negative values still remaining, while the EPD flows were not smoothed but adjusted annually to remove negative values.

Two-year moving averages of the unimpaired flows and the average precipitation over the watershed draining this reach are shown in **Figure 3.14.3**. The USACE and EPD datasets show similar trends. However, both datasets show significantly damped averages from 1970 to 2002 in comparison to the pre 1970 and post 2002 periods. Both datasets also do not correspond well with general precipitation trends from 1970 to 2002 or at least do so with much less responsiveness to precipitation than the pre 1970 and post 2002 flows. Thus, the UIF period from 1970 to 2002 potentially contains significant mean and variability biases.

3.14.2 Observed Streamflow Filling

The observed streamflows at the upstream Newton node are not available over the whole study period and are discussed in the section pertaining to the Newton reach. The Bainbridge streamflow records were incomplete over the study period, and the flows between 1970 and 2001 were filled in using relationships developed with the streamflow at the Newton node. Instead of calibrating a relationship, the MOVE2 statistical model (Hirsch, 1982) that estimates Bainbridge flows from Newton flows was adopted. The MOVE2 model consists of monthly linear relationships whose parameters are estimated from ratios of the means and standard deviations of the two nodes. Streamflow measurements at both nodes prior to 1970, as well as statistics of the Newton streamflows between 1970 and 2002, were used to estimate the parameters. The errors between the predicted and observed streamflows prior to 1970 are shown in **Figure 3.14.4** and reveal that there can be large errors (up to 10,000 cfs) on a daily basis. However, the errors decrease when considering a monthly time resolution. As will be discussed shortly, the MOVE2 statistical filling procedure is the cause of the UIF inconsistencies over the 1970 to 2002 period.

3.14.3 Streamflow Routing

A Muskingum model was used to route observed streamflows from the upstream Newton node to the Bainbridge node. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.14.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.14.5**. These withdrawals are fairly small (up to -10 cfs) and exhibit some differences between the USACE and EPD datasets. As

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can be seen from the 1980 to 1993 data, hindcasts that keep withdrawals constant on a decadal basis introduce uncertainties of up to 6 cfs.

3.14.5 Agricultural Withdrawals

The agricultural withdrawals are shown in **Figure 3.14.6**. There are significant differences between the USACE and EPD datasets prior to 2002 of up to 300 cfs.

3.14.6 Net Evaporation

Net evaporation losses are not modeled for this reach in the UIF derivation.

3.14.7 Discussion

The daily UIFs contain large errors on the order of several thousand cfs. The two year moving averages of the unimpaired flows (**Figure 3.14.3**) show significantly and unnaturally dampened fluctuations of the unimpaired flows from 1970 to 2002 and very little response to precipitation. An order of magnitude analysis of the water budget terms in this reach reveals that estimates of the Bainbridge streamflows are likely responsible for this unusual behavior. Between 1970 and 2002 observed streamflow measurements at Bainbridge do not exist and a linear statistical model (MOVE2) was used to estimate streamflow values as a function of measurements taken at the Newton node. A closer review of the statistical model reveals that the slopes of the linear model are only slightly larger than one. The statistical model therefore primarily estimates streamflows based on constant values with little fluctuation due to the Newton flows. As a result, the final unimpaired flows only slightly fluctuate over time and are significantly dampened. It is recommended that the streamflow estimation procedure for Bainbridge be revised. Toward this goal, **Figure 3.14.7** shows unimpaired flows that were generated by using the GWRI hydrologic model to estimate Bainbridge streamflows. These hydrologic unimpaired flows are significantly more variable and follow the general precipitation trends more closely than the original USACE unimpaired flows. For several years in the 1970 to 2002 period, the average, two-year value of the new UIFs exceeds that of the existing UIFs by 1,000 to 2,000 cfs. These are significant volume differences, and their existing UIFs should be corrected accordingly.

The daily USACE and EPD unimpaired flows can be significantly different (up to 10,000 cfs) even when the same streamflow measurements are used. The filled in observed streamflow values at the upstream node (Newton) also add significant daily uncertainties. Alternative estimation procedures of missing values could be considered to mitigate these errors. Additional daily errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

There are also significant differences between the USACE and EPD agricultural withdrawal data (of up to 300 cfs) that should be resolved. Lastly, the net M&I discrepancies are small, but there is no reason why they should exist.

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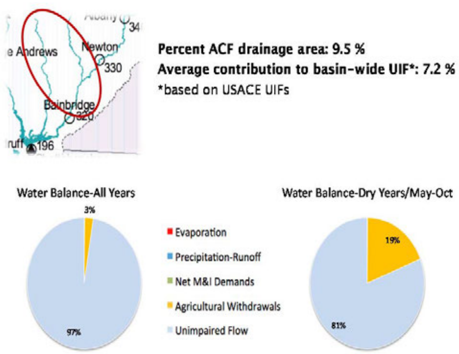

Figure 3.14.1: Bainbridge reach overview.

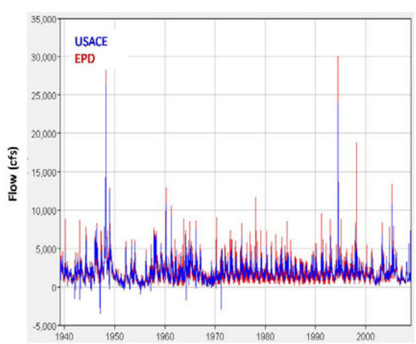

Figure 3.14.2: Bainbridge reach daily unimpaired flows.

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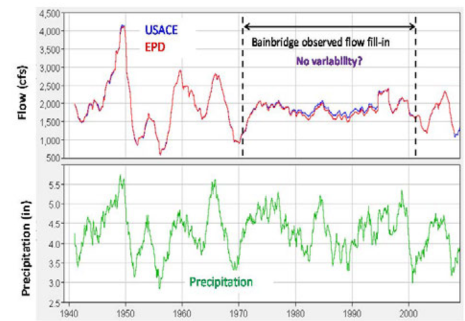

Figure 3.14.3: Two year moving averages of unimpaired flows and precipitation in the Bainbridge reach.

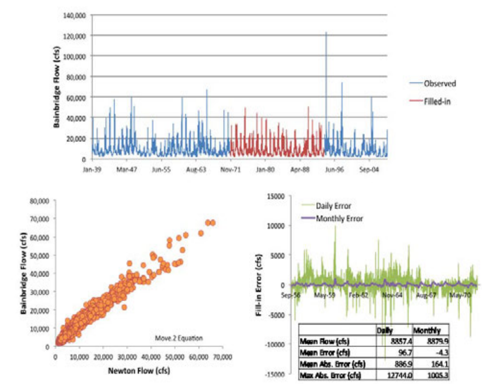

Figure 3.14.4: Estimation of Bainbridge node streamflows.

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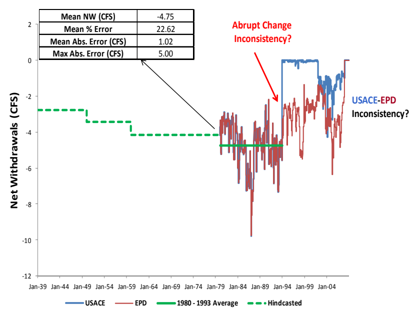

Figure 3.14.5: Bainbridge reach net municipal & industrial withdrawals.

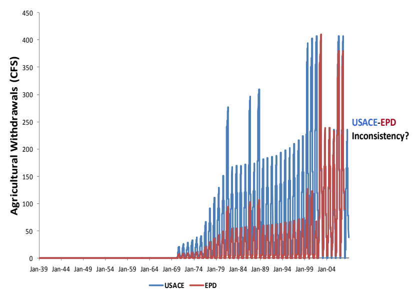

Figure 3.14.6: Bainbridge reach agricultural withdrawals.

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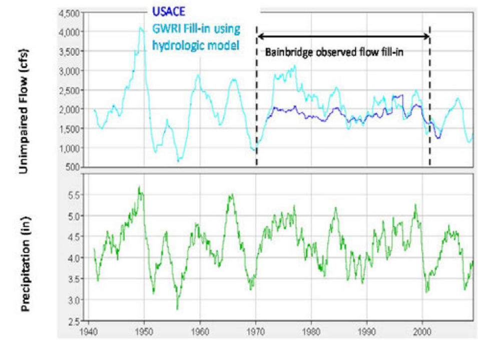

Figure 3.14.7: Comparison of USACE Bainbridge unimpaired flows and recomputed UIFs based on the GWRI hydrologic model driven by watershed precipitation and evapotranspiration.

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3.15 Jim Woodruff

The J. Woodruff reach is bounded by the J. Woodruff node at the downstream end. The reach is bounded by two upstream nodes, George Andrews and Bainbridge, since it includes the confluence of the Chattahoochee and Flint rivers. Summary information for the reach is shown in **Figure 3.15.1** indicating a basinwide flow contribution of 12%. The unimpaired flows constitute the largest portion of the water budget, though the agricultural withdrawals (8%) and evaporation (10%) terms are also significant during dry periods. Data from the EPD dataset was derived by summing the unimpaired flows for the Iron City and J. Woodruff reaches to create a series compatible with that of the USACE reach configuration.

3.15.1 Final Unimpaired Flows

The unimpaired flows are shown in **Figure 3.15.2** and reveal significant differences between the daily USACE and EPD datasets, occasionally exceeding 30,000 cfs. The differences arise due to the fact that the USACE flows were smoothed with 7 day centered moving averages (with negative flows as large as 25,000 cfs remaining). The EPD flows were only adjusted to remove negative values using a combination of local adjustments (for the Iron City data) and adjustments that redistribute flows over the entire period of record (for the J. Woodruff data). Period of record adjustments are unfortunate as they perturb the UIFs away from their natural interannual, seasonal, weekly, and daily patterns (Chapter 2).

Two-year moving averages of the unimpaired flows and average reach precipitation are shown in **Figure 3.15.3**. While following the same trends, the USACE and EPD datasets show differences of several hundred cfs over the study period due to the fact that the EPD flows were adjusted by adding water to negative flows and removing it from positive flows. Both datasets also show noticeable increases in the average unimpaired flows after the early 1960s. These increases do not correspond to trends in precipitation amounts, which stay constant or even slightly decrease over time. These observations indicate that potentially large biases exist in the J. Woodruff UIFs.

3.15.2 Observed Streamflow Filling

The streamflows at the J. Woodruff node were estimated by directly using the observed streamflows from the USGS Chattahoochee gage which is located below J. Woodruff Dam. The streamflows at the upstream nodes, George Andrews and Bainbridge, were not complete over the whole study period and are discussed in the sections pertaining to the corresponding reaches.

3.15.3 Streamflow Routing

A modified Muskingum model was used to route streamflows from George Andrews to the J. Woodruff node, while the streamflows from the Bainbridge node were not routed to the J. Woodruff node. It is unclear how the George Andrews to J. Woodruff routing model was calibrated since the downstream measurements at J. Woodruff also include flow contributions from the other upstream node, Bainbridge. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach. Since negative flows are often followed by large positive flows (**Figure 3.15.4**), it is likely that many of the negative unimpaired flows in the USACE dataset are the result of routing errors.

3.15.4 Municipal & Industrial Withdrawals

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The net municipal & industrial withdrawals are shown in **Figure 3.15.5** and range from 200 to -50 cfs. There are some minor differences between the USACE and EPD datasets and both exhibit an abrupt unaccounted for change in 1994 by about 150 cfs. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveals that errors up to 80 cfs are introduced by hindcasts that keep withdrawals constant on a decadal basis.

3.15.5 Agricultural Withdrawals

The agricultural withdrawals are shown in **Figure 3.15.6** and amount up to 400 cfs. Prior to 2001 there are differences of up to 100 cfs between the USACE and EPD datasets.

3.15.6 Net Evaporation

The different datasets used to compute the net evaporation from J. Woodruff reservoir are shown in **Figures 3.15.7** to **3.15.10**. It should be noted that prior to 2001 the EPD dataset is based on the same net evaporation rates as the USACE dataset. However, in order to facilitate comparison between the USACE and EPD net evaporation estimation approaches, the EPD results shown depict the quantities that would have been computed if the EPD approach had also been used prior to 2001.

USACE and EPD evaporation rates are shown in **Figure 3.15.7** and are relatively similar, though the EPD rates tend to be higher during the months with high evaporation rates. The average GWRI rates are significantly larger than the USACE and EPD rates. The GWRI rates also show wider intra-annual fluctuations and are usually smaller than the USACE and EPD rates during the low evaporation months. The precipitation data used by USACE, EPD, and GWRI are shown in **Figure 3.15.8** and are generally similar in magnitude. However, there are some noticeable differences during dry and wet periods. The constant runoff coefficients used by USACE and EPD are depicted in **Figure 3.15.9**, with the USACE coefficient being 0.4 and the EPD coefficient 0.28. The GWRI coefficients are based on the result of the GWRI hydrologic model and reveal that runoff coefficients can exhibit significant monthly variation. The final net evaporation timeseries computed by combining the evaporation, precipitation, and runoff datasets are shown in **Figure 3.15.10**. The EPD net evaporation flows are consistently higher than those computed by USACE, on average by about a factor of 2. The average GWRI net evaporation flows are on average in between the USACE and EPD flows and exhibit wider intra-annual fluctuations.

The USACE dataset also contains an unexplained abrupt spike on September 30, 2000. The net evaporation losses on that day are about 30 times larger in magnitude than the net losses during the preceding days.

3.15.7 Discussion

Both the EPD and USACE unimpaired flows significantly increase after the early 1960s. These increases are not explained by precipitation trends which tend to remain constant or decrease. It is likely that errors committed at upstream locations are being transferred to the J. Woodruff reach. Observed streamflow records at both upstream nodes (George Andrews and Bainbridge) were incomplete and had to be estimated. As discussed in the sections pertaining to those reaches, the estimated UIFs contain errors that could affect the J. Woodruff unimpaired flows. For example, a consequence of the systematic flow underestimation at Bainbridge over the 1970 to 2002 time period (highlighted in **Figure 3.14.7**) is to increase by a similar amount the UIFs in the J. Woodruff reach. If the Bainbridge flow is corrected, then part of the unnatural UIF increase in J. Woodruff (**Figure 3.15.3**) would also be removed. A similar effect might occur if the George Andrews

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unimpaired flows were to be recalculated since they also seem to have been systematically underestimated for portions of the study period. The possibility also exists that there are flows into and out of the reach that were not properly accounted for during the development of the unimpaired flows. These discrepancies should be resolved to ensure that the apparent systematic UIF biases are removed.

The J. Woodruff reach is subject to frequent and large negative unimpaired flows, even after smoothing. The flow adjustment techniques employed in the development of the USACE and EPD unimpaired flows also result in significant differences between the datasets on the order of several thousand cfs. While the 7-day central moving averages applied by USACE change the appearance of the daily flows, they should not significantly affect flows on larger (decadal, annual, seasonal, and weekly) time scales. On the hand, the EPD adjustments applied to remove negative values significantly affect the hydrographs over the whole period of record since water is added to periods with negative unimpaired flows and taken from periods with positive unimpaired flows that may be weeks, months, or years apart. This compromises the hydrologic consistency of the UIFs which essentially represent the watershed response to precipitation and evapotranspiration. The daily USACE and EPD unimpaired flows can be significantly different (up to 30,000 cfs) despite the fact that the same streamflow measurements were used in their derivation. The filled in observed streamflow values in this reach also add significant daily uncertainties. Alternative estimation procedures of missing values could be considered to mitigate these errors. Additional daily errors and uncertainties can be introduced by the routing model used in the unimpaired flow derivation.

There are significant differences between the net evaporation flows computed by USACE and EPD by about 40 to 50 cfs. On average, the EPD flows are twice as high as the USACE flows. An additional aspect of the evaporation loss differences is that they are systematic, accumulate over time, and may lead to significant discrepancies in reservoir levels and other system performance measures. The differences between the USACE and EPD datasets are unexpected since the individual datasets (evaporation rate, precipitation, and runoff coefficients) used to calculate the net evaporation losses are relatively similar. Additionally, the USACE and EPD documentation mention similar derivation procedures. Closer analysis indicates that the EPD derivation deviates from the procedure and values discussed in the EPD documentation. The runoff factor used in the derivation was not 0.28 as shown in **Figure 3.15.9**, but rather 0.4. The precipitation data was also multiplied by a factor of 0.5. While these adjustments may have been motivated by the need to improve on the USACE net evaporation rates, they do not follow a consistent climatological approach. The alternative net evaporation flows that were computed by GWRI for informational purposes are in between the EPD and USACE flows and exhibit wider fluctuations intra-annually. Overall, the net evaporation loss differences are significant and should be reconciled based on a consistent and scientifically valid basis across the ACF basin. Considering all four federal reservoirs, the EPD evaporation losses are higher than those of the USACE by about 200 cfs on average. As indicated earlier, this discrepancy is systematic and cumulative, and is exacerbated further by the manner in which net evaporation losses from the private reservoirs are handled (Section 3.7).

There are significant differences between the USACE and EPD agricultural withdrawals, and abrupt changes in the average municipal & industrial withdrawals. Reconciling these inconsistencies and removing the unaccounted for abrupt changes would help improve UIF validity.

The J. Woodruff node uses streamflows measured at a downstream location (Chattahoochee gage). It is possible that the unimpaired flows include flows that should be attributed to the next downstream reach. The magnitude of these flows is however expected to be small.

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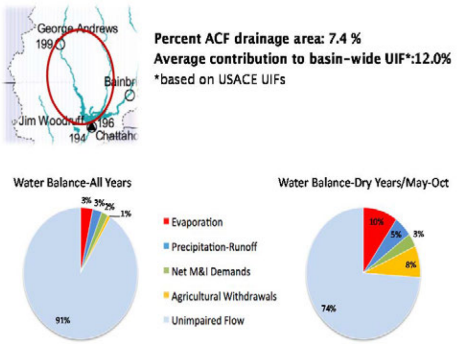

Figure 3.15.1: J. Woodruff reach overview.

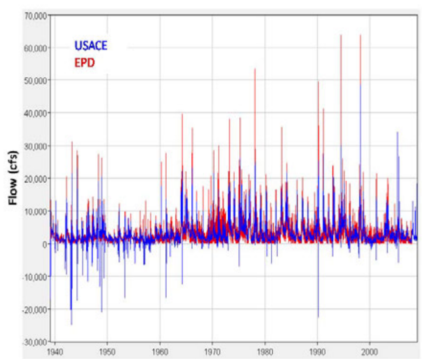

Figure 3.15.2: J. Woodruff reach daily unimpaired flows.

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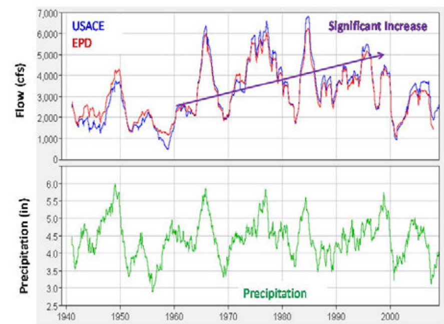

Figure 3.15.3: Two year moving averages of unimpaired flows and precipitation in the J. Woodruff reach.

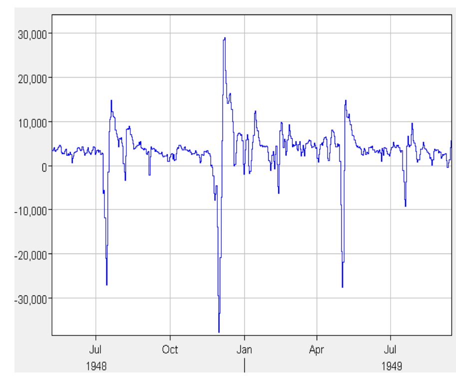

Figure 3.15.4: Unimpaired flow patterns in the J. Woodruff reach.

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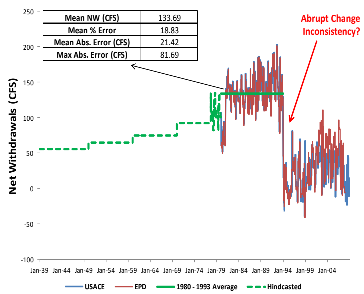

Figure 3.15.5: J. Woodruff reach net municipal & industrial withdrawals.

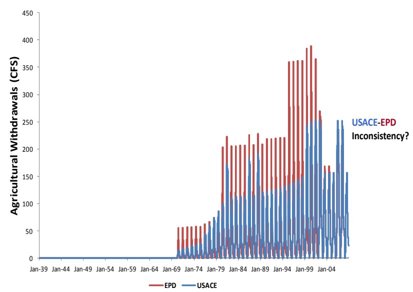

Figure 3.15.6: J. Woodruff reach agricultural withdrawals.

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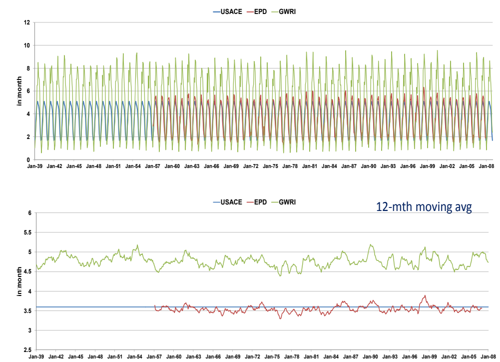

Figure 3.15.7: J. Woodruff reservoir evaporation rates.

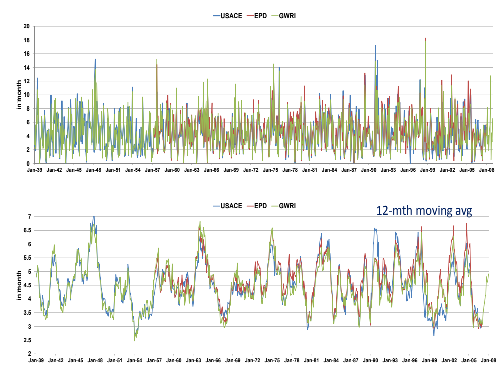

Figure 3.15.8: Mean aerial precipitation over J. Woodruff reservoir.

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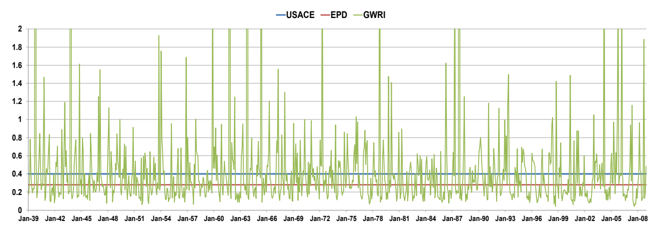

Figure 3.15.9: Runoff coefficients in the vicinity of J. Woodruff reservoir.

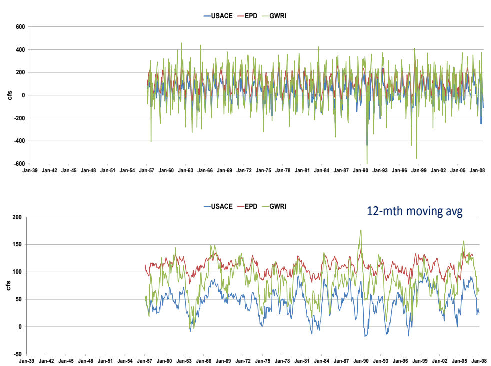

Figure 3.15.10: Net evaporation flows out of J. Woodruff reservoir.

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3.16 Chattahoochee

The Chattahoochee reach is located between the J. Woodruff and Chattahoochee nodes. Summary information for the reach is shown in **Figure 3.16.1**. The reach is very small and only makes a minor contribution to the basinwide flows (less than 1%). This contribution is however not an inflow, but rather a loss since natural inflows are not modeled in this reach. The reason for this is that the streamflows at the upstream J. Woodruff node are not based on the actual releases from J. Woodruff dam. Instead, they are based on the streamflows recorded at the downstream Chattahoochee node. As a result, there are no local unimpaired inflows being assigned to the Chattahoochee reach. However, very small municipal & industrial demands are modeled, resulting in negative unimpaired flows. No pie charts are shown for this reach since the water budget is made up entirely (100%) of the municipal & industrial demands. The EPD dataset does not include unimpaired flows at this location.

3.16.1 Final Unimpaired Flows

The final unimpaired flows are shown in **Figure 3.16.2**. The flows are nearly zero for most of the period of study, though there are a few large spikes.

3.16.2 Observed Streamflow Filling

No observed streamflow filling was used. The upstream and downstream nodes measure streamflows at the same location.

3.16.3 Streamflow Routing

No streamflow routing was used.

3.16.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.16.3** and are very low in magnitude (less than -0.5 cfs).

3.16.5 Agricultural Withdrawals

Agricultural withdrawals are not modeled for this reach in the unimpaired flows.

3.16.6 Net Evaporation

Net evaporation losses are not modeled for this reach.

3.16.7 Discussion

The reach unimpaired flows are zero except for a few spikes reaching up to 750 cfs. It is unclear how these spikes have resulted, since the only data used in the unimpaired flow derivation for this reach pertains to the municipal & industrial withdrawals which do not exhibit such large variations.

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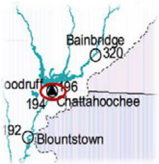

Percent ACF drainage area: 0.3 %
Average contribution to basin-wide UIF*: <1 %
*based on USACE UIFs

Figure 3.16.1: Chattahoochee reach overview.

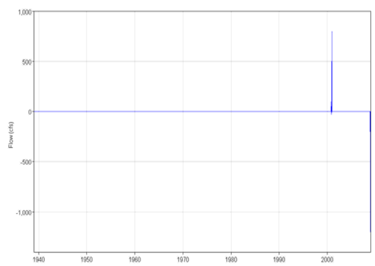

Figure 3.16.2: Chattahoochee reach daily unimpaired flows.

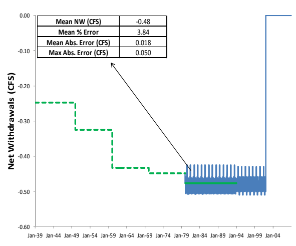

Figure 3.16.3: Chattahoochee reach net municipal & industrial withdrawals.

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3.17 Blountstown

The Blountstown reach is located between the Chattahoochee and Blountstown nodes. Summary information for the reach is shown in **Figure 3.17.1** indicating a basinwide contribution of 2.3%. The unimpaired flows make up the large majority of the water budget, even during dry periods. The EPD dataset does not include unimpaired flows at this location.

3.17.1 Final Unimpaired Flows

The final unimpaired flows are shown in **Figure 3.17.2** and were smoothed using 7 day moving averages. However, negative values are very frequent and very large (up to -45,000 cfs).

Two-year moving averages of the unimpaired flows and average reach precipitation are shown in **Figure 3.17.3**. The unimpaired flows are often negative, even when averaged over two years. There also seems to be a declining trend in the unimpaired flows over time. While there is also a decline in precipitation over time, the unimpaired flows often do not follow the same trends as the precipitation averages, and periods of high precipitation are frequently accompanied by low unimpaired flows, and vice versa.

These observations provide strong evidence that the UIFs are uncertain and possibly contain large errors over a wide range of temporal scales, from daily to decadal.

3.17.2 Observed Streamflow Filling

According to the USACE documentation ,observed streamflows at the upstream (Chattahoochee) and downstream (Blountstown) nodes were available over the whole study period and did not have to be estimated. However, according to the USGS website associated with the gage that was used to specify the Blountstown observed streamflow measurements, data is only available after 1957. It is possible that the USACE maintains their own records, though they were not accessible via the internet.

3.17.3 Streamflow Routing

A Muskingum model was used to route flows from Chattahoochee to Blountstown. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.17.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.17.4** and range between 100 cfs and -100 cfs. They also exhibit abrupt temporal changes and disparate patterns. Analysis of measured and averaged flows in the mid 1990s shows that hindcasts that keep withdrawals constant on a decadal basis introduce errors of up to 100 cfs.

3.17.5 Agricultural Withdrawals

Agricultural withdrawals are shown in **Figure 3.17.5** and are less than 4 cfs.

3.17.6 Net Evaporation

Net evaporation losses are not modeled for this reach.

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3.17.7 Discussion

The unimpaired flows in this reach include frequent large negative values (up to -45,000 cfs) and do not correspond well with the associated precipitation data. Since the withdrawals (agricultural as well as municipal & industrial) are relatively small compared to the unimpaired flows, this implies the existence of large UIF errors and biases across a wide range of temporal scales from daily to decadal. Such errors may be due to unreliable observed streamflow records, unaccounted for withdrawals or other flows (e.g., pumping influences) in and out of this reach. The UIFs in this reach should be revised to remove or at least mitigate these errors and biases.

Significant daily errors and uncertainties can also be introduced by the routing model used in the unimpaired flow derivation. The filled in observed streamflow values in this reach also add significant uncertainties on a daily basis. Alternative estimation procedures of missing values could be considered to mitigate these errors.

The net municipal & industrial withdrawals contain errors that should also be corrected.

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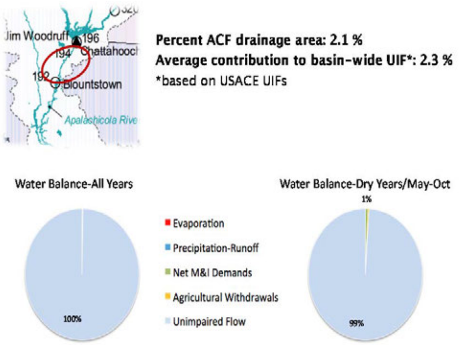

Figure 3.17.1: Blountstown reach overview.

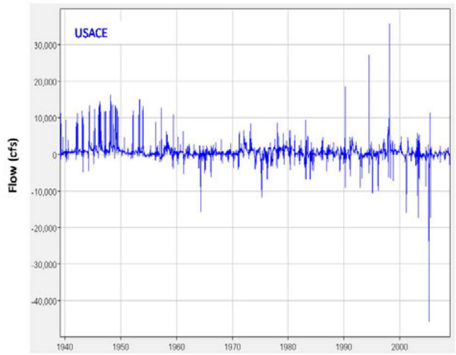

Figure 3.17.2: Blountstown reach daily unimpaired flows.

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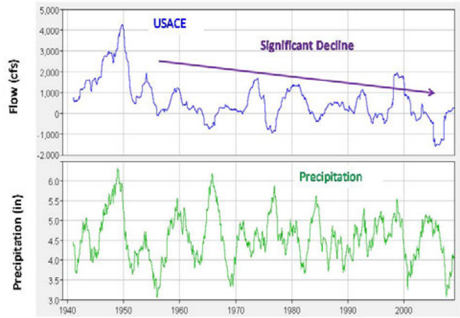

Figure 3.17.3: Two year moving averages of unimpaired flows and precipitation in the Blountstown reach.

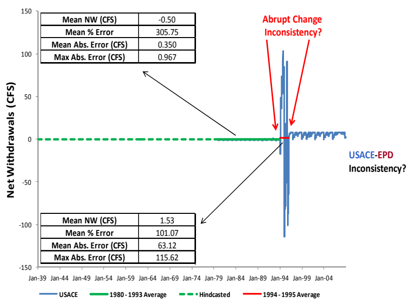

Figure 3.17.4: Blountstown reach net municipal & industrial withdrawals.

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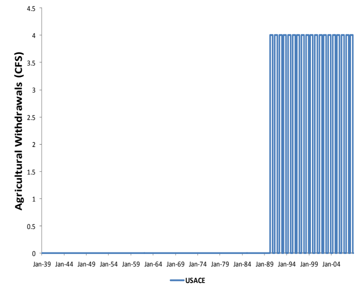

Figure 3.17.5: Blountstown reach agricultural withdrawals.

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3.18 Sumatra

The Sumatra reach is located between the Blountstown and Sumatra nodes. Summary information for the reach is shown in **Figure 3.18.1** indicating a basinwide flow contribution of 13.5%. The unimpaired flows make up the large majority of the water budget, even during dry periods. The EPD dataset does not include unimpaired flows at this location.

3.18.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.18.2** and were smoothed with 7 day centered moving averages. The UIF data series contains many negative values frequently ranging up to -10,000 cfs, and occasionally reaching up to -50,000 cfs.

Two-year moving averages of the unimpaired flows and average reach precipitation are shown in **Figure 3.18.2**. The variability of the unimpaired flows is unnaturally low prior to the early 1950s and between the late 1950s and 1970s. There is also little correspondence with precipitation trends during those time periods and in the period from the mid 1980s to 2000.

These observations provide strong evidence that the Sumatra UIFs contain large systematic errors and biases.

3.18.2 Observed Streamflow Filling

Observed streamflows at the upstream Blountstown node are discussed in the section pertaining to the Blountstown reach. The Sumatra streamflow records, on the other hand, were incomplete and the flows at several time periods were filled in using relationships developed based on the Blountstown streamflow measurements, as shown in **Figure 3.18.3**. The period from 1950 to 1989 was used to calibrate the relationship, which was then used to estimate the streamflows from 1939 to 1950. The errors between the predicted and observed streamflows during the calibration period reveal large daily errors in the range of ±60,000 cfs. The daily error structure also changes over time, with the errors between 1970 and 1976 being smaller on average than the errors during other time periods. Monthly errors are smaller than daily errors, but remain sizeable up to 11,000 cfs.

The missing data filling procedures for the Sumatra streamflow record should be revised to remove or at least mitigate the above systematic errors and biases.

3.18.3 Streamflow Routing

The flow between Blountstown and Sumatra is not always contained within the main river channel during high flow events and may spill over the banks. As a result, flood travel times and attenuations may be significantly different during high flows. A modified Puls model that has different routing behavior for regular and high flows was used to route streamflows from Blountstown to Sumatra. Significant daily errors, including negative unimpaired flows, can result from the routing model since it is an approximation of the true hydraulics and was calibrated without full knowledge of the local inflows to the reach.

3.18.4 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.18.4** and range between ±60 cfs. They also exhibit abrupt temporal changes. Analysis of the differences between measured and

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averaged flows from 1980 to 1993 reveal uncertainties of up to 20-25 cfs are introduced by hindcasts that are kept constant over the span of a decade.

3.18.5 Agricultural Withdrawals

Agricultural withdrawals are shown in **Figure 3.18.5** and are less than 80 cfs.

3.18.6 Net Evaporation

Net evaporation losses are not modeled for this reach.

3.18.7 Discussion

The daily UIFs for this reach contain frequent and large negative values (up to -50,000 cfs). In addition, the two-year moving averages reveal that there are periods when the unimpaired flows remain unnaturally steady and show little correspondence with precipitation. One of these periods occurs prior to 1950 and overlaps with the period when Sumatra streamflow measurements were missing and had to be estimated using Blountstown flows. The other period is between the late 1950s and 1970s. According to the USACE documentation, observed streamflow measurements were available for the Sumatra node during this period and did not have to be estimated. However, according to the USGS website associated with the gage that was used to specify the observed streamflow measurements by USACE, streamflow measurements are only available after 1977. It is unclear how USACE obtained Sumatra streamflow measurements prior to 1977 and whether they are reliable. If the streamflows are not reliable prior to 1977, then the flows between 1950 and 1977 would also have to be estimated. Furthermore, the relationship used to estimate Sumatra streamflows prior to 1950 would also have to be re-evaluated since its calibration period includes the years between 1950 and 1977. A third period where the UIFs do not correspond well with precipitation over the watershed that drains the Sumatra reach is from the mid 1980s to 2000. Further investigation into the reliability of the Sumatra observed flow measurements is highly recommended.

Significant daily errors and uncertainties can also be introduced by the routing model used in the unimpaired flow derivation.

Net M&I withdrawals are relatively small but exhibit abrupt temporal changes and hindcasting errors that should (and can easily) be resolved.

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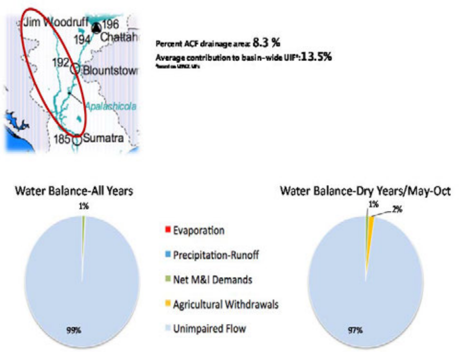

Figure 3.18.1: Sumatra reach overview.

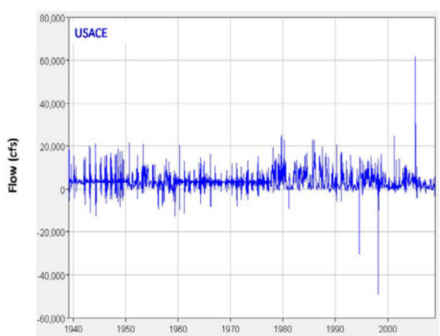

Figure 3.18.2: Sumatra reach daily unimpaired flows.

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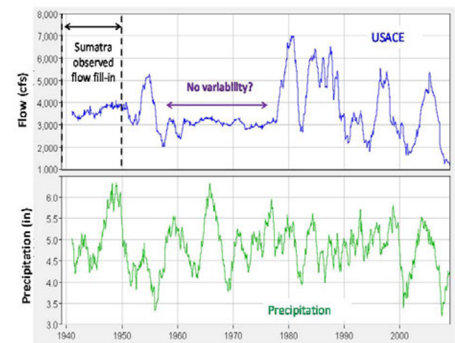

Figure 3.18.3: Two-year moving averages of unimpaired flows and precipitation in the Sumatra reach.

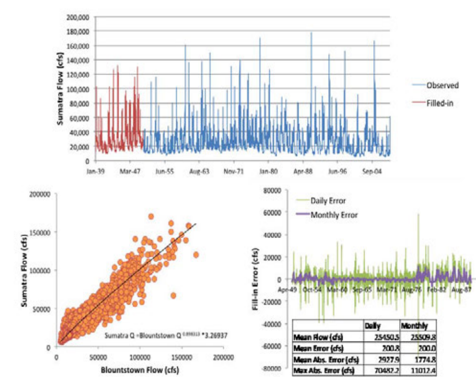

Figure 3.18.4: Estimation of Sumatra node streamflows.

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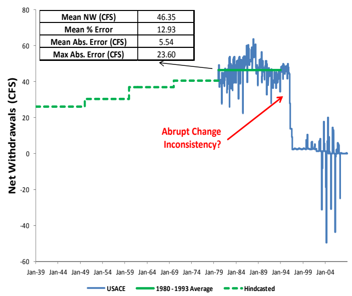

Figure 3.18.5: Sumatra reach net municipal & industrial withdrawals.

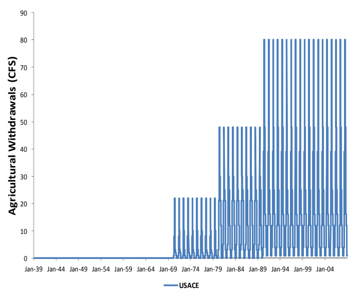

Figure 3.18.6: Sumatra reach agricultural withdrawals.

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3.19 ACF River Basin Summary

Information pertaining to the entire ACF basin was produced in addition to analyses of the unimpaired flows and water budget at the individual nodes. Summary information for the entire ACF basin including all reaches from the headwaters (Buford and Griffin) to the downstream outlet (Sumatra) is shown in **Figure 3.19.1**. The unimpaired flows constitute the largest portion of the water budget. During the dry periods, this portion is still the largest but the relative contributions of the other terms become more significant. Net evaporation losses (evaporation – altered runoff) from the four major federal reservoirs (Lake Lanier, West Point, W.F. George, and J. Woodruff) account for 4% of the water balance, while the agricultural withdrawals and net M&I withdrawals account for 7% and 6%, respectively. **Figure 3.19.2** shows the same water budget when also taking into account tentative estimates of the net evaporation losses from smaller and medium size impoundments in the ACF basin that were not considered during the unimpaired flow development. A discussion of how these losses were estimated is presented in **Appendix B**. Under the assumptions stated in the appendix, the basin-wide net evaporation losses from small and medium impoundments could amount to 6% of the water budget. Overall, **Figure 3.19.2** indicates that the combined amount of net evaporation losses and consumptive water use (i.e., the total basin-wide water abstractions) from May to October during severe droughts is estimated at approximately 22% of the total UIF volume. This percentage would exceed 25% under the EPD net evaporation losses. The impact of other systematic UIF errors would be to increase or decrease this basin-wide water use percentage.

3.19.1 Final Unimpaired Flows

The daily unimpaired flows are shown in **Figure 3.19.3** and represent the cumulative flows occurring in every reach up to and including Sumatra.

Two-year moving averages of the unimpaired flows and average reach precipitation are shown in **Figure 3.19.4**. A comparison between the unimpaired flow and precipitation moving averages reveals that the trends are generally similar but also contain visible inconsistencies.

3.19.2 Municipal & Industrial Withdrawals

The net municipal & industrial withdrawals are shown in **Figure 3.19.5** and range between 50 and 850 cfs. Analysis of the differences between measured and averaged flows from 1980 to 1993 reveal uncertainties of over 300 cfs are introduced by hindcasts that are kept constant over the span of a decade.

3.19.3 Agricultural Withdrawals

Agricultural withdrawals are shown in **Figure 3.19.6**. The data reveals that there has been a significant increase in the agricultural withdrawals starting in the 1970s.

3.19.4 Net Evaporation

The total net evaporation losses occurring at the four major federal reservoirs (Lake Lanier, West Point, W.F. George, and J. Woodruff) are shown in **Figure 3.19.7**. The basin-wide net evaporation losses estimated by EPD are almost twice as high as those estimated by USACE, while the losses estimated by GWRI are in between the EPD and USACE estimates.

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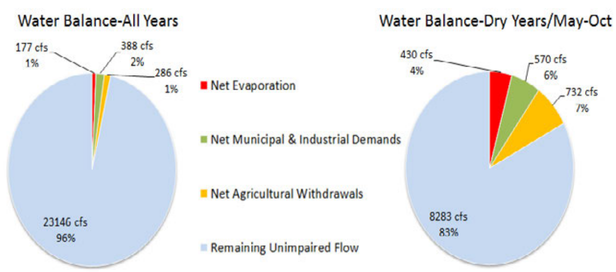

Figure 3.19.1: Entire ACF Basin overview since 1980.

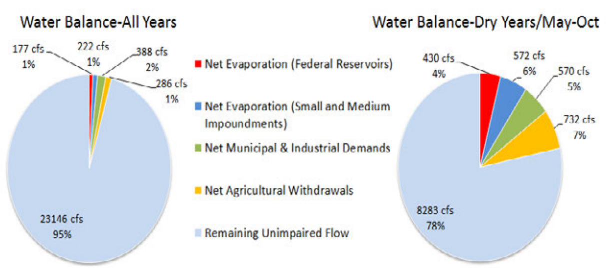

Figure 3.19.2: Entire ACF Basin overview since 1980: includes net evaporation losses from small and medium impoundments.

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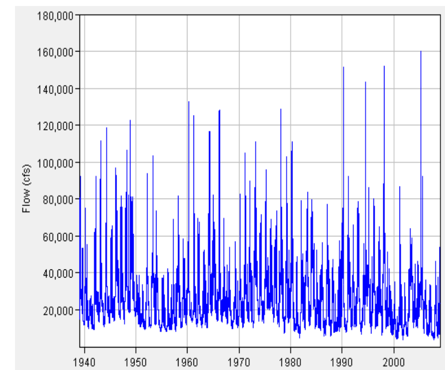

Figure 3.19.3: Entire ACF Basin cumulative daily unimpaired flows.

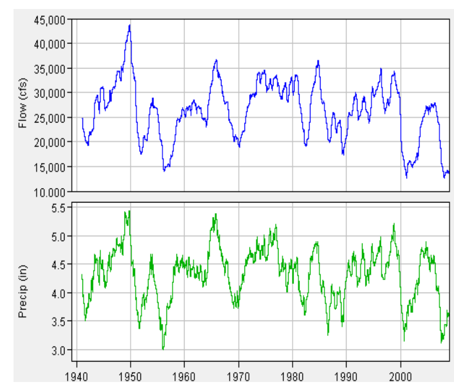

Figure 3.19.4: Two year moving averages of unimpaired flows and precipitation in the entire ACF Basin.

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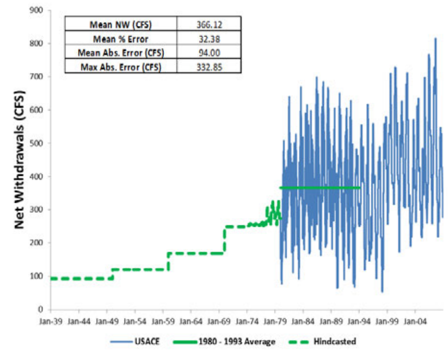

Figure 3.19.5: Entire ACF Basin net municipal & industrial withdrawals.

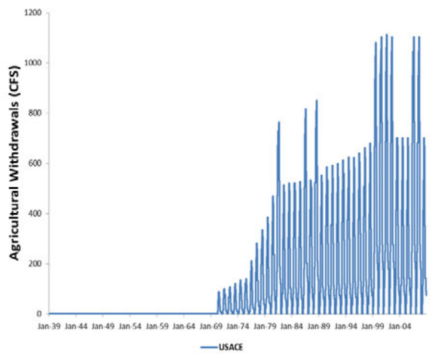

Figure 3.19.6: Entire ACF Basin reach agricultural withdrawals.

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DRAFT UIF Assessment Report | GWRI, October 2012 MAY NOT REFLECT ACFS VIEWS

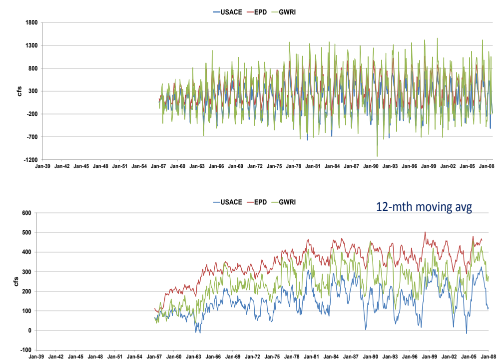

Figure 3.19.7: Total net evaporation losses out of the four major federal reservoirs (Lake Lanier, West Point, W.F. George, J. Woodruff).

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4. Unimpaired Flow Uncertainty Implications for SWMP

The unimpaired flow sequences play a key role in the development of the ACF sustainable water management plan. They represent the hydrologic basis against which alternative development and management options are assessed and compared. The general process comprises several steps:

(i) Identify alternative water development and management plans (including potential infrastructure changes, water use and environmental flow targets, conservation strategies, and operational rules);
(ii) Model these plans through river basin simulation and management tools, such as the ResSim and the ACF-DSS, using the historical UIFs (and possibly future UIFs) as hydrologic inputs;
(iii) Simulate the ACF response for each alternative plan; and
(iv) Assess the relative merits and impacts of the plans against agreed upon performance criteria (and associated metrics) including, among others, provision of reliable water supply for domestic, industrial, and agricultural use; environmental and ecological flow requirements; reservoir level drawdowns; hydropower production; flood protection; navigation access; and recreation opportunities.

Since unimpaired flows serve as the hydrologic basis for these comparisons, their errors and uncertainties may be passed on to the model output variables, potentially biasing the metrics used to assess the relative desirability of alternative water management plans. This chapter aims to supplement the diagnostic, reach-by-reach UIF assessments described earlier by assessing the *cumulative* UIF uncertainty impacts on the basin-wide response.

Major differences between the USACE and EPD UIF sequences are explored first. Additional assessments are then performed by examining the potential sensitivity of the ResSim outputs to the USACE and EPD UIF sequences. The relative differences, if any, quantify the impact of the different assumptions and approximations underlying the development of the UIF sequences.

Further assessments are also performed to quantify the uncertainties that may exist at different temporal scales. All of the ACF unimpaired flow datasets are daily. The ResSim simulation model also operates on a daily time step and therefore generates output at the same temporal resolution. Even though some performance metrics are related to time averages, several others are computed directly from the daily unimpaired flows and model outputs. While time series with daily resolutions make it possible to compute such metrics, uncertainties about the accuracy of these variables remain. As shown in **Table 1.1**, many of the flow datasets used in the unimpaired flow data derivation are only available at coarser resolutions. With the exception of the observed streamflows, which are usually measured on a daily basis, most other quantities are only estimated as weekly, monthly, or even decadal time averages. Furthermore, derivation procedures such as streamflow routing and the estimation of missing streamflows are subject to large daily errors. Flow smoothing and adjustment techniques are also capable of seriously altering the daily character of the unimpaired flows and the values of any other metrics (e.g., ecological flow requirements and ResSim outputs) that depend on them. Several assessments are carried out to determine the time resolution that provides the most reliable information. These assessments are performed for both the unimpaired flows as well as ResSim model outputs to determine their suitability to support the stakeholder metrics.

4.1 Unimpaired Flow Assessments

Two different unimpaired flow datasets are used in the uncertainty assessments. The first dataset corresponds to the latest USACE dataset (1939-2008). The second dataset corresponds to the

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dataset developed by EPD (1939-2007). While each dataset is discussed in detail in Chapters 2 and 3, this section presents assessments aiming to identify major systematic differences between the datasets. Additionally, the USACE dataset is also analyzed for temporal consistency. The suitability of the unimpaired flows at daily time resolution analyses is also examined.

4.1.1 Comparison between USACE and EPD Datasets

Detailed comparisons between the *local* unimpaired flows within each reach are discussed in Chapter 3. Additional comparisons between the *cumulative* unimpaired flows were also performed. (Cumulative unimpaired flows are computed by routing and adding all of the individual local unimpaired flows occurring upstream of a particular node.) The cumulative flows represent river flows that would occur at a certain node if human influences on the water cycle were removed, and provide a natural baseline against which to assess the impacts of human water use and infrastructure.

Figure 4.1.1 shows monthly cumulative unimpaired inflows above the Chattahoochee gage associated with the USACE (blue) and EPD (red) datasets. Even though the USACE and EPD datasets span from 1939 to 2008 and 2007, respectively, the results presented in this section focus on the period from 2002 to 2007. The reason for this is that EPD only performed unimpaired flow derivation for this time period and used previously developed USACE unimpaired flows for the time period prior to 2002. While the USACE and EPD monthly flows at Chattahoochee follow similar patterns, they can be different by up to 3,000 cfs (as shown in the middle plot of **Figure 4.1.1**). The percent differences of the unimpaired flows between the USACE and the EPD datasets are also shown in the bottom plot of **Figure 4.1.1**. The largest percent differences occur in mid to late 2007, when the USACE flows can be over 20% less than the EPD flows. The EPD unimpaired flows are also consistently higher than the USACE for several consecutive months during this time period.

Differences between the USACE and EPD unimpaired flow datasets can arise due to a variety of reasons. First, each dataset was developed using slightly different datasets of flows (withdrawals, net evaporation, etc.) into and out of each individual reach. Furthermore, different adjustments to the unimpaired flows were made to give them a more natural appearance and remove negative values. In fact, when averaged over the entire 2007 year, the EPD unimpaired flows are less than 100 cfs higher than the USACE flows. However, during the period of low flows from mid to late 2007, the EPD flows exceed the USACE flows by 500 cfs on average. Since negative unimpaired flows occur during this time period in several reaches, the adjustments made to remove those negative values in the EPD dataset increased the associated unimpaired flows. The degree to which these *systematic* differences in the unimpaired flows affect ResSim outputs is explored in **Section 4.3**.

The differences between the USACE and EPD unimpaired flows on shorter time scales were also explored. Unimpaired flow sequences for each reach are presented in Chapter 3 and visual analyses of these sequences show large uncertainties on a daily basis. A comparison of the USACE and EPD datasets reveals that the daily values can differ by hundreds, thousands, and even tens of thousands of cubic feet per second. The EPD sequences generally display significantly higher day to day variations. These differences primarily arise due to the fact that different flow adjustment techniques were applied during the development of each dataset. The USACE flows were usually smoothed over several days while the EPD dataset was adjusted to remove negative values where and when they occurred.

Further to the Chapter 3 assessments, the Indicators of Hydrologic Alteration (IHA) software developed by The Nature Conservancy (2009) was used to compare the daily time scale character

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of the EPD and USACE sequences. IHA is a software package that computes a host of statistical streamflow indicators that can be used to assess differences between two hydrologic regimes. **Figure 4.1.2** shows three daily indicators computed based on the USACE and EPD sequences of cumulative unimpaired flows at the Chattahoochee gage in Florida. The number of reversals (instances when the hydrograph switches from rising to falling) is significantly higher for the EPD dataset and the rise and fall rates (differences between flows on consecutive days) are also more extreme under the EPD sequences. Similar differences exist for many other daily statistics and most ACF nodes. These results indicate that the daily characteristics of the USACE and EPD are significantly different.

4.1.2 Consistency of USACE Unimpaired Flows

In addition to the differences between the daily characteristics of the USACE and EPD unimpaired flows, each dataset exhibits inconsistencies over time. These can be visually analyzed by comparing flows at the same location and for the same dataset at two different time periods. **Figure 4.1.3** shows USACE unimpaired flows at Buford for a time period before the reservoir was built (1942-1956) and a time period after the reservoir had already been constructed (1993-2007)[1]. The characteristics of the two hydrographs are visibly different, with the post reservoir hydrographs showing significantly larger short term fluctuations than the pre reservoir hydrograph.

The IHA software was again used to analyze the consistency of the USACE unimpaired flows between the 1942-1956 (pre-reservoir) and 1993-2007 (post-reservoir) periods. **Figure 4.1.4** shows three different daily indicators computed based on pre and post-reservoir sequences. The number of reversals is significantly higher and the rise and fall rates are also more extreme after the construction of the reservoir. Statistical analysis reveals that the average absolute magnitudes of the daily fluctuations (i.e., the flow difference between consecutive days) differ by over 25%. The differences are even more striking for the EPD dataset because the unimpaired flows were not smoothed. The daily fluctuations occurring in the post reservoir period are almost 90% higher on average than the pre reservoir fluctuations. However, when the flows are averaged over a week, the differences are mitigated to less than 5%. Similar results can be observed at most other nodes on the Chattahoochee River for both the local and cumulative (sum of all upstream local) unimpaired flows. The daily unimpaired flow changes on the Flint River are not as drastic between the two time periods.

The daily uncertainties can be partially explained by reviewing how the unimpaired flows were computed. Even though the derivation procedures are identical for the pre and post reservoir periods, the individual flow datasets used in the derivation are different. Before the construction of the reservoirs, the only water budget terms needed for the derivation are streamflow records and estimates of withdrawals. However, water withdrawals during this time period are small and negligible for most reaches. As a result, the only datasets required are observed streamflows for which records exist on a daily basis at many nodes. For the post reservoir (more recent) period, additional flow datasets are needed to quantify net evaporation and reservoir holdouts. Holdouts are usually computed from observations but are subject to measurement errors that may be substantial on a daily basis. Net evaporation rates are estimated from datasets based on monthly or even decadal time scales. Additionally, even though withdrawal measurements are available for most reaches during the post reservoir period, they are often specified on a monthly basis and ignore daily fluctuations. The increased daily fluctuations of the unimpaired flows during the post

[1] The post-reservoir time period was chosen such that average precipitation amounts were similar to those occurring in the pre-reservoir time period. However, additional post-reservoir time periods were also evaluated and yielded similar results.

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reservoir period can therefore be attributed to the fact that the daily fluctuations in some flow datasets are not well represented. As a result, the final unimpaired flow sequences exhibit daily characteristics that deviate significantly from earlier time periods.

4.1.3 Reconstruction of Observed Streamflows

Smoothing techniques were routinely applied to the USACE unimpaired flows in order to dampen excessive daily fluctuations and produce time series with more natural characteristics. However, the smoothed unimpaired flows are not necessarily accurate on a daily basis. In this regard, an assessment was carried out to identify the reliability of the unimpaired flows for different time resolutions based on the concept of reconstructing the historically *observed* streamflows using the unimpaired flows. This approach essentially reverses the procedures used in unimpaired flow development. Instead of deriving unimpaired flows from streamflow records and other datasets of flows into and out of the river system, the derived unimpaired flows are used to reconstruct the observed streamflows and compare them with the *actually* observed values. The reconstruction process consists of taking the local unimpaired flows of a headwater basin and routing them to the next reach outlet. The observed streamflows are then reconstructed by adding the local unimpaired inflows as well as accounting for any other flows that come in or are removed from the system within the reach. This process can then be repeated further downstream by routing the reconstructed observed streamflows to the next reach outlet and again using the local unimpaired inflows and any other fluxes to reconstruct the streamflows at that location. If the unimpaired flows have consistent characteristics then the reconstructed streamflows should be consistent with the observed streamflows at each reach outlet.

Figure 4.1.5 shows comparisons between the observed and reconstructed streamflows at the Whitesburg and Chattahoochee nodes. The reconstructed streamflows are based on the USACE unimpaired flows. The plots reveal that the observed and reconstructed streamflows are significantly different on a daily basis by several thousand cfs. The differences arise due to the fact that the USACE unimpaired flows are smoothed over several days for most reaches. While flow smoothing gives the local unimpaired flows a more natural appearance, it also results in reconstructed streamflows that deviate from the observed streamflow patterns. However, when the flows are averaged over a month, the correspondence improves, as depicted in **Figure 4.1.6**.

4.2 River Simulation and Management Model (ResSim)

The HEC-ResSim (ResSim)[2] management model was used to assess how uncertainties in the unimpaired flows may affect the performance metrics. The model was developed by USACE and spans the entire ACF basin. The facilities considered in the model represent the current system configuration and include the major USACE projects, several non-federal projects, as well as a host of diversion and return locations. The model runs on a daily time step. The system inflows are specified by unimpaired flows and occur at the same nodes that were used to develop the unimpaired flow datasets.

4.2.1 Operational Procedures

Operational procedures represent the procedures used by the USACE to manage the projects in the ACF basin. There are a variety of water uses throughout the basin and the operational procedures are chosen such that all authorized purposes can be met or at least be satisfied to an acceptable level during periods of low water availability. Common authorized water uses include flood control,

[2] Specifically, HEC-ResSim Version 3.1 "Release Candidate 3, Build 42".

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hydropower generation, ecosystem conservation, recreation, water supply, and navigation. Detailed descriptions of authorized water uses and operational procedures in the ACF basin are presented in USACE (2012).

Operational decisions are usually made based on the storages of the major projects (Lake Lanier, West Point, W. F. George and J. Woodruff). Each reservoir is divided into several action zones that correspond to unique ranges of elevation, with Zone 1 being the highest elevation zone and Zone 4 corresponding to the lowest elevation zone. When the reservoir level is in Zone 1, water is allocated to meet all authorized purposes. On the other hand, when the reservoir level is in Zone 4, certain water uses may be curtailed or not supported at all. Zones 2 and 3 represent intermediate conditions for which support for certain uses may be limited. Ideally, the projects are operated to maintain reservoir storage at the top of Zone 1. However, this may not always be possible due to the host of other water uses that need to be met throughout the ACF basin. Furthermore, while each project is assigned (authorized) to support certain uses, the projects are also operated to balance reservoir storage throughout the system. Specifically, the projects are operated such that the reservoir levels for each individual project are kept in the same zones as much as possible.

Certain water uses also depend on basin-wide reservoir storages and inflows, such as the *minimum* discharge required below J. Woodruff, the federal reservoir furthest downstream. The magnitude of this minimum discharge is determined based on (**i**) a composite reservoir storage index, and (**ii**) a basin inflow index. The composite reservoir storage index is currently defined as the sum of the storages of the three major projects (Lake Lanier, West Point and W.F. George). This composite storage is again distinguished in several zones reflecting the total amount of water stored in the basin. The currently defined basin inflow index is the combined *unimpaired* inflows that enter the ACF basin above and including J. Woodruff minus water withdrawals and evaporation losses. As a result, the basin inflow index does not represent unimpaired (natural) inflows but rather unimpaired inflows *adjusted* for the effects of water use withdrawals and reservoir evaporation losses. Furthermore, basin inflows are not computed directly by summing tributary inflows, but rather indirectly by taking the difference between reservoir inflows and discharges throughout the ACF basin. Both daily and 7-day averaged basin inflows are computed, though system operations are primarily based on the 7-day averages (see **Sections 4.2.1.1** and **4.2.1.2**). The final minimum discharge requirements are computed as a function of the composite storage and adjusted basin inflows, with release requirements becoming lower as these indices decrease.

4.2.1.1 Current Operational Procedures

Two different operational procedures were simulated as part of the UIF uncertainty assessments using ResSim. These are described in this and the following sections. The reason for using two operational procedures is to assess whether the degree to which UIF uncertainties impact the system response also depends on the operational procedures.

The first are the *current* operational procedures used by USACE to operate the ACF federal reservoirs. The action zones considered for Lake Lanier, West Point, and W. F. George under the current operations are shown in **Figure 4.2.1**. The zone limits are time varying, with lower zone elevations specified during the wet winter months (reflecting flood protection requirements). The logic used to specify the minimum discharge requirements from the J. Woodruff project is shown in **Table 4.1** and is known as the Revised Interim Operations Plan (RIOP). As shown in **Figure 4.2.2**, there are five composite storage zones (the fifth being the Drought zone) for which the discharge requirements may vary. Within each composite zone, the required release may also be a function of the adjusted 7-day averaged basin inflows, with higher inflows associated with higher release requirements.

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In addition to being subject to minimum discharge requirements, the rate of release from J. Woodruff also has to follow certain patterns. **Table 4.2** shows the maximum fall rates that should not be exceeded at the Chattahoochee gage downstream of J. Woodruff. The fall rate is defined as the drop in the average river stage between two consecutive calendar days. These requirements only apply when the river stage is on a downward trend.

The RIOP also includes a drought operations plan. Drought operations are triggered when the composite storage falls below the bottom of composite storage Zone 3 (see **Figure 4.2.2**). During drought operations, the minimum discharge requirements are no longer dependent on the 7-day averaged basin inflows and are set at 5,000 cfs when the composite storage is in Zone 4 or at 4,500 cfs when the composite storage is in the Drought Zone (see **Table 4.1**). Additionally, the maximum fall rate requirements are no longer binding and "winter pool guide curve" (USACE, 2012) at W.F. George and West Point reservoirs may be temporarily increased to store additional water that could be used to alleviate the severity of the drought. Drought operations stay in effect until the composite storage is larger than the top of composite storage Zone 4. The current operational procedures include a variety of other rules and requirements. A detailed discussion of these procedures is provided in USACE (2010) and USACE (2012).

4.2.1.2 Improved Operational Procedures

A recent USACE report (USACE, 2012) describes alternative operational procedures referred to as "improved" operations. These procedures are *not* currently used to operate the ACF system but are being considered for future implementation.

The improved operational procedures are similar to the current operational procedures, but they also include some differences. One area where the procedures differ is the definition of the reservoir action zones. The new action zones are shown in **Figures 4.2.3**. For Lake Lanier, the minimum elevation of Zone 4 is raised by five feet, thereby allowing for more water in the reservoir when drought operations are initiated. Several changes were also made to the West Point and W. F. George reservoir zones.

The computation of the minimum release requirements was also changed to follow a new procedure termed the modified RIOP (MRIOP). The new composite storage zones are shown in **Figure 4.2.4.**, the composite storage/basin inflow combinations that determine the minimum release requirements are shown in **Table 4.3**. Graphical comparisons between the RIOP and modified RIOP are shown in **Figures 4.2.5**. From March to May, the procedure used to compute the minimum release magnitude remains unaltered. However, the procedures are different from June to November. Under the MRIOP, the release requirements for J. Woodruff are required to be the same as the 7-day averaged basin inflows for a wider range of flows (up to 10,000 cfs as opposed to u 8,000 cfs under the RIOP) if the composite storage is in Zone 1, 2, or 3. The MRIOP release requirements are also different from those mandated by the RIOP for the period from December to February. Under the RIOP, this requirement is 5,000 cfs (regardless of the adjusted basin inflows) when the composite storage is in Zones 1, 2, or 3. This requirement still applies under the MRIOP when basin inflows are below 10,000 cfs. However, it is increased to 10,000 cfs when the basin flows are above this threshold.

The maximum fall rate requirements for the stage at the Chattahoochee gage were also slightly modified under the MRIOP. The new requirements are shown in **Table 4.4.** The rates specified under the RIOP and MRIOP are identical when the J. Woodruff releases are very low or very high, but the rates required when the releases are between 16,000 and 30,000 cfs are slightly different.

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Even though the altered minimum discharge requirements from J. Woodruff seem to have been slightly increased under the MRIOP, the drought operations were modified to avoid excessive storage drawdown and allow for more rapid recovery after a drought. The bottom of the third composite storage zone was raised (see **Figure 4.2.4**) so that drought operations are triggered earlier with more water in the reservoirs than under the RIOP. Once triggered, the drought operations are similar to the original RIOP drought operations. However, one key difference is that drought operations are not suspended until the composite storage has reached the top of composite storage Zone 2. The drought operations therefore stay longer in effect, helping the system recover faster after a drought has occurred.

The MRIOP also includes guidelines to support a navigation season by providing a minimum navigable channel (requiring a flow of around 16,000 cfs based on recent surveys) on the Apalachicola River from January through April. The navigation season will only be supported if the composite storage is in Zone 1 or 2 and if drought operations have not been triggered. The navigation season may be extended until May provided that favorable hydrologic and climatic conditions exist and are expected to continue.

There are other differences between the current and improved operations, including minor changes to the hydropower operations. A detailed discussion is provided in USACE (2012).

4.2.2 Unimpaired flow datasets

Two different unimpaired flow datasets are used in the uncertainty assessments. The first dataset corresponds to the latest USACE dataset (1939-2008). The second dataset corresponds to the dataset developed by EPD (1939-2007). Each of these datasets is discussed in detail in Chapters 2 and 3. Some of the EPD flows were aggregated or disaggregated to be compatible with the USACE node structure since the EPD dataset uses a slightly different spatial representation than the USACE dataset at some locations. Furthermore, because the EPD dataset does not include flows in Florida, the USACE unimpaired flow sequences were used instead.

Each unimpaired flow dataset was used in association with appropriate sequences of net evaporation rates. The USACE dataset uses the net evaporation rates computed by USACE during the unimpaired flow development process, while the EPD dataset employs net evaporation rates calculated by EPD. The procedures and data used to develop these rates are described in Chapters 2 and 3.

Both unimpaired flow datasets were used with the same withdrawal and return datasets corresponding to 2007 water use levels.

4.3 ResSim Output Assessments

Several ResSim runs were carried out to highlight various UIF differences. Four of these runs are discussed in detail below. The first two use the current operational procedures, and the other two use the improved operational procedures. The runs in each set differ in that one uses the USACE UIF series and the other the EPD UIF series. Even though the USACE and EPD datasets span from 1939 to 2008 and 2007, respectively, the ResSim results presented in this section focus on the period from 2002 to 2007. The reason for this is that EPD only performed unimpaired flow derivation for this time period and used previously developed USACE unimpaired flows for the time period prior to 2002. The comparisons aim to assess how differences in the unimpaired flows may manifest themselves in management model outputs.

4.3.1 Current Operational Procedures

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Figures 4.3.1 and **4.3.2** show daily reservoir elevation sequences for Lakes Lanier, West Point, W.F. George, and J. Woodruff. These results correspond to the current operational procedures and either the USACE UIFs (blue lines) or the EPD UIFs (red lines). Differences begin to occur at Lake Lanier starting in mid-2007 (during the most recent drought) when the simulated elevations corresponding to the EPD dataset are up to 2.5 feet higher than those corresponding to the USACE dataset. The elevations at West Point show similar trends with the EPD sequences exceeding those of USACE by up to 4 feet (occasionally) during wet periods and 2 feet during droughts (more systematically). The differences at W. F. George and J. Woodruff are not as pronounced but become more noticeable during the drought period. Frequency curves of daily reservoir elevations are shown in **Figures 4.3.3** and **4.3.4**, with differences mostly associated with the lower and upper extremes. The EPD results also tend to be lower in the middle portion of the frequency distributions, especially for J. Woodruff.

The differences in the reservoir elevations in 2007 are the result of UIF differences. As discussed in **Section 4.1.1** and depicted in **Figure 4.1.1,** the USACE flows can be over 20% less than the EPD flows in 2007 and are also consistently lower for several consecutive months during this time period. These differences result from the different assumptions and adjustments underlying the development of the respective UIF datasets. The higher EPD reservoir levels during the dry periods are largely due to the annual and interannual adjustments made to eliminate negative UIF values. This arbitrary transfer of water from the wet to dry periods leads to higher reservoir levels and more water during droughts to meet water use targets and river flow requirements. As a result, the performance metrics appear to be better than what they actually are. In fact, drought operations were not triggered at all when the EPD sequences were used, while drought operations went into effect in October 2007 for the scenario based on the USACE sequences.

Plots of reservoir releases are shown in **Figures 4.3.5** and **4.3.6**, depicting similar but opposite trends. Starting in the middle of 2007, most releases associated with the USACE dataset tend to be higher than those associated with the EPD dataset, especially at Lake Lanier. During the 2007 drought, Lake Lanier USACE releases exceed EPD releases by as much as 3,500 cfs. This is because Buford is the only reservoir with sufficient storage to supplement the adjusted basin inflows and meet the RIOP release requirement at J. Woodruff. This is not necessary for the EPD sequences because more water is artificially available. The releases at J. Woodruff (**Figure 4.3.6**) for both sequences are similar and equal to the minimum requirements. Prior to 2007, the EPD releases often exceed those of USACE by up to 4,000 cfs at Lanier and up to 15,000 cfs at West Point (**Figure 4.3.5**). Similar daily discrepancies exist at W.F. George and J. Woodruff. The release frequency curves are shown in **Figures 4.3.7** and **4.3.8**. The results are very similar for the lower ends of the distribution. However, these similarities arise due to the fact that each reservoir has minimum release requirements that need to be met. More significant differences between the datasets are visible within other distributional ranges. Comparing the time series plots (**Figures 4.3.5** and **4.3.6**) with the corresponding frequency plots (**Figures 4.3.7** and **4.3.8**), it is worth noting that, by construction, frequency curves obscure day to day differences in the actual time series.

In all, the previous comparisons show that the ResSim reservoir level and release results are sensitive to UIF uncertainties, with the releases exhibiting higher sensitivity levels. The reason for these different sensitivities is that reservoir levels are the outcome of inflows and releases *accumulating* over time, and, as a result, day to day uncertainties are averaged out and mitigated. Thus, reservoir level differences are evidence of persistent and systematic errors in the input variables, while reservoir release differences result from random *and* systematic errors.

Time series of hydropower generation are shown in **Figures 4.3.9** and **4.3.10**, and the associated frequency curves are depicted in **Figures 4.3.11** and **4.3.12**. Daily differences are as high as 1,500

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MWH per day and follow patterns similar to those seen for the reservoir releases. This is expected since hydropower generation depends strongly on discharge (and less on reservoir level).

River flow sequences at selected ACF locations are shown in **Figures 4.3.13** through **4.3.16**. Focusing first on the drought period (2007), significant flow differences can be seen at Atlanta and Columbus between the USACE and EPD ResSim outputs, with the USACE sequences exhibiting higher peak flows. Outside of the drought period, the daily flows are also significantly different (up to several thousand cfs) at all locations. The frequency curves mitigate these day to day differences, especially at low flows when upstream reservoir releases are required to meet the same minimum release targets. Still fewer differences appear at Bainbridge because the Flint flows are unregulated

4.3.2 Improved Operational Procedures

The ResSim reservoir sequences associated with the improved operational procedures are shown in **Figures 4.3.17** through **4.3.20**. The results follow a similar pattern as those associated with the current operations. However, the differences between the USACE and EPD sequences are now larger. Significant differences between the two datasets again appear starting in the mid-2007 when the simulated reservoir elevations corresponding to the EPD dataset are up to 6 feet higher than those corresponding to the USACE dataset.

The daily reservoir releases associated with the USACE dataset are shown in **Figures 4.3.21** through **4.3.24**. During the 2007 drought, the USACE releases from Lake Lanier again tend to be higher (by up to 5,000 cfs) than those associated with the EPD dataset. For earlier times, EPD releases are higher than USACE releases by up to 4,000 cfs at Lanier, 16,000 cfs at West Point, 10,000 cfs at W.F. George, and 13,000 cfs at Woodruff.

Daily hydropower generation sequences are shown in **Figures 4.3.25** through **4.3.28**. During the drought, USACE generation is often higher by up to 1,250 MWH per day, while at other times, EPD generation exceeds that of USACE by similar amounts (following the release discrepancy patterns). The differences are more pronounced for Lake Lanier and West Point. Daily river flow sequences at selected ACF locations are shown in **Figures 4.3.29** through **4.3.32**. Significant flow differences are noted in 2007 at Atlanta and Columbus (of up to 5,000 cfs), with the USACE datasets exhibiting higher flows. Outside of the drought period, the river flows at each location are again significantly different by several thousand cfs with the EPD flows exceeding those of USACE.

Thus, the previous comparisons indicate that the USACE and EPD UIFs lead to significant differences in the ResSim output variables under the improved operational procedures. The differences are exacerbated during droughts where systematic as well as random errors compound.

Lastly, comparing the sequences associated with the two operational procedures, it is important to note that the impact of UIF discrepancies (between the USACE and EPD datasets) increase considerably under improved operations. This is evident by examining **Figures 4.3.1** and **4.3.17** at Lanier. The EPD Lanier levels are higher under improved operations than under current operations, while the USACE Lanier levels are higher under current operations than under improved operations. As a result, the differences between the USACE and EPD Lanier levels are much more exacerbated under improved operations than under current operations. Thus, the impacts of UIF uncertainties on the ResSim outputs (and performance metrics) depend not only on the UIF uncertainties themselves, but also on the operational procedures used to manage the system.

4.3.3 Further Assessments of Daily Uncertainties

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Additional ResSim scenarios were run to assess the reliability of ResSim model outputs at different temporal scales. These assessments pertain to the USACE unimpaired flows and included new UIF scenarios that were not subjected to smoothing. While these flows are developed using the same procedures as the smoothed USACE flows and are similar when viewed on weekly or monthly timescales, they are significantly different on a daily basis. This allows for exploration of the effects that large daily uncertainties may have on ResSim outputs and the metrics based on them. Two new scenarios were created, one corresponding to the current operational procedures and a second corresponding to the improved operational procedures.

Figures 4.3.33 and **4.3.34** compare the reservoir releases resulting from the smoothed and unsmoothed flows. There can be significant daily differences in the daily releases (of up to several thousand cfs), with the releases based on the unsmoothed flows showing more significant short term variations. The simulated streamflows, depicted in **Figures 4.3.35** and **4.3.36**, at several locations throughout the basin exhibit significant differences (of up to 10,000 cfs at Atlanta and Columbus, and 20,000 cfs at Chattahoochee). The associated reservoir elevations at the major projects are shown in **Figures 4.3.37** and **4.3.38**. In general, the average reservoir elevations do not diverge significantly between the two datasets during the drought period in 2007. However, there are some time periods (in 2002 and 2006) when the two datasets result in different drawdowns (up to 1 ft.) at West Point, W.F. George, and J. Woodruff over several months.

Figures 4.3.39 to **4.3.44** depict similar sequences resulting when the improved operational procedures are used to manage the system. The conclusions are similar to those noted for the current operational procedures. The results associated with the unsmoothed flows exhibit wider short term fluctuations than those associated with smoothed flows. There are also a few periods where sustained minor differences occur between the reservoir elevations at West Point, W.F. George, and J. Woodruff. Generally, however, reservoir levels are not greatly impacted by temporally local smoothing operations due to their inherent averaging character.

The simulation results show that daily characteristic of the unimpaired flow sequences affect the daily characteristics of output variables such as reservoir elevations, discharges, and river flows. The assessments show that reservoir releases and river flows are impacted the most. Thus, any performance metrics that are based on daily ResSim outputs will also include significant uncertainties.

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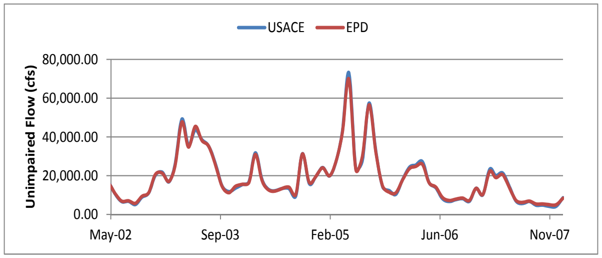
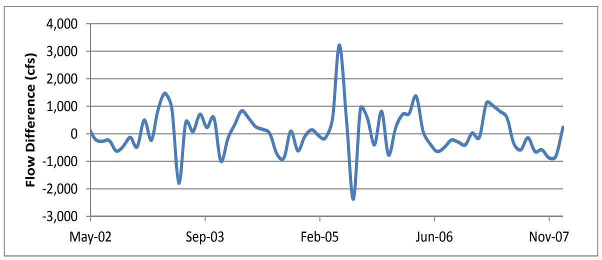
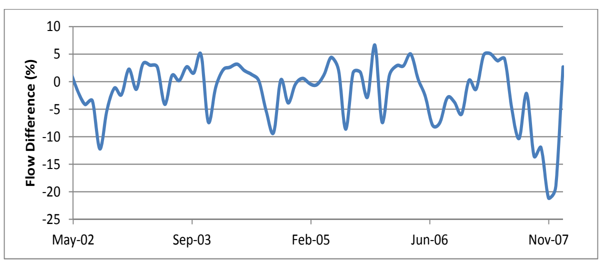


Unimpaired flows



Difference between the USACE and EPD unimpaired flows



Percent difference between the USACE and EPD unimpaired flows

Figure 4.1.1: Monthly basin-wide unimpaired flows upstream of Chattahoochee gage.

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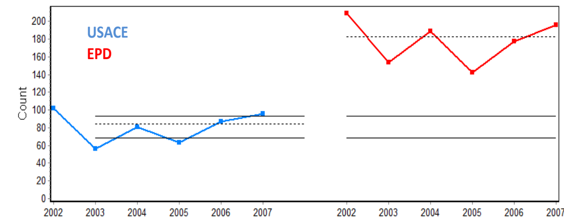
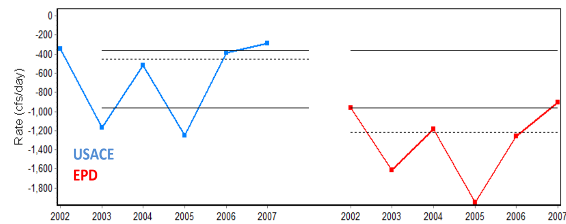
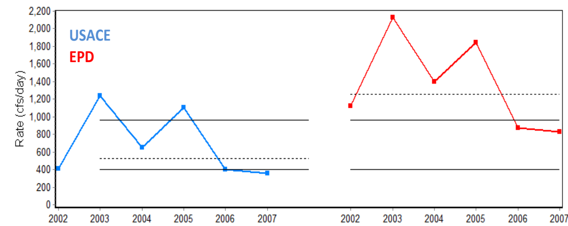


Number of flow reversals per year



Median fall rates



Median rise rates

Figure 4.1.2: IHA indicators for USACE and EPD basin-wide unimpaired flows at Chattahoochee gage. The solid black lines represent the 25th and 75th percentiles of the USACE data, while the dotted black lines represent the medians of the USACE and EPD data. Even though ideally at least 20 years of data should be analyzed, large changes in the median statistics or the frequency with which data points fall in different ranges (below the 25th percentile, between the 25th and 75th percentiles, and above the 75th percentile) indicate significant differences between the USACE and EPD-based hydrologic regimes.

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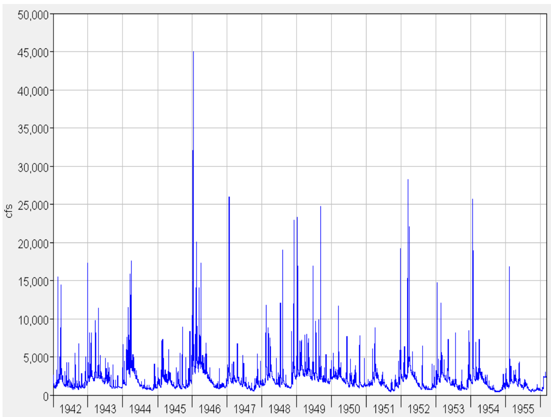
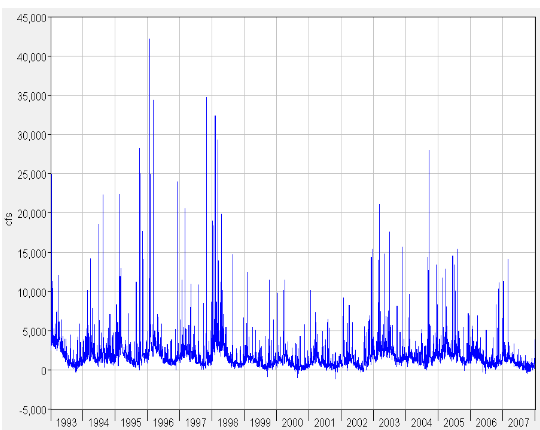


Prior to the construction of Lake Lanier (1942-1956)



After the construction of Lake Lanier (1993-2007)

Figure 4.1.3: Buford reach unimpaired flows prior and after the construction of Lake Lanier.

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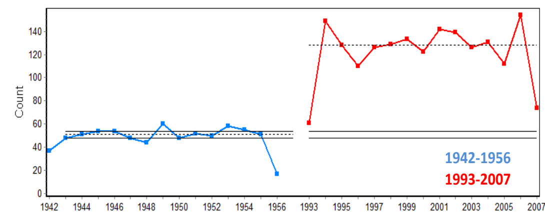
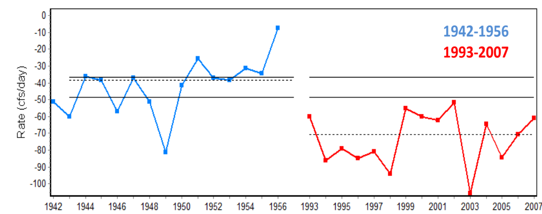
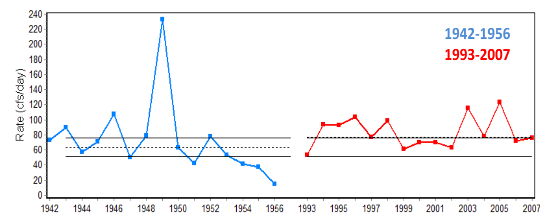


Number of flow reversals per year



Median annual fall rates



Median annual rise rates

Figure 4.1.4: IHA indicators for USACE basin-wide unimpaired flows at Chattahoochee gage. The USACE sequence was split into two periods: 1942-1956 and 1993-2007. The solid black lines represent the 25th and 75th percentiles of the 1942-1956 data, while the dotted black lines represent the medians of the 1942-1956 and 1993-2007 data. Even though ideally at least 20 years of data should be analyzed, large changes in the median statistics or the frequency with which data points fall in different ranges (below the 25th percentile, between the 25th and 75th percentiles, and above the 75th percentile) indicate significant alterations in the hydrologic regimes from the 1942-1956 period to the 1993-2007 period.

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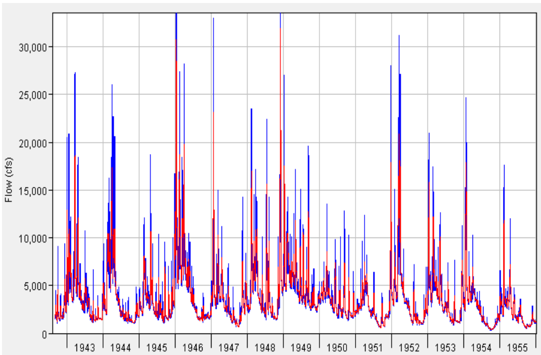
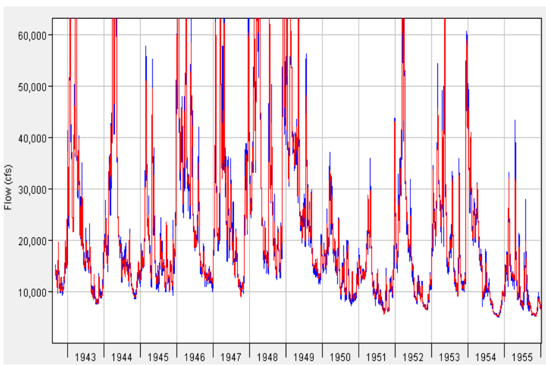


Whitesburg



Chattahoochee

Figure 4.1.5: Observed (blue) and reconstructed (red) daily streamflows

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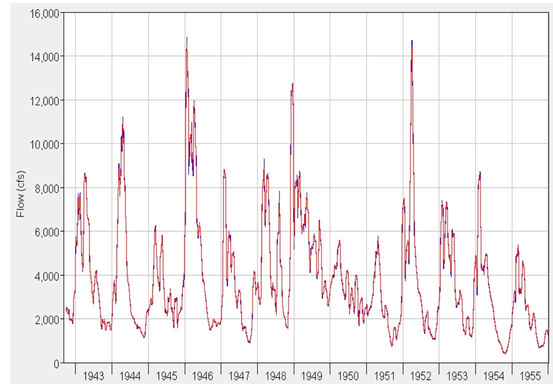
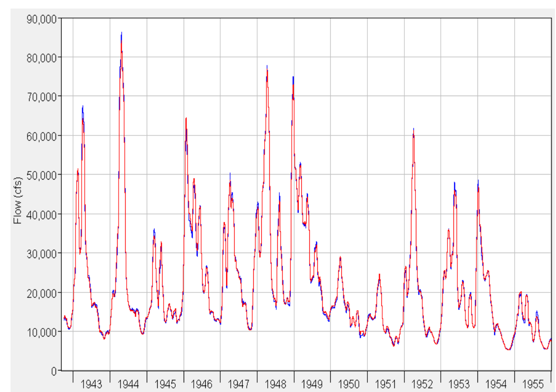


Whitesburg



Chattahoochee

Figure 4.1.6: Observed (blue) and reconstructed (red) monthly streamflows

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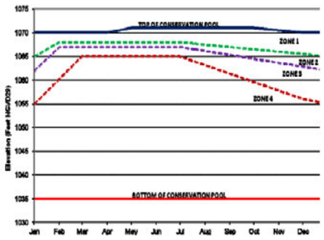
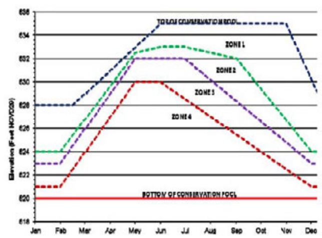
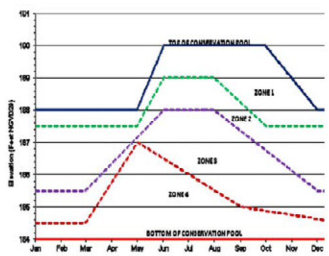


Lake Lanier



West Point



W.F. George

Figure 4.2.1: Action zones for Lakes Lanier, West Point, and W.F. George under the current operational procedures (USACE, 2012).

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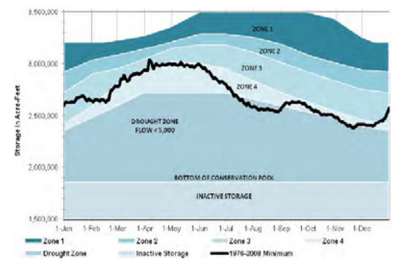

Figure 4.2.2: Composite reservoir storage zones under the current operational procedures (RIOP; USACE, 2012). The composite storage is the sum of the storages at Lakes Lanier, West Point, and W.F. George.

Months	Composite conservation storage zone	Basin inflow (BI) (cfs)	Releases from JWLD (cfs)	BI available for storage[a]
March–May	Zones 1 and 2	>= 34,000	>= 25,000	Up to 100% BI > 25,000
		>= 16,000 and < 34,000	>= 16,000 + 50% BI > 16,000	Up to 50% BI > 16,000
		>= 5,000 and < 16,000	>= BI	
		< 5,000	>= 5,000	
	Zone 3	>= 39,000	>= 25,000	Up to 100% BI > 25,000
		>= 11,000 and < 39,000	>= 11,000 + 50% BI > 11,000	Up to 50% BI > 11,000
		>= 5,000 and < 11,000	>= BI	
		< 5,000	>= 5,000	
June–November	Zones 1, 2, and 3	>= 24,000	>= 16,000	Up to 100% BI > 16,000
		>= 8,000 and < 24,000	>= 8,000 + 50% BI > 8,000	Up to 50% BI > 8,000
		>= 5,000 and < 8,000	>= BI	
		< 5,000	>= 5,000	
December–February	Zones 1, 2, and 3	>= 5,000	>= 5,000 (Store all BI > 5,000)	Up to 100% BI > 5,000
		< 5,000	>= 5,000	
At all times	Zone 4	NA	>= 5,000	Up to 100% BI > 5,000
At all times	Drought zone	NA	>= 4,500[b]	Up to 100% BI > 4,500

Table 4.1: J. Woodruff minimum release requirements under the current operational procedures (USACE, 2012).

Release range (cfs)	Maximum fall rate, measured at Chattahoochee gage (ft/d)
> 30,000[b]	No ramping restriction[c]
> 20,000 and <= 30,000[a]	1.0 to 2.0
Exceeds powerhouse capacity (~ 16,000) and <= 20,000[a]	0.5 to 1.0
Within powerhouse capacity and > 8,000[a]	0.25 to 0.5
Within powerhouse capacity and <= 8,000[a]	0.25 or less

Notes: a. Maximum fall rate schedule is suspended in Composite Zone 4. b. Consistent with safety requirements, flood-control purposes, and equipment capabilities. c. For flows greater than 30,000 cfs, it is not reasonable and prudent to attempt to control the down-ramping rate, and no ramping rate is required.

Table 4.2: Maximum fall rates at Chattahoochee gage under the current operational procedures (USACE, 2012).

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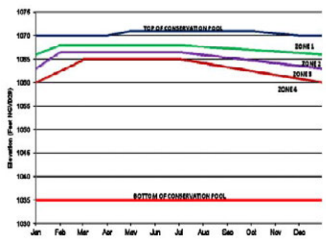
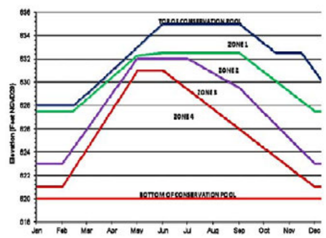
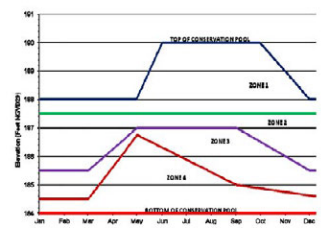


Lake Lanier



West Point



W.F. George

Figure 4.2.3: Action zones for Lakes Lanier, West Point, and W.F. George under the improved operational procedures (USACE, 2012).

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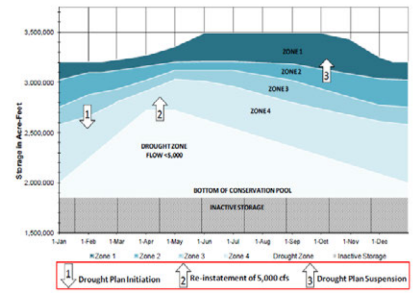

Figure 4.2.4: Composite reservoir storage zones under the improved operational procedures (USACE, 2012). The Composite storage is the sum of the storages at Lakes Lanier, West Point, and W.F. George.

Months	Composite Storage Zone	Basin Inflow (BI) (cfs)	Releases from JWLD (cfs)	Basin Inflow Available for Storage[13]
March - May	Zones 1 and 2	>= 34,000	>= 25,000	Up to 100% BI > 25,000
		>= 16,000 and < 34,000	>= 16,000 + 50% BI > 16,000	Up to 50% BI > 16,000
		>= 5,000 and < 16,000	>= BI	None
		< 5,000	>= 5,000	None – Augment releases from storage
	Zone 3	>= 39,000	>= 25,000	Up to 100% BI > 25,000
		>= 11,000 and < 39,000	>= 11,000 + 50% BI > 11,000	Up to 50% BI > 11,000
		>= 5,000 and < 11,000	>= BI	None
		< 5,000	>= 5,000	None – Augment releases from storage
June - November	Zones 1,2, and 3	>= 22,000	>= 16,000	Up to 100% BI > 16,000
		>= 10,000 and < 22,000	>= 10,000 + 50% BI > 10,000	Up to 50% BI > 10,000
		>= 5,000 and < 10,000	>= BI	None
		< 5,000	>= 5,000	None – Augment releases from storage
December - February	Zones 1,2, and 3	=10,000	>=10,000	100% BI > 10,000
		>= 5,000 and <10,000	>= 5,000	None – Augment releases from storage
At all times	Zone 4	NA	>= 5,000	Up to 100% BI > 5,000
At all times	Drought Zone	NA	>= 4,500[14]	Up to 100% BI > 4,500

Table 4.3: J. Woodruff minimum release requirements under the improved operational procedures (USACE, 2012).

Release range (cfs)	Maximum fall rate, measured at Chattahoochee gage (ft/d)
> 30,000[c]	No ramping restriction[d]
Exceeds powerhouse capacity (~ 16,000) and <= 30,000[a]	Match 1-day basin inflow fall rate
Within powerhouse capacity and > 8,000[a]	0.25 to 0.5
Within powerhouse capacity and <= 8,000[a]	0.25 or less

Notes:
a. Maximum fall rate schedule is suspended in Composite Zone 4.
b. Any changes to the RIOP minimum flows or maximum fall rate provisions resulting from reinitiation of consultation will be incorporated and evaluated.
c. Consistent with safety requirements, flood-control purposes, and equipment capabilities.
d. For flows greater than 30,000 cfs, it is not reasonable and prudent to attempt to control the down-ramping rate, and no ramping rate is required.

Table 4.4: Maximum fall rates at Chattahoochee gage under the improved operational procedures (USACE, 2012).

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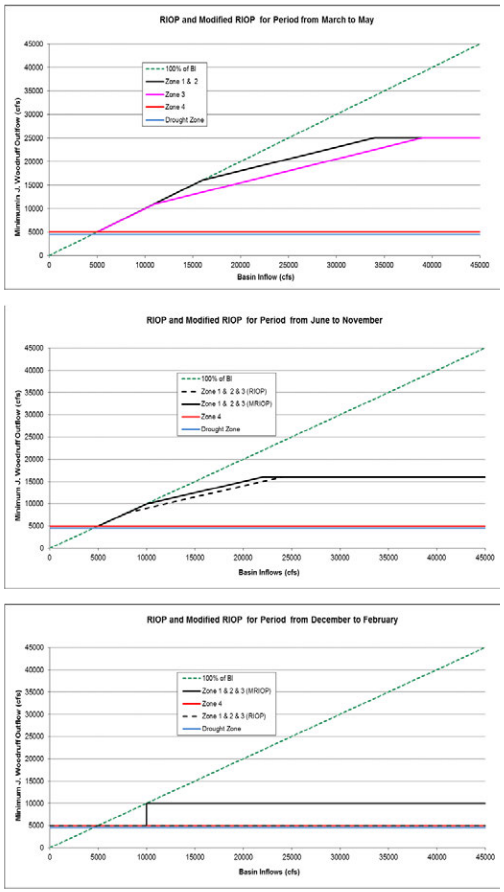

Figure 4.2.5: Comparison between the J. Woodruff minimum discharge requirements for the current (RIOP) and improved or modified RIOP (MRIOP) operations sets.

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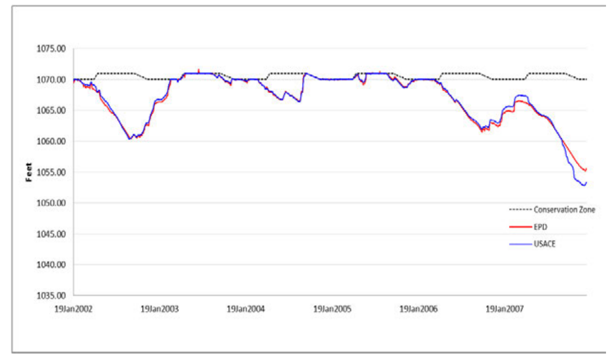
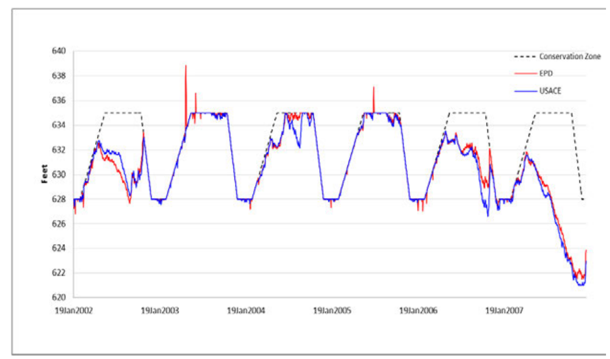


Lake Lanier



West Point

Figure 4.3.1: Daily reservoir elevation sequences for Lakes Lanier and West Point corresponding to the current operational procedures.

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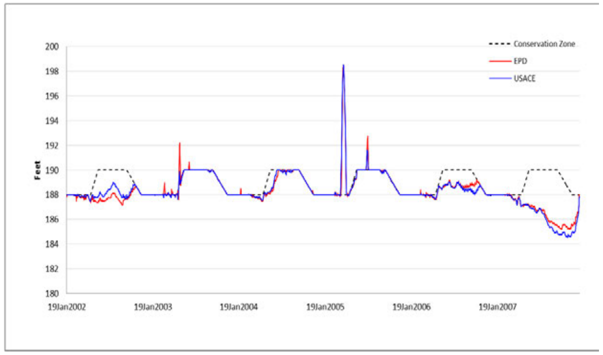
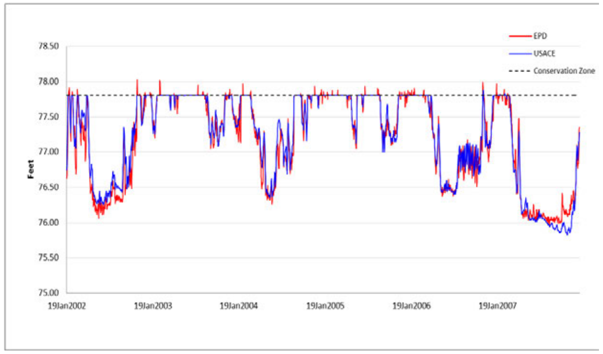


W.F. George



J. Woodruff

Figure 4.3.2: Daily reservoir elevation sequences for W.F. George and J. Woodruff corresponding to the current operational procedures.

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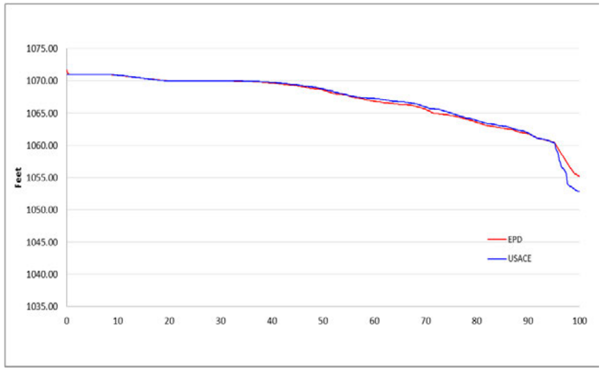
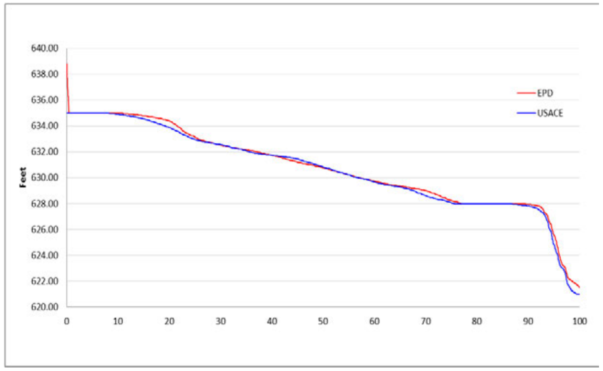


Lake Lanier



West Point

Figure 4.3.3: Frequency curves of daily reservoir elevations for Lakes Lanier and West Point corresponding to the current operational procedures.

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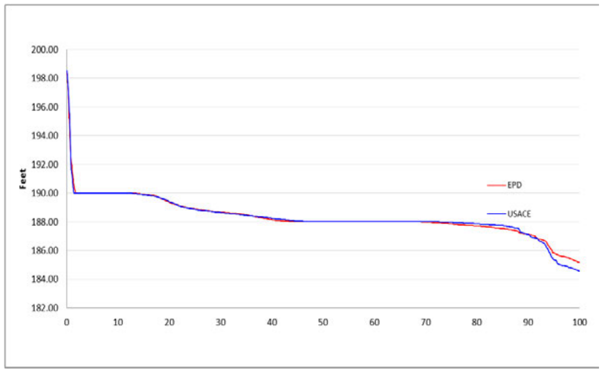
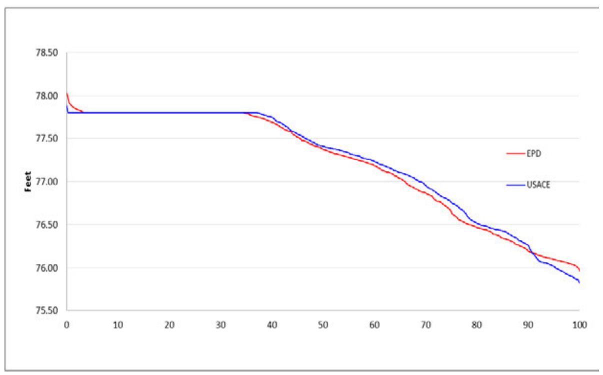


W.F. George



J. Woodruff

Figure 4.3.4: Frequency curves of daily reservoir elevations for W.F. George and J. Woodruff corresponding to the current operational procedures.

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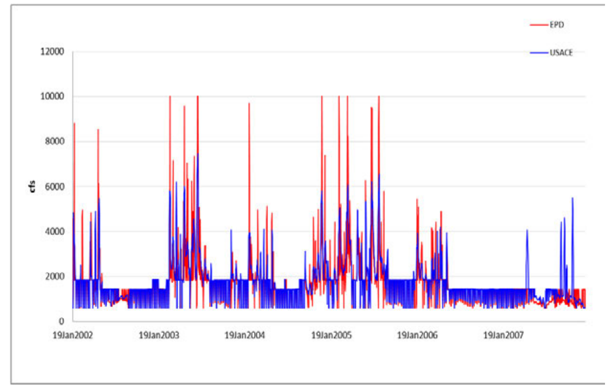
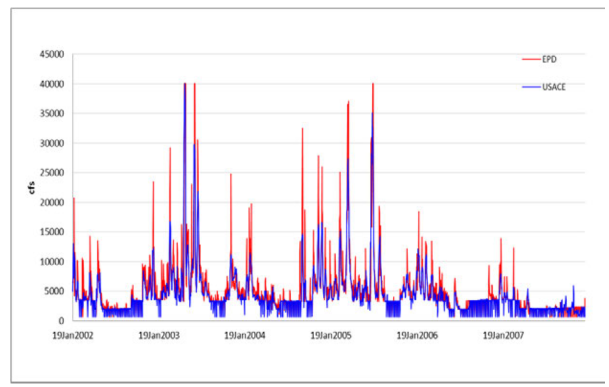


Lake Lanier



West Point

Figure 4.3.5: Daily reservoir release sequences for Lakes Lanier and West Point corresponding to the current operational procedures.

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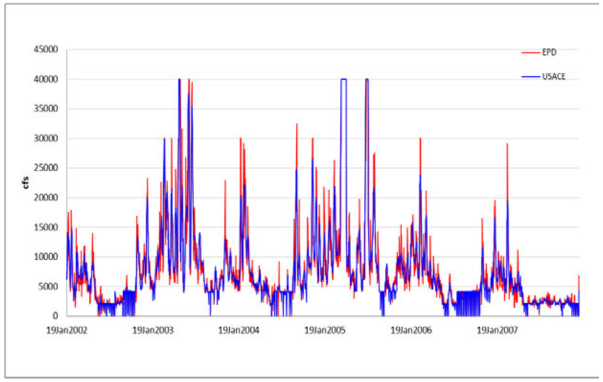
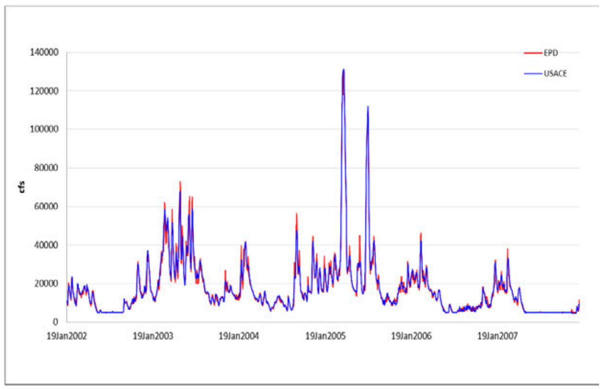


W.F. George



J. Woodruff

Figure 4.3.6: Daily reservoir release sequences for W.F. George and J. Woodruff corresponding to the current operational procedures.

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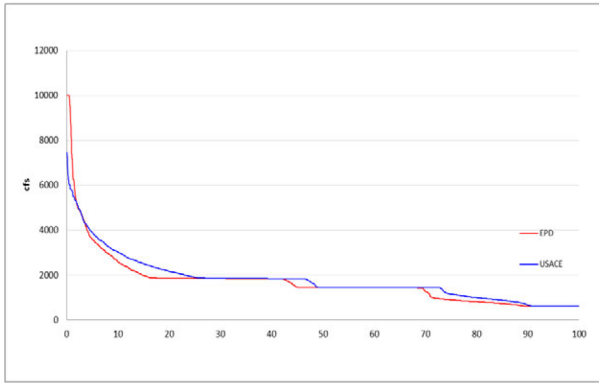

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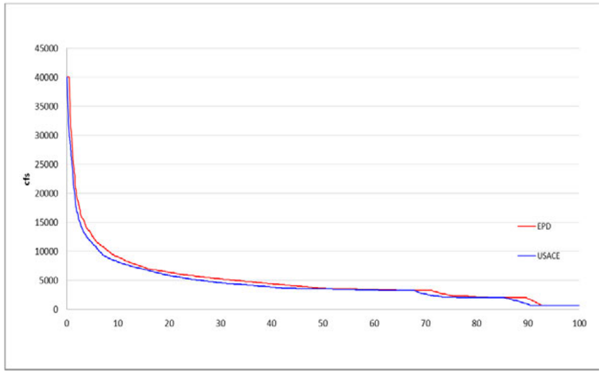

West Point

Figure 4.3.7: Frequency distributions of daily reservoir releases for Lake Lanier and West Point corresponding to the current operational procedures.

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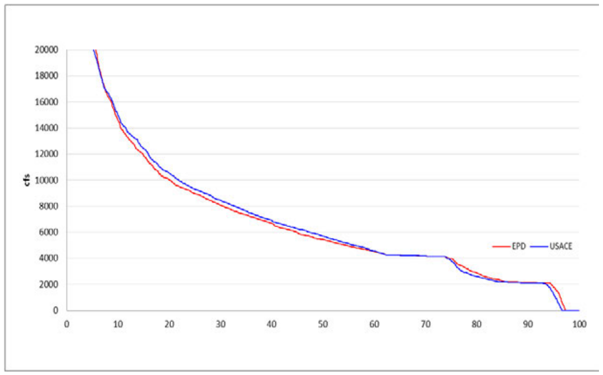
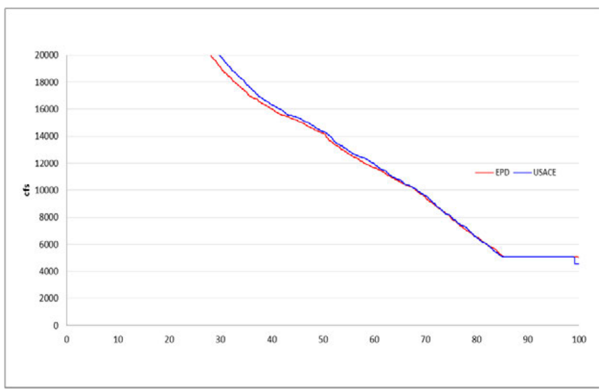


W.F. George



J. Woodruff

Figure 4.3.8: Frequency distributions of daily reservoir releases for W.F. George and J. Woodruff corresponding to the current operational procedures.

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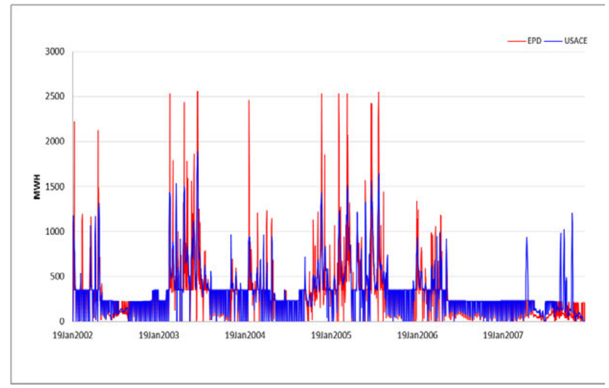
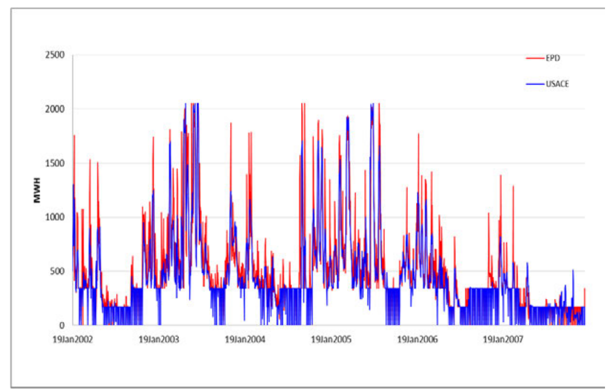


Lake Lanier



West Point

Figure 4.3.9: Daily hydropower generation sequences for Lakes Lanier and West Point corresponding to the current operational procedures.

Turner, Billy

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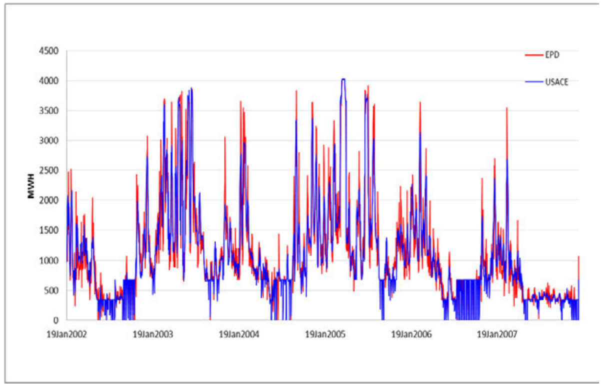
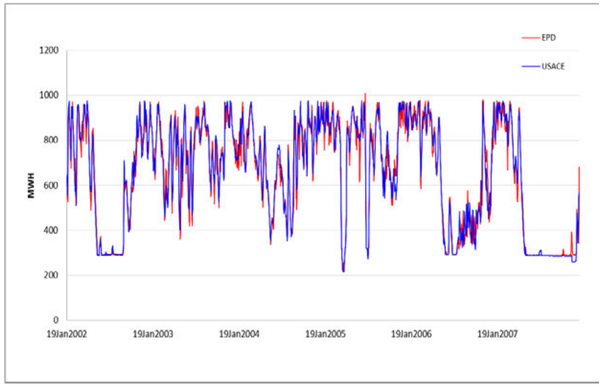


W.F. George



J. Woodruff

Figure 4.3.10: Daily hydropower generation sequences for W.F. George and J. Woodruff corresponding to the current operational procedures.

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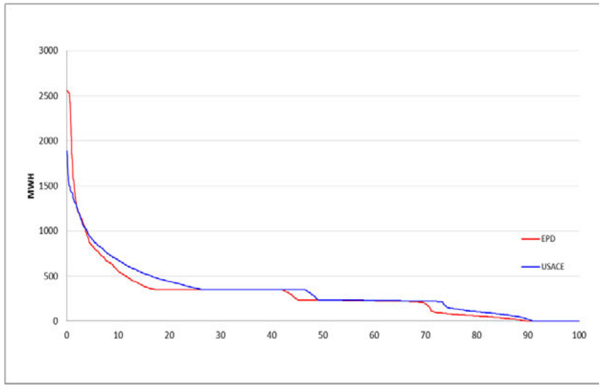
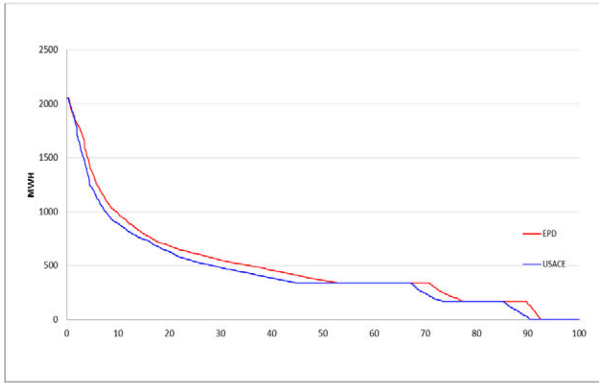


Lake Lanier



West Point

Figure 4.3.11: Frequency distributions of daily hydropower generation for Lakes Lanier and West Point corresponding to the current operational procedures.

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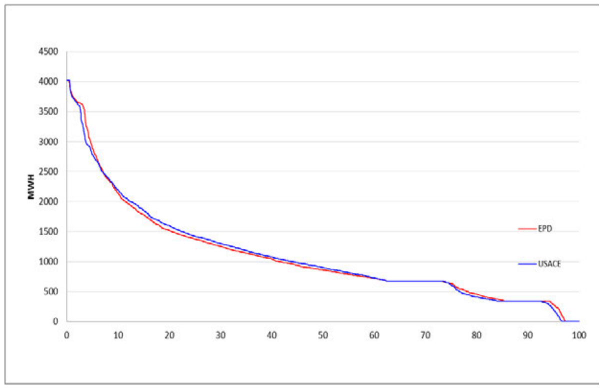
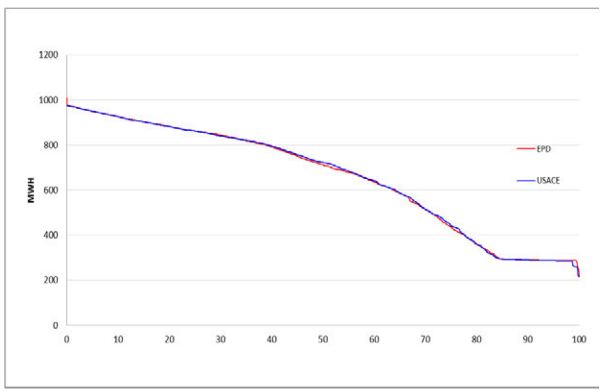


W.F. George



J. Woodruff

Figure 4.3.12: Frequency distributions of daily hydropower generation for W.F. George and J. Woodruff corresponding to the current operational procedures.

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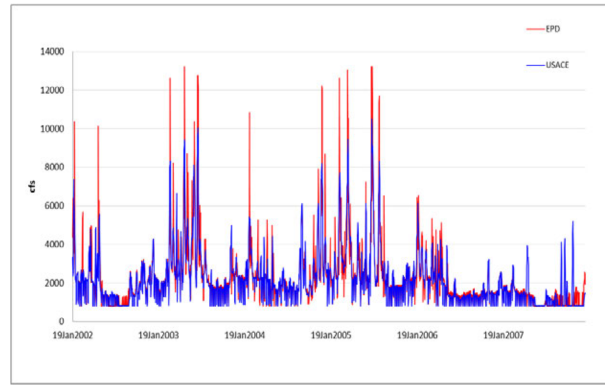
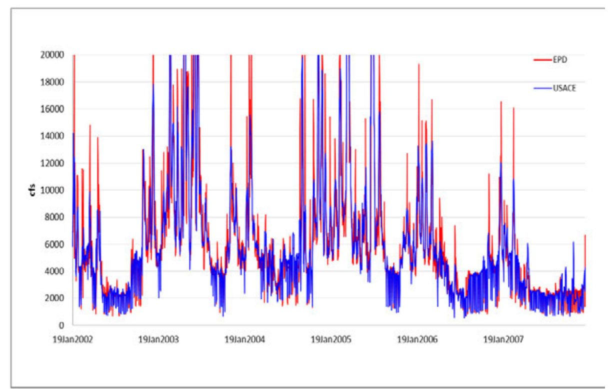


Atlanta



Columbus

Figure 4.3.13: Daily river flow sequences at Atlanta and Columbus corresponding to the current operational procedures.

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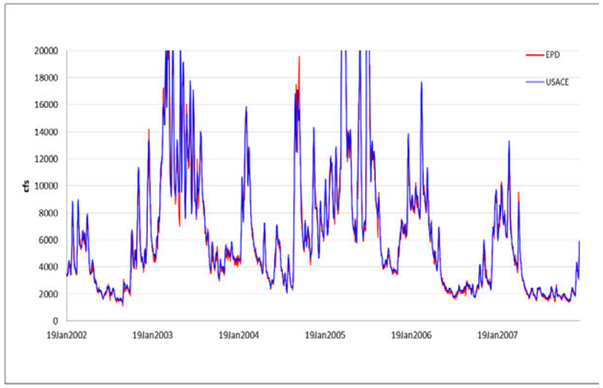
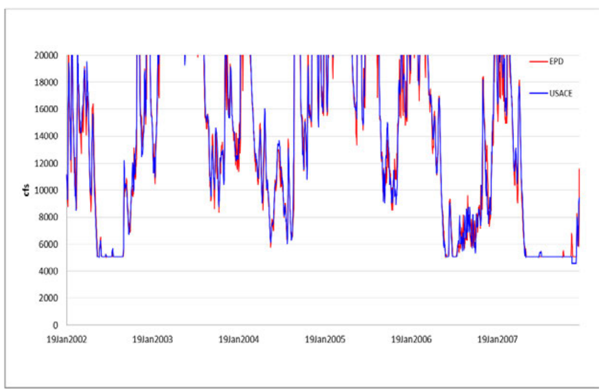


Bainbridge



Chattahoochee

Figure 4.3.14: Daily river flow sequences at Bainbridge and Chattahoochee corresponding to the current operational procedures.

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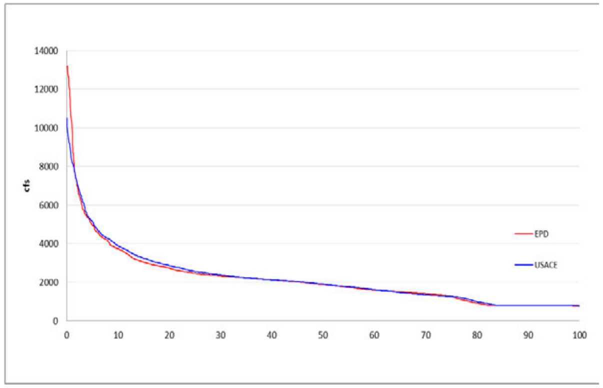

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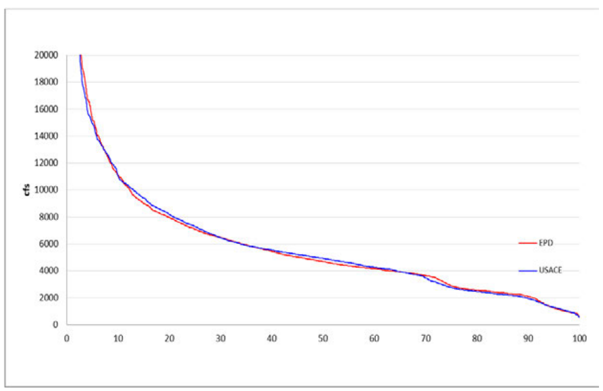

Columbus

Figure 4.3.15: Frequency distributions of daily river flows at Atlanta and Columbus corresponding to the current operational procedures.

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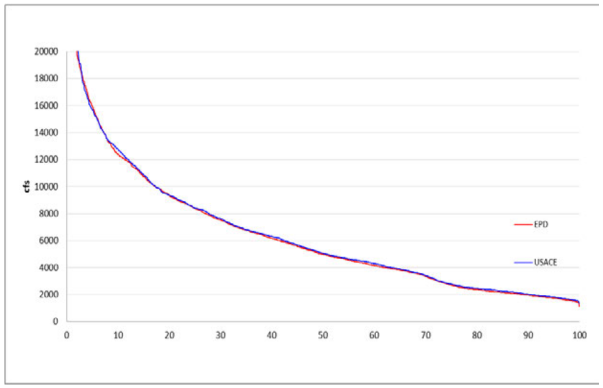
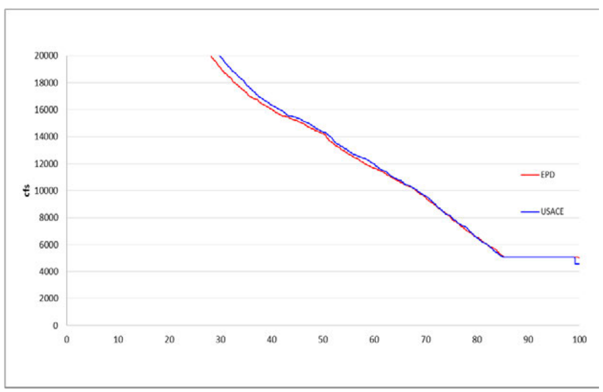


Bainbridge



Chattahoochee

Figure 4.3.16: Frequency distributions of daily river flows at Bainbridge and Chattahoochee corresponding to the current operational procedures.

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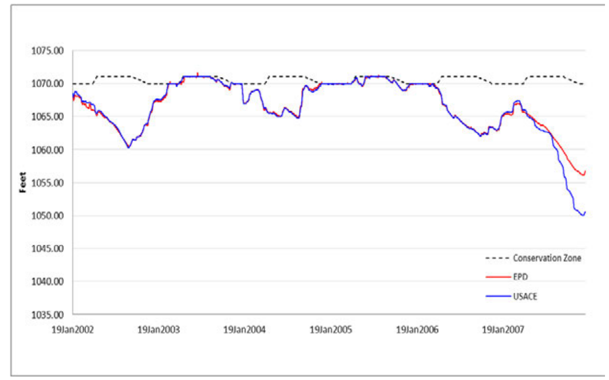
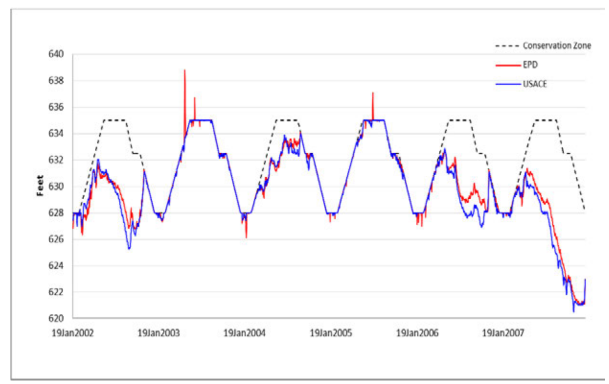


Lake Lanier



West Point

Figure 4.3.17: Daily reservoir elevation sequences for Lakes Lanier and West Point corresponding to the improved operational procedures.

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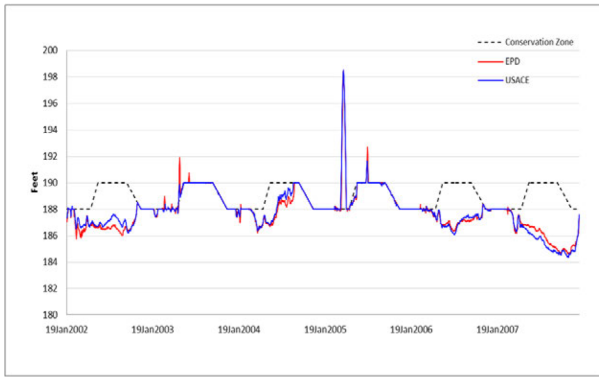
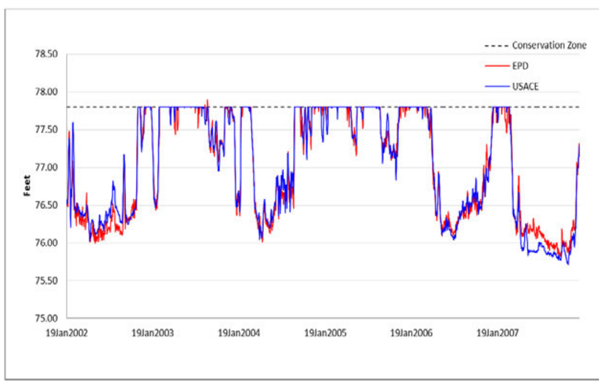


W.F. George



J. Woodruff

Figure 4.3.18: Daily reservoir elevation sequences for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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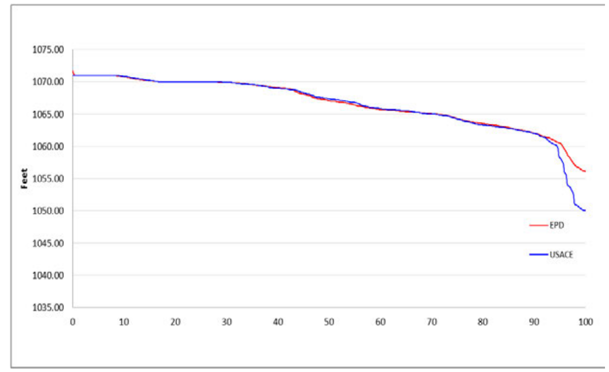
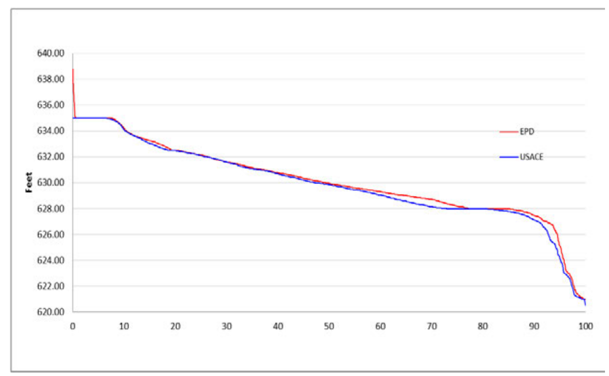


Lake Lanier



West Point

Figure 4.3.19: Frequency curves of daily reservoir elevations for Lakes Lanier and West Point corresponding to the improved operational procedures.

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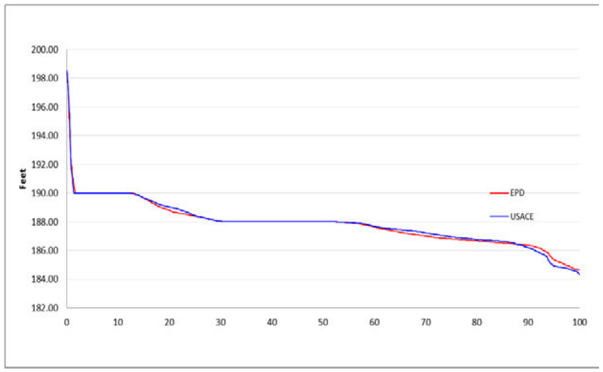
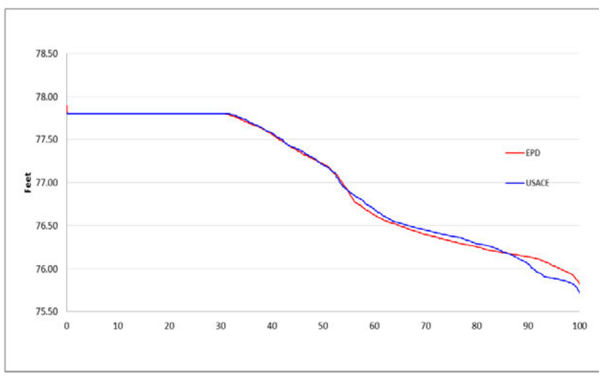


W.F. George



J. Woodruff

Figure 4.3.20: Frequency curves of daily reservoir elevations for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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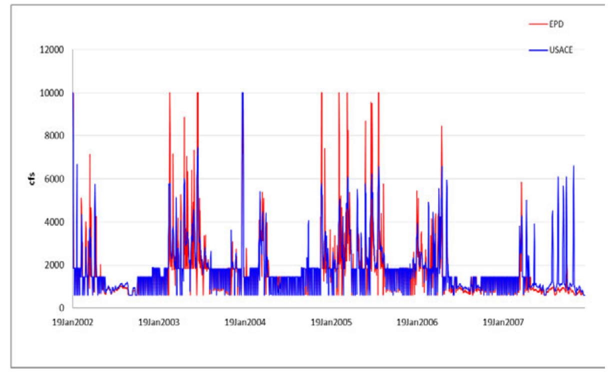
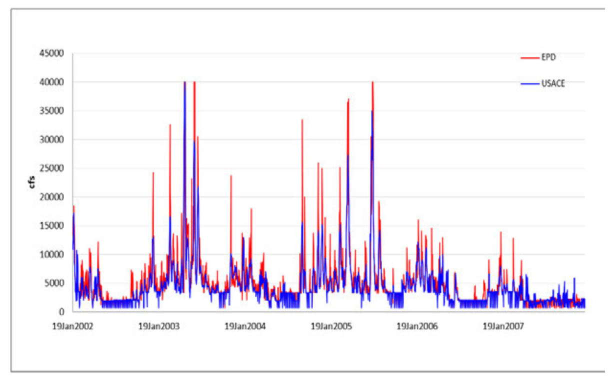


Lake Lanier



West Point

Figure 4.3.21: Daily reservoir release sequences for Lakes Lanier and West Point corresponding to the improved operational procedures.

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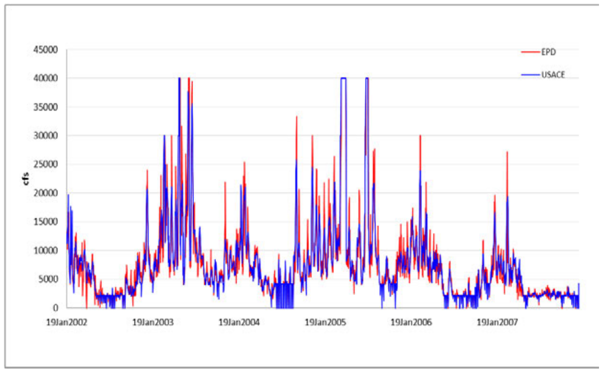
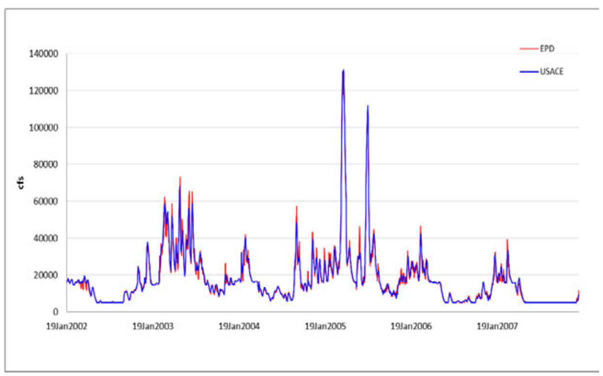


W.F. George



J. Woodruff

Figure 4.3.22: Daily reservoir release sequences for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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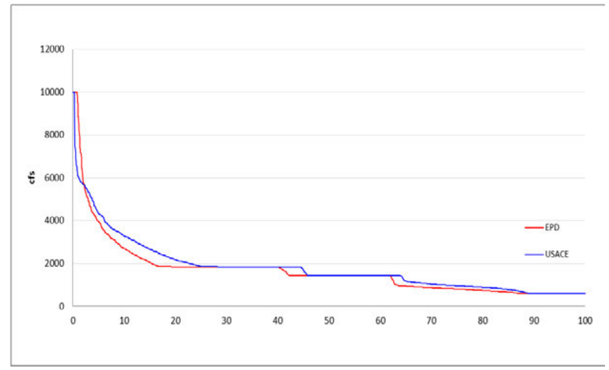
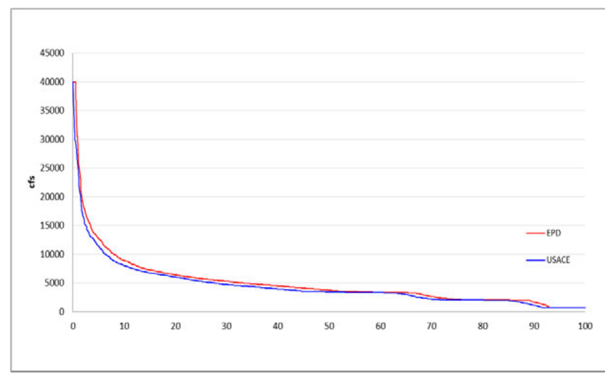


Lake Lanier



West Point

Figure 4.3.23: Frequency distributions of daily reservoir releases for Lakes Lanier and West Point corresponding to the improved operational procedures.

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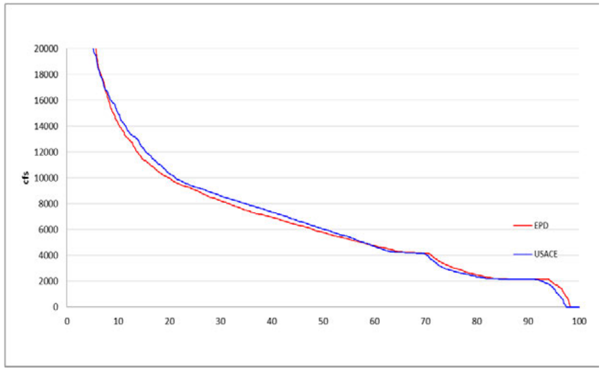
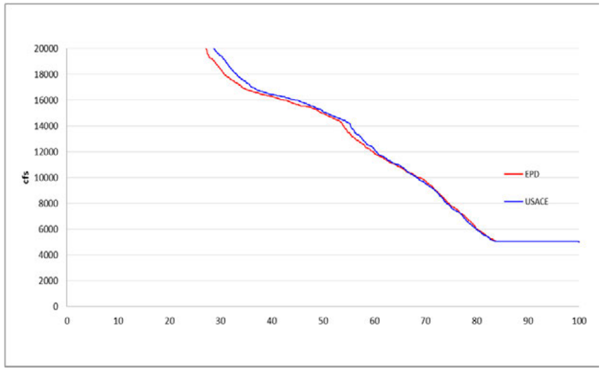


W.F. George



J. Woodruff

Figure 4.3.24: Frequency distributions of daily reservoir releases for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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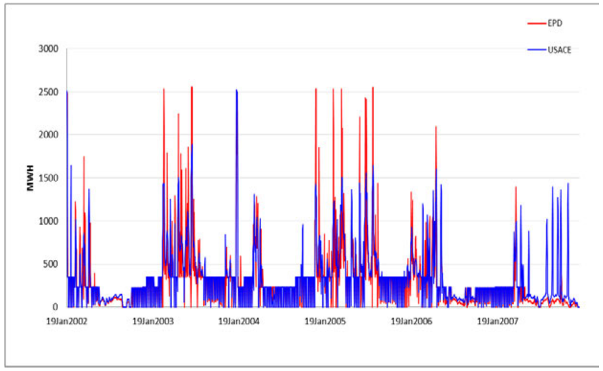
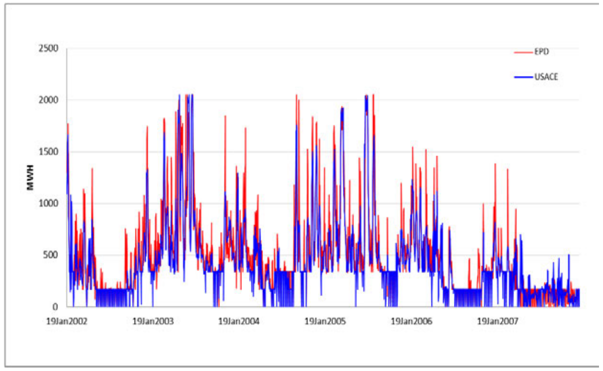


Lake Lanier



West Point

Figure 4.3.25: Daily hydropower generation sequences for Lakes Lanier and West Point corresponding to the current operational procedures.

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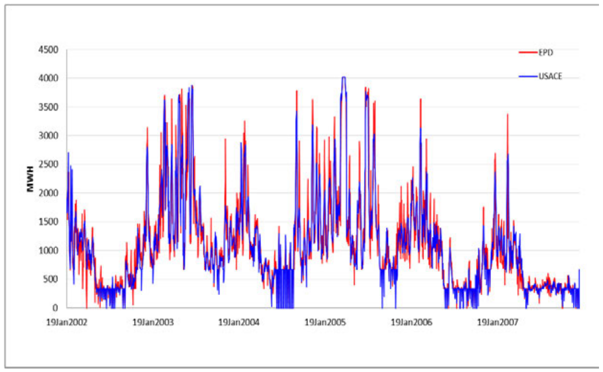
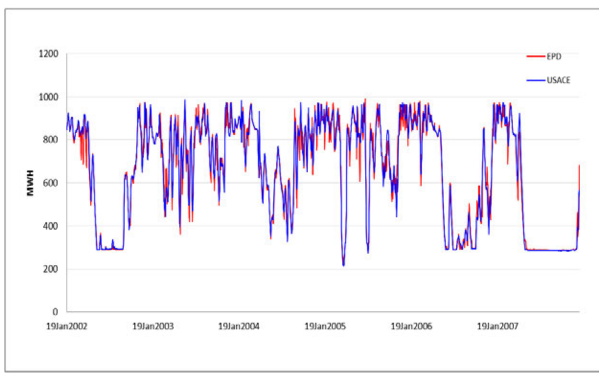


W.F. George



J. Woodruff

Figure 4.3.26: Daily hydropower generation sequences for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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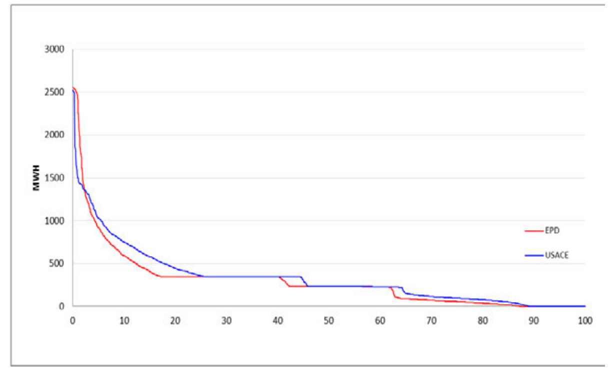
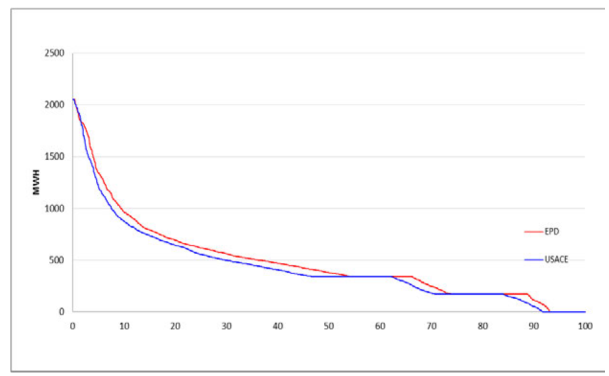


Lake Lanier



West Point

Figure 4.3.27: Frequency distributions of daily hydropower generation for Lakes Lanier and West Point corresponding to the improved operational procedures.

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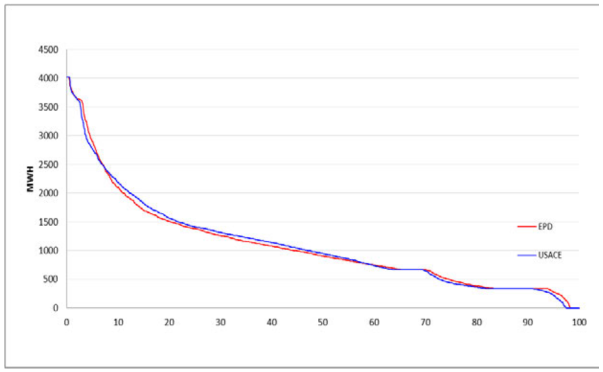
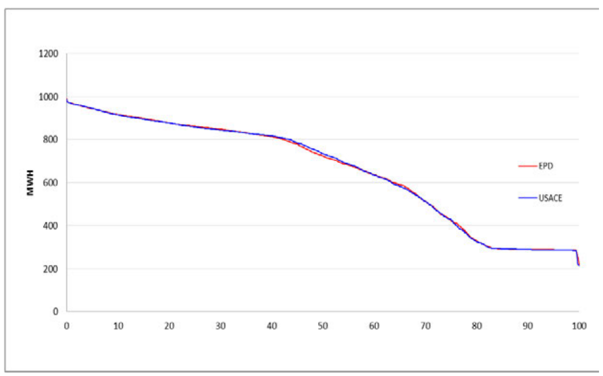


W.F. George



J. Woodruff

Figure 4.3.28: Frequency distributions of daily hydropower generation for W.F. George and J. Woodruff corresponding to the improved operational procedures.

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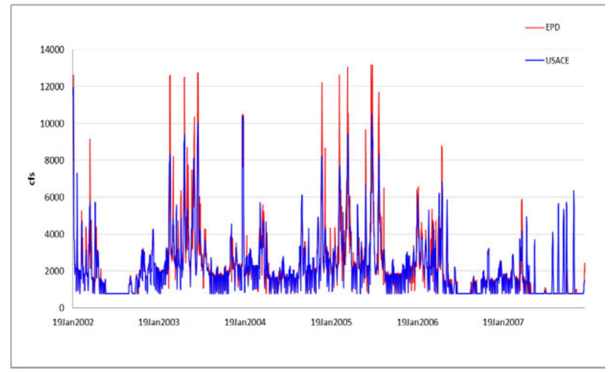
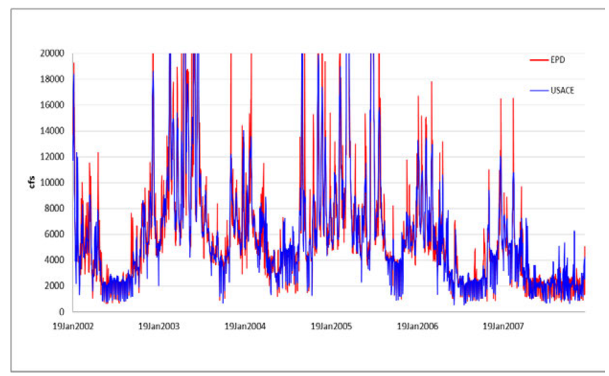


Atlanta



Columbus

Figure 4.3.29: Daily river flow sequences at Atlanta and Columbus corresponding to the improved operational procedures.

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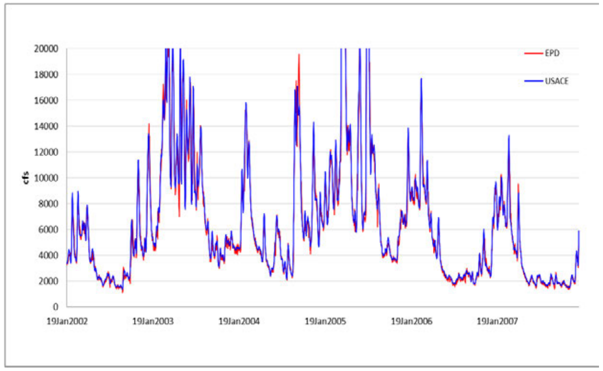
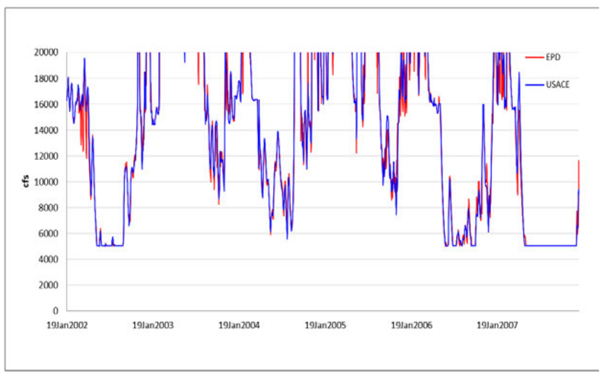


Bainbridge



Chattahoochee

Figure 4.3.30: Daily river flow sequences at Bainbridge and Chattahoochee corresponding to the improved operational procedures.

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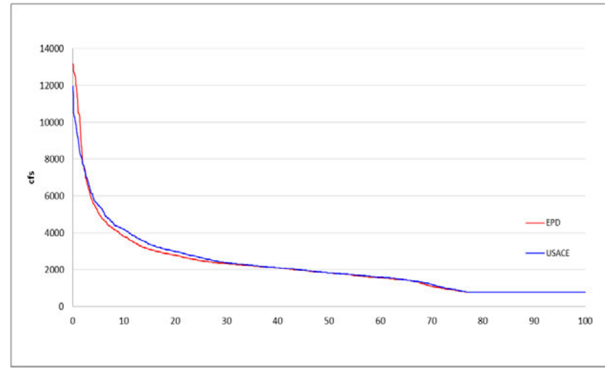
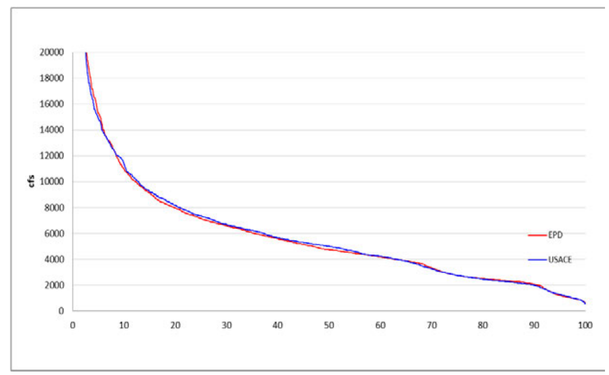


Atlanta



Columbus

Figure 4.3.31: Frequency distributions of daily river flows at Atlanta and Columbus corresponding to the improved operational procedures.

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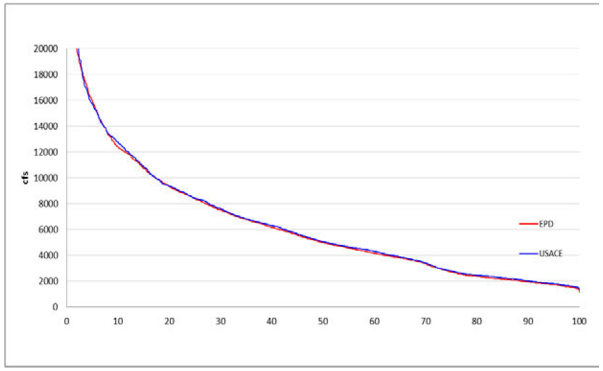

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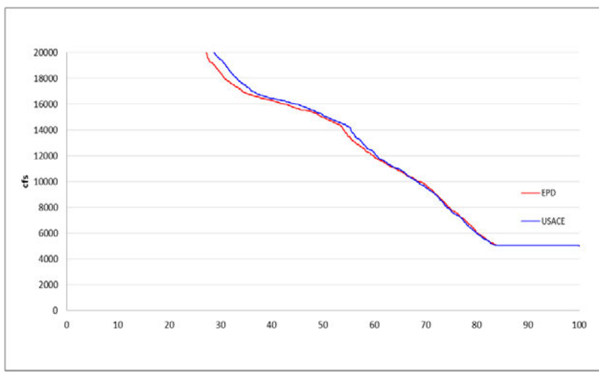

Chattahoochee

Figure 4.3.32: Frequency distributions of daily river flows at Bainbridge and Chattahoochee corresponding to the improved operational procedures.

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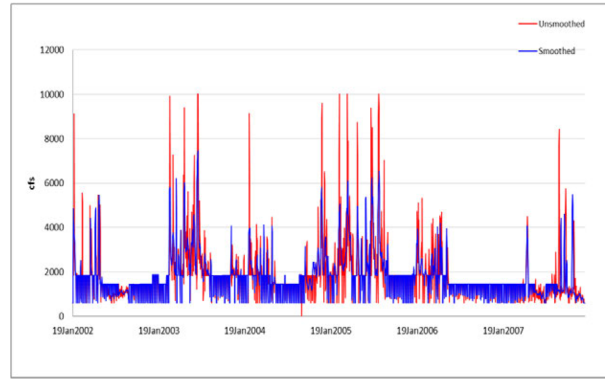
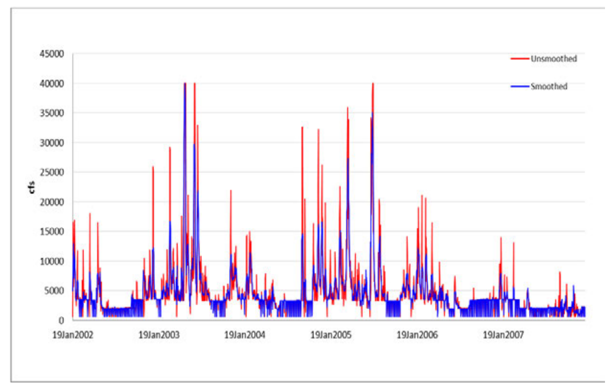


Lake Lanier



West Point

Figure 4.3.33: Reservoir release sequences for Lakes Lanier and West Point associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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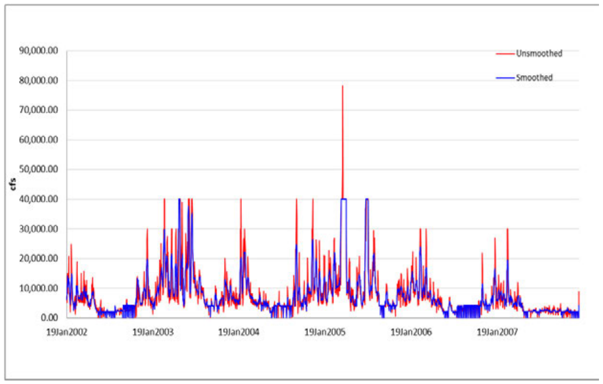
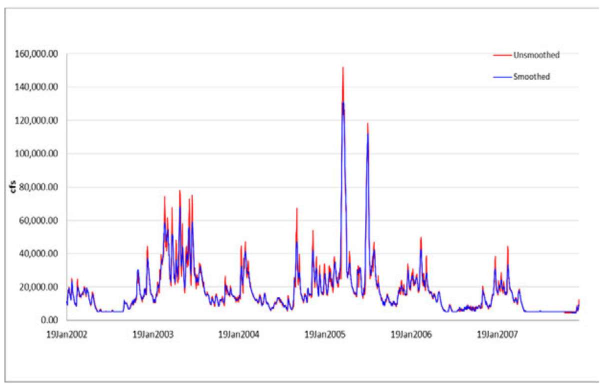


W.F. George



J. Woodruff

Figure 4.3.34: Reservoir release sequences for W.F. George and J. Woodruff associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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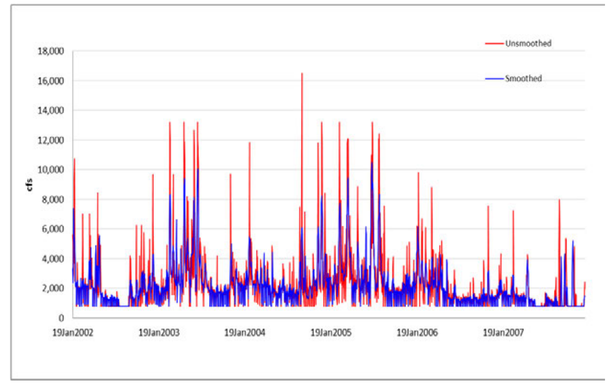
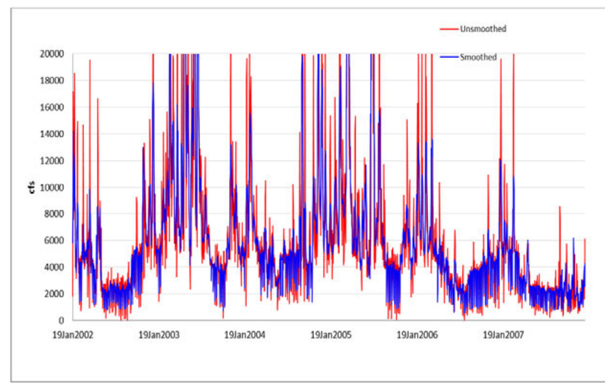


Atlanta



Columbus

Figure 4.3.35: River flow sequences for Atlanta and Columbus resulting from smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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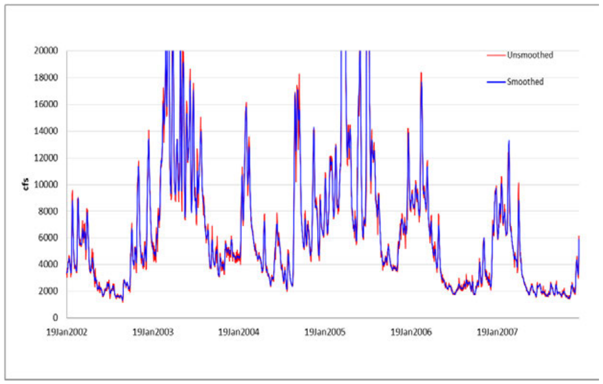
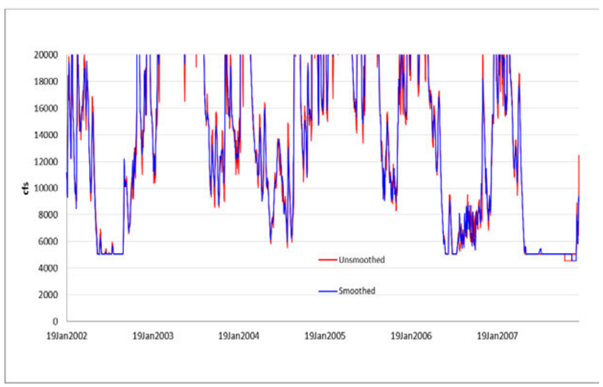


Bainbridge



Chattahoochee

Figure 4.3.36: River Flow sequences for Bainbridge and Chattahoochee associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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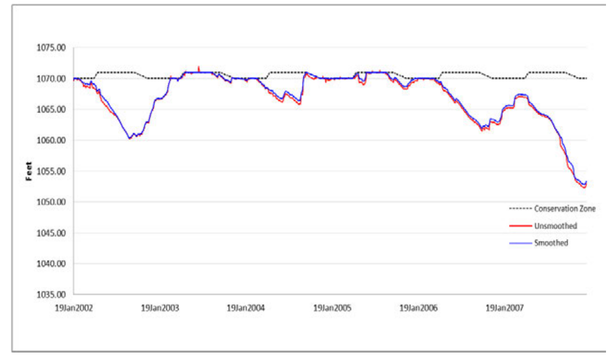
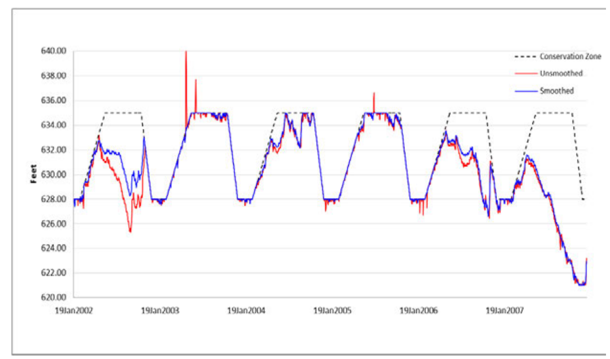


Lake Lanier



West Point

Figure 4.3.37: Reservoir elevation sequences for Lake Lanier and West Point associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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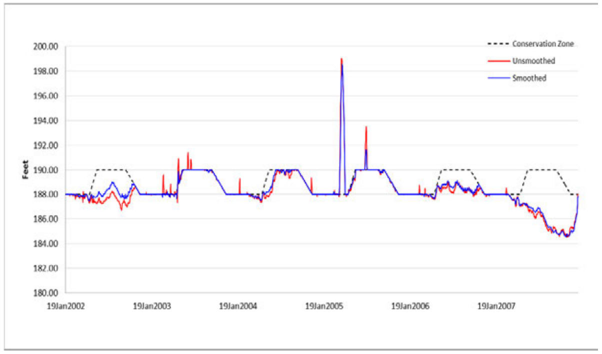
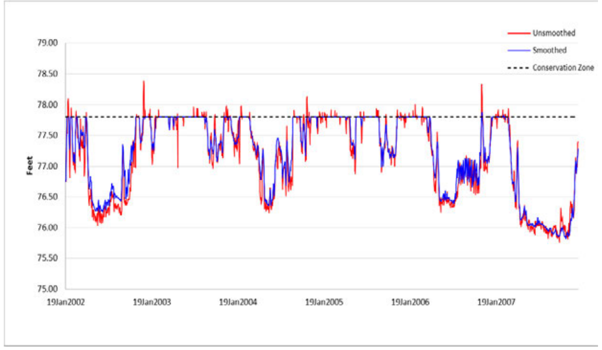


W.F. George



J. Woodruff

Figure 4.3.38: Reservoir elevation sequences for W.F. George and J. Woodruff associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the current operational procedures.

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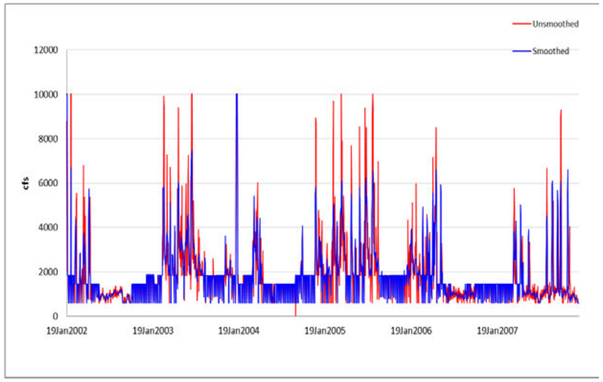
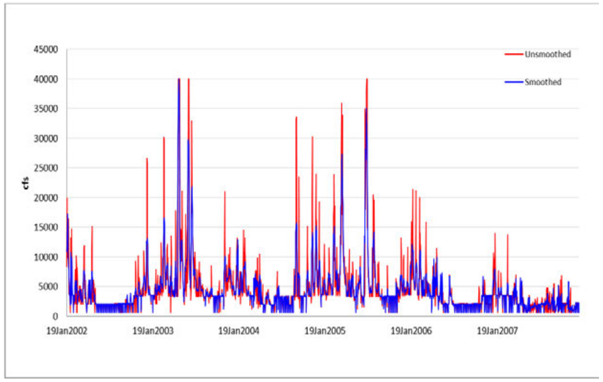


Lake Lanier



West Point

Figure 4.3.39: Reservoir release sequences for Lakes Lanier and West Point associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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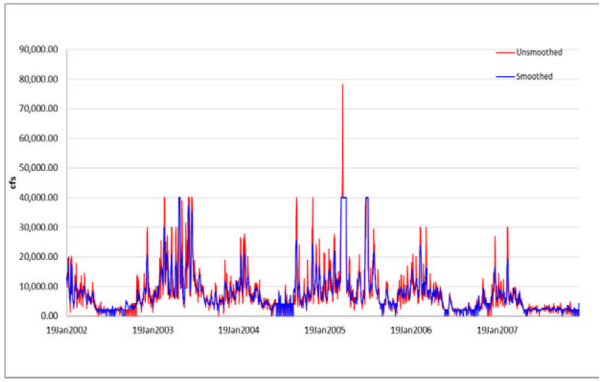
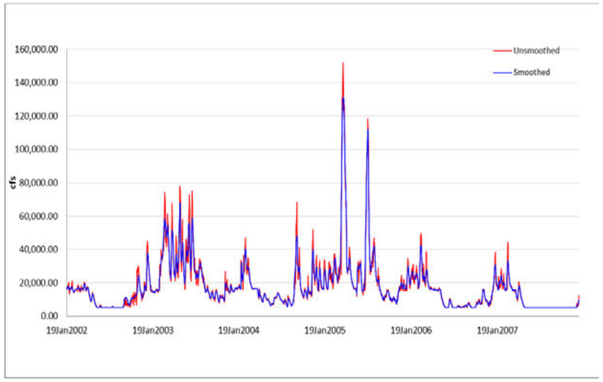


W.F. George



J. Woodruff

Figure 4.3.40: Reservoir release sequences for W.F. George and J. Woodruff associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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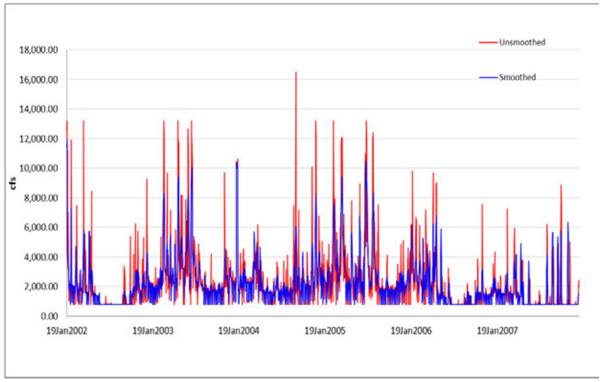
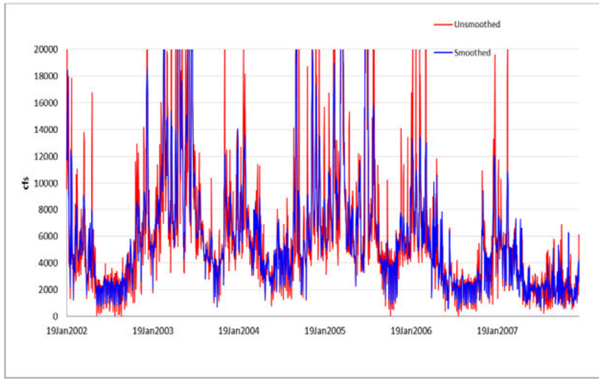


Atlanta



Columbus

Figure 4.3.41: River flow sequences for Atlanta and Columbus resulting from smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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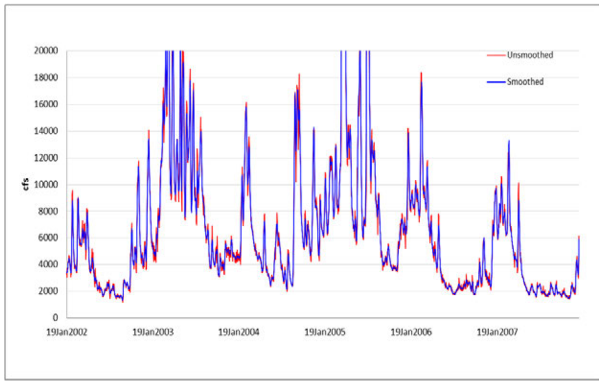
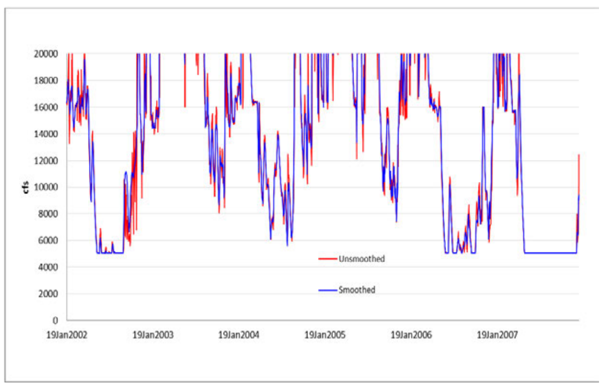


Bainbridge



Chattahoochee

Figure 4.3.42: River Flow sequences for Bainbridge and Chattahoochee associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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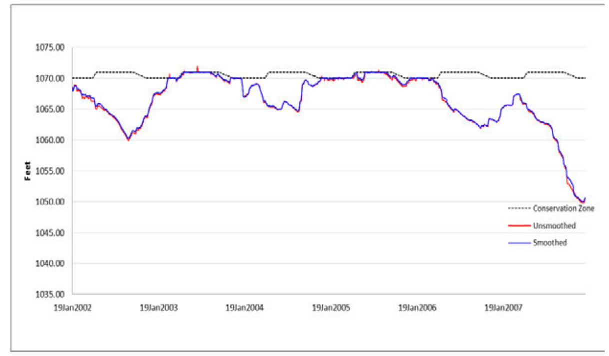
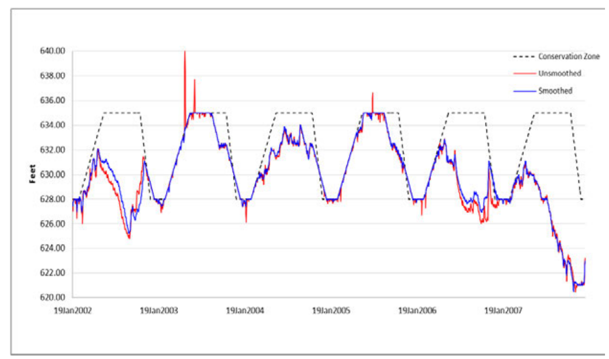


Lake Lanier



West Point

Figure 4.3.43: Reservoir elevation sequences for Lakes Lanier and West Point associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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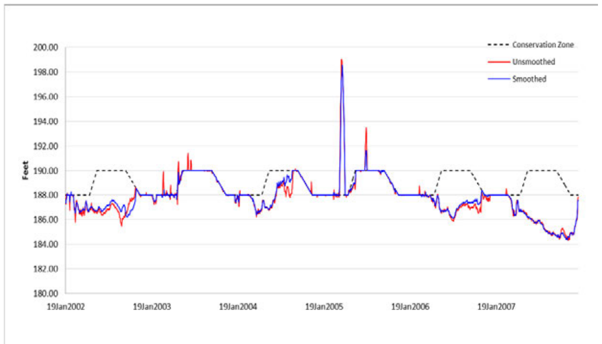
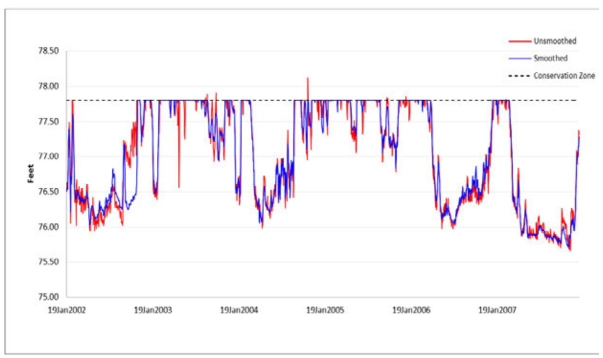


W.F. George



J. Woodruff

Figure 4.3.44: Reservoir elevation sequences for W.F. George and J. Woodruff associated with smoothed (blue) and unsmoothed (red) USACE unimpaired flows under the improved operational procedures.

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5. Summary of Findings and Recommendations

5.1 Summary of Findings

This report describes an assessment of the unimpaired flow (UIF) datasets developed by the USACE, Mobile District and by Georgia EPD for the Apalachicola-Chattahoochee-Flint (ACF) river basin. The assessment included two main phases: (**1**) A detailed, reach-by-reach analysis of the local data used in the water budget computations and (**2**) a basin-wide evaluation of the cumulative UIF uncertainty impacts. The assessment goals were to identify the individual uncertainty sources at each river reach, quantify their magnitude, and characterize their potential basin-wide impacts. Toward these goals, the assessment employed a variety of tools and tests:

- Comprehensive evaluation of all individual data used in every ACF river reach;
- Reconstruction of all methods and procedures used to develop the original UIF series;
- Data and methods consistency assessments;
- Evaluation of alternative procedures for filling in missing data;
- Evaluation of the discrepancies introduced by river routing;
- UIF consistency tests with climate data;
- Double mass analyses of streamflow measurements at different stations;
- Comparisons between the USACE and EPD UIFs at different time resolutions;
- Comparisons of the same UIF series at different time periods;
- Comparisons with hydrologic UIFs generated by physically-based models;
- Comparisons of irrigation water use data against crop model results;
- Comparisons of alternative evaporation estimation methods;
- UIF assessments based on the Index of Hydrologic Alterations (IHA) software; and
- Evaluation of UIF uncertainties based on river basin simulation models (ResSim) and alternative operational procedures.

The overarching study finding is that while the existing UIFs contain valuable technical information, they are in need of improvement to effectively support the development of a sustainable water management plan for the ACF river basin. Detailed UIF assessment findings have been presented in Chapters 3 and 4. This chapter summarizes the outstanding UIF issues and provides improvement recommendations that would benefit the ACFS planning process.

5.1.1 UIF Error Types

UIF errors are distinguished in random and systematic. **Random errors** result from incorrect measurements (or estimates) of various water budget components such as observed streamflows and water use amounts. Such errors are associated with components that are otherwise *correctly* represented in the UIF derivation process, are temporally uncorrelated, and vanish when averaged over weekly or monthly time steps. Typical such errors are associated with (**i**) streamflow measurements (usually having a ± 5-10% discrepancy with respect to actual flow) and (**ii**) isolated erroneous data entries such as the ones noted in Section 3.16 (Buford reach) where the net evaporation losses (of the USACE dataset) on September 30, 2000, are 30 times larger than the losses of preceding days, or the erroneous M&I data entries in **Figure 3.1.5** (of the EPD dataset). These types of errors can be ignored (if they pertain to uncorrelated measurement discrepancies), as they are not expected to significantly alter the average system response away from actual conditions (Liang et al., 2012), or they can be easily corrected (if they pertain to erroneous data entries).

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Systematic errors are much more critical than random errors, as they introduce biases that persist over long periods and impact the system response (and associated performance metrics) across a range of time scales (from daily to decadal). Systematic errors may affect long term UIF levels as well as daily variability, creating false assurances on the amount of water available during droughts, inaccurate estimates of reservoir drawdowns and releases, incorrect assessments of water supply reliability, and/or unrealistic representations of environmental flow regimes. In what follows, systematic errors are further distinguished in (**i**) errors impacting the average UIF levels on monthly, seasonal, annual, and even decadal time scales, and (**ii**) errors impacting the daily UIF level and variability.

5.1.2 Systematic Errors Impacting Average UIF Levels for Long Periods

The ACF UIFs were shown to contain systematic errors impacting their average levels over long periods. The severity of these errors depends on the nature of the underlying error source. The error sources and the reaches where such errors exist are summarized next in order of descending importance.

Estimation of Missing Streamflow Measurements: Streamflow records were unavailable at several locations and had to be estimated. Unfortunately, some of the estimation procedures have systematic biases and produce inaccurate streamflow estimates over several years. In particular, the estimated streamflows at Bainbridge, George Andrews, W.F. George, and Sumatra should be reevaluated and revised.

Unaccounted for Trends in Unimpaired Flows: Several reaches exhibit unimpaired flow trends that are clearly inconsistent with precipitation trends. More specifically, the UIFs in the Norcross reach exhibit an abrupt rise, in W.F. George a sustained decline, in J. Woodruff a large increase, and in Blountstown a significant decline and persistent negative values. Likely causes for these errors have been identified in Section 3. Additional efforts are however needed to fully identify the underlying error sources and remove the errors. A particularly challenging error occurs from changes in the interaction between surface water and groundwater bodies. Such changes can be associated with changes in precipitation and recharge (i.e., with changes due to natural water cycle drivers) or with changes in groundwater use (i.e., with changes due to aquifer pumping). Natural changes are handled correctly by the UIF derivation process and are simply part of the overall (surface water and groundwater) watershed response. However, groundwater pumping changes are not correctly accounted for by the UIF derivation process and manifest themselves as UIF declining trends. In such instances, UIF derivation must separately quantify the natural and human induced influences and add the latter back to the estimated UIFs. Examples of reaches where such considerations are important include the W.F. George (see discussion in Section 3.8.7) and potentially other ACF reaches in the lower Chattahoochee, lower Flint, and upper Apalachicola rivers.

Negative Flow Adjustments: Local negative flow adjustments do not impact UIF average levels. However, the adjustments employed by EPD/ARCADIS for some ACF river reaches result in artificial and systematic water transfers from wet seasons and years to drought periods. Such adjustments are hydrologically invalid and can lead to over-optimistic assessments (as discussed in Sections 4.3.1 and 4.3.2).

West Point Reservoir Contributing Area: For portions of the study period, the West Point UIFs include flows that occur downstream of the reservoir. Unimpaired flows for this reach should be redeveloped to ensure that the amount of flow that occurs upstream and downstream of the reservoir is properly modeled (see discussion in Section 3.5.7). Although this error is mitigated if

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one considers the sum of the UIFS associated with the West Point and its downstream reach, it impacts the flow into the West Point reservoir and introduces systematic biases in the estimation of its storage, release, and energy generation sequences.

Net Municipal & Industrial Withdrawals: Systematic and significant discrepancies exist between the net withdrawal amounts in the USACE and EPD datasets as has been illustrated in several sections of Chapter 3. The individual datasets are also internally inconsistent for some reaches. More specifically, when UIF extensions were performed, certain reach withdrawals and returns were added, removed, or corrected given new information. However, such changes were not carried backwards prior to the extension period. All such discrepancies should be reconciled and corrected.

Agricultural Withdrawals: Agricultural withdrawals are based on estimates that do not sufficiently account for their dependence on climate variability (see discussion in Section 2.4.2). As a result, seasonal agricultural withdrawals (from surface waters as well as groundwater aquifers) are potentially overestimated during wet years and underestimated during dry years. In this regard, the EPD estimation procedures represent a clear improvement over those used in previous USACE datasets. However, further improvements can be realized through appropriate use of more recent groundwater pumping data and a combination of crop and groundwater models.

Net Evaporation Losses from the Federal Reservoirs: There are significant and systematic differences between the net evaporation losses estimated by USACE, EPD, and GWRI at Lakes Lanier, West Point, W.F. George, and J. Woodruff. The estimation methods should be assessed further, and the UIFs in the affected reaches should be redeveloped to remove the existing biases in the USACE and EPD datasets (see discussion in Section 3.15.7).

Net Evaporation Losses from the Georgia Power Projects: Net evaporation losses from several Georgia Power projects in the reach between West Point and Columbus are not directly modeled in the USACE unimpaired flow derivation process. On the other hand, such losses are directly considered in river basin simulation studies. This inconsistent handling of net evaporation losses results in subtracting them twice, one time indirectly through the UIFs and a second time directly in the river basin simulations (see discussion in Section 3.7.7). The USACE dataset should be revised to treat the net evaporation losses from the Georgia Power reservoirs directly and similarly to the net evaporation losses from the main federal reservoirs.

Net Evaporation Losses from other Basin Impoundments: Systematic UIF errors also result from many small and medium size impoundments that have been constructed in the ACF watersheds to serve water supply and other purposes. At present, the total surface area of these impoundments is estimated to be about half of the total surface area of the main river stem reservoirs (including all Federal and Georgia Power projects). The water losses or gains associated with these impoundments (including net evaporation losses, consumptive water uses, and additional infiltration) are reflected on the streamflow measurements at the downstream node of each river reach where the impoundments exist, but they are not accounted for in the USACE and EPD UIFs. Proper consideration of these losses or gains would require that they be respectively added to or subtracted from the UIF values generated by the current derivation procedures. This, however, would require additional data that are not readily available. **Appendix B** provides a first order assessment of the collective net evaporation losses from these impoundments for the ACF basin and for each individual river reach. Basin-wide, monthly net evaporation losses vary in the range from -750 cfs (net gain) to about 1,200 cfs (net loss), while mean annual net evaporation losses are estimated at around 225 cfs. This analysis is only intended to provide lower and upper bounds of

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the potential net evaporation losses and does not consider any other losses or gains associated with these impoundments.

5.1.3 Systematic Errors Impacting Daily UIF Level and Variability

In addition to systematic errors affecting the long term UIF levels, the UIFs also contain significant systematic errors impacting their daily level and variability. These errors exist in nearly all ACF river reaches and are the underlying causes of repeated negative UIF values, sizeable discrepancies between the USACE and EPD datasets, and considerably more variable recent UIFs versus earlier UIFs. These errors affect the daily UIF values and usually disappear when the UIFs are averaged over monthly or longer time periods. As such, they also impact the system performance metrics related to daily river flows, releases, and other quantities. The main causes for these errors are elaborated next in order of descending importance.

Estimation of Missing Streamflow Measurements: The procedures employed for the estimation of missing streamflow values were shown (in Chapter 3) to introduce daily errors as large as the UIFs themselves. Thus, during periods of missing streamflow measurements, the estimated UIF values are highly unreliable and unnaturally variable. The estimation of missing values can be improved through more suitable, physically-based methods.

Streamflow Routing: River routing computations are employed in most ACF reaches to synchronize the upstream and downstream streamflow measurements and implement the water budget computations outlined in Section 1 and **Figure 1.3**. While flow routing is necessary, the manner in which it was implemented is prone to large daily errors. Specifically, for each daily time interval, the flow at the upstream node was routed to the downstream node assuming no significant inflow within the reach itself. The routing model parameters were calibrated to synchronize (as much as possible) the peak flow timing between routed flows and downstream measurements. Then, the water budget computations were carried out as indicated in Section 1. This approach is problematic in that the timing and magnitude of the routed flows also depend on the unknown UIF inflows to the reach. This dependence is particularly strong in reaches and periods where the unknown UIFs represent a significant portion of the upstream flow being routed. As a result, the routing process misrepresents the true flow timing and underestimates or over-estimates the flow peaks, generating large positive or negative errors, usually in succession. These errors can be avoided by adopting more accurate and iterative river routing methods.

Data with Different Temporal Resolutions: As indicated in **Table 1.1**, the data used in the UIF derivation process have varied temporal resolutions. Specifically, all M&I and agricultural withdrawals and returns as well as reservoir evaporation rates and runoff coefficients are used as monthly, annual, or multi-year average values (with some exceptions in more recent years). The nature of the UIF derivation process is such that when long term averages are used in the place of actual daily values, the unrepresented data variability is transferred onto the generated UIFs inflating their own natural daily variability. This is the reason why early UIFs, which are predominantly based on daily streamflow measurements, are smooth while more recent UIFs are rough and uncharacteristic of daily watershed drainage patterns (**Figures 4.1.3** and **4.1.4**). On the other hand, UIFs averaged over monthly time periods become smoother and assume more natural shapes (**Figure 3.8.10**). A first step toward mitigating these errors is to employ data with monthly or finer temporal resolution. This would require that all net evaporation terms as well as M&I and agricultural withdrawal hindcasts be expressed in monthly sequences reflecting their true monthly variability. Beyond this step, additional improvements are possible but they would require the use of true daily data and models.

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5.1.4 Implications for Water Management Plan Assessments

The previous UIF errors have basin-wide implications which were assessed as described in Chapter 4. These implications suggest that the existing UIF datasets need to be improved before they can support valid water management assessments.

UIF improvements are especially critical for stakeholder interests and performance metrics pertaining to *daily* time scales, exhibiting river flow and reservoir release errors frequently exceeding several thousand cfs (e.g., **Figures 4.3.33** and **4.3.41**). These errors undermine the results of ResSim and other river basin simulation models operating on daily time steps. As a consequence, model outputs are not representative of actual system conditions.

Certain UIF errors and their basin-wide implications are mitigated at *monthly* time scales, but others remain significant enough (e.g., **Figures 3.8.10**, **3.13.6**, **3.14.7**, **3.15.3**, **3.15.10**, **3.17.3**, and **B.2**) to challenge the validity of water management assessment results and conclusions. Such errors should also be removed (or minimized) before water management plan assessments are carried out.

5.2 Recommendations

The previous summary of assessment findings demonstrates that the existing UIFs should be improved to serve the needs of the ACFS planning process. For scientific as well as practical reasons, the recommended way forward is to follow a two-phase improvement process focusing first on improvements associated with monthly UIFs and subsequently on improvements associated with daily UIFs. The rationale of this approach is that the existing UIFs already exhibit fairly good attributes at a monthly temporal resolution, can readily be improved, and can then guide daily UIF improvements.

5.2.1 Monthly UIF Improvements

First, several obvious data errors and inconsistencies exist in the USACE and EPD UIFs that need to be corrected. These include isolated erroneous data entries and incompatible M&I and agricultural withdrawal sequences. It is recommended that the different data bases be reconciled to establish a trustworthy (and shared) information system on which to build reliable UIFs.

Second, efforts should be made to address most of the issues listed in Section 5.1.2 as well as the monthly data compatibility issue raised in the last paragraph of Section 5.1.3 to ensure that monthly UIFs are characteristic of watershed drainage processes and are thus realistic everywhere in the basin. With the exception of two error types, these improvements can be completed in a few months using tools and procedures that have already been developed. The two challenging improvements relate to the effects of (**i**) human-induced groundwater changes and (**ii**) small and medium size impoundments. Direct and full consideration of these issues would respectively require the development of new or better groundwater models and non-trivial data collection efforts. As an alternative, these effects can be assessed through rainfall-runoff models. Such models can be calibrated based on early hydrologic periods (when these effects were negligible) and subsequently used to generate hydrologically consistent UIFs for recent periods. The difference between the hydrologic and the derived UIFs would provide a realistic assessment of the collective groundwater and impoundment impacts. (The proposed process would be similar to that used in Section 3.8.7 and demonstrated in **Figure 3.8.10**.)

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Third, it is recommended that a panel of experts be formed from USACE, USGS, USFWS, USEPA, USNPS, SERFC (NWS), the states, ACFS, and possibly other organizations to oversee, guide, support, and validate the proposed UIF improvement efforts.

5.2.2 Daily UIF Improvements

Once the monthly UIF improvements are completed, daily UIF improvements can also be undertaken to address the issues highlighted in Section 5.1.3. The goal of this effort would be to disaggregate the monthly UIFs consistently into a daily resolution. In this regard, the first two issues in Section 5.1.3 could be addressed through daily river routing models, rainfall-runoff models, and suitable statistical disaggregation models. The third issue in Section 5.1.3 (i.e., the lack of historical water use data with daily resolution) could be addressed using the existing daily water use measurements to hindcast daily water use in previous periods with realistic daily mean and variability statistics.

Although some of the tools required for the recommended daily UIF improvements would need to be developed (calibrated), the model development process would be facilitated by the monthly modeling experience and tools.

5.2.3 Phased Assessment of Water Management Plan Alternatives

In view of the UIF improvement recommendations, the water management plan assessments can also follow a similar two-phased approach. First, once the monthly UIF improvements are completed, water management assessments can be initiated using performance metrics that are meaningful at monthly temporal resolution. Such metrics should also reflect daily stakeholder interests and water use targets properly aggregated to monthly time scales. Examples of such aggregated metrics pertaining to environmental and ecological river flow targets can be found in the recent ACF Environmental Flow Assessment Study (Atkins, 2012). The purpose of the Phase I assessments will *not* be to develop *final* water management plan recommendations, but rather to identify areas of system stress, quantify important basin-wide water use tradeoffs, initiate stakeholder dialogue associated with these tradeoffs, eliminate clearly undesirable management alternatives, and formulate more relevant development and management options.

Management assessments Phase II can begin once daily UIFs are available. This phase would aim to expand the Phase I deliberations by further developing the most attractive water management alternatives and evaluating their benefits, impacts, and tradeoffs across *all* stakeholder interests with respect to performance metrics properly expressed in daily and monthly time scales.

The recommended UIF improvements and follow-up water management assessments would create a credible information and knowledge base on which to build a sustainable water management plan for the ACF river basin as well as to assess its effectiveness once it is deployed.

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Nov 13, 2012
Working copy -- Not for general release.
Content may not reflect the opinion of ACFS membership.

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Appendix A: GWRI Net Evaporation Estimation Procedure

The impact of net reservoir evaporation has to be removed in order to derive unimpaired flows for reaches that include reservoirs. Net evaporation (NEVAP) represents the net loss of water from a reservoir due to increased evaporation (E), precipitation (P), and runoff (R) and can be computed as follows:

$$\mathrm{NEVAP(cfs)} = \left[\,\mathrm{E(ft/day)} - \mathrm{P(ft/day)} + \mathrm{R(ft/day)}\right] \times \mathrm{A(acres)} \times 0.504\,,$$

where *A* is the reservoir surface area and 0.504 is the unit conversion. Evaporation can be estimated from meteorological data, and precipitation is available from rainfall stations. However, runoff that would have drained to the river from the inundated area may not be directly measured. Thus, a runoff coefficient (ROC) that is a ratio of long-term average runoff to rainfall is usually adopted to estimate runoff (i.e., R = ROC x P).

The Georgia Water Resources Institute developed a modified Hamon approach to estimate monthly evaporation rates for each reservoir. The modified approach approximates the traditional Hamon equation using a second-order Taylor series expansion at the mean daily maximum temperature. The equation can be expressed as

$$\mathrm{PET_{monthly}} = \mathrm{KPET}\ \mathrm{N_d}\left\{\mathrm{C_2}\left[\mathrm{VAR}[\mathrm{T_{max}}] + \left(\mathrm{E}[\mathrm{T_{max}}]\right)^2\right] + \mathrm{C_1}\ \mathrm{E}[\mathrm{T_{max}}] + \mathrm{C_0}\right\},$$

where KPET includes all numerical coefficients of the original Hamon equation, $\mathrm{N_d}$ denotes the days of the month, C_2, C_1 and C_0 are constant terms from the Taylor series expansion, and $\mathrm{VAR}[\mathrm{T_{max}}]$ and $\mathrm{E}[\mathrm{T_{max}}]$ are the variance and mean of the daily maximum temperatures for each month. The KPET coefficient is calibrated to match the means of free water surface evaporation for each month (derived from the NCDC data), this approach was shown to provide more accurate monthly evaporation estimates than the original Hamon method (Georgakakos and Zhang, 2011).

Because of the monthly resolution, GWRI directly derived monthly precipitation data from the PRISM data set by identifying grids that cover the ACF reservoir surface areas. In contrast to the constant runoff coefficients adopted by the USACE and EPD, GWRI used a lumped conceptual watershed model to simulate the monthly runoff coefficients for each reservoir.

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Appendix B: Evaporation from Basin Impoundments

B.1 Introduction

Apart from the four federal reservoirs (Lakes Lanier, West Point, W.F. George, and J. Woodruff), net evaporation losses also occur from other impoundments distributed within the ACF river basin watersheds. Such impoundments vary from small to medium size and serve water supply, flood retention, and other purposes. Net evaporation losses from these impoundments were not *directly* considered in the development of the USACE unimpaired flows. The EPD UIFs additionally include net evaporation losses from the Georgia Power reservoirs on the main river stem. The net evaporation losses for the rest of the impoundments are *indirectly* subtracted from the UIFs through their corresponding reduction of the streamflow observations at the downstream reach nodes. When these losses are positive, this approach implies that the computed UIFs are somewhat smaller than the full natural UIFs generated by the watershed. The opposite occurs when these losses are negative (gains).

Direct handling of these losses is difficult because of the large number of these impoundments, their transient storage (and surface area) in response to climatic conditions, and the lack of detailed available data. Thus, this section only aims to estimate the *range* of the net evaporation losses in the various ACF basin reaches based on aggregate impoundment data.

B.2 Assessment Methodology

A recent study (Ignatius, 2009) developed a geographic database of all ACF reservoirs. Three size categories (small, medium, and large) were mapped using aerial photography, topographic maps, and land cover data. The database contains information on impoundment location, number, surface area, volume, and time of construction (**Figure B.1**).

Net evaporation losses from these impoundments were herein calculated by multiplying net evaporation rates at the impoundment location by surface area. The net evaporation rates were estimated by the same methodology used for the main stem reservoirs (described in **Appendix A**). For each reach, evaporation rates are obtained from the modified Hamon PET approach (Georgakakos and Zhang, 2011). Mean aerial precipitation (per unit area) within each reach are generated from the PRISM database. Monthly varying runoff coefficients are determined from lumped conceptual hydrologic watershed models calibrated for each reach.

The surface areas are estimated from the data compiled in Ignatius (2009). The surface areas are determined under the assumption that the impoundments are full. This approximation overestimates the net evaporation losses as most of these impoundments are expected to dry out at the early stages of a severe drought. Actual losses are difficult to compute since historical surface area measurements are not available for most of these impoundments. Additionally, both in-stream and off-stream impoundments are considered in the area calculations since the information compiled by Ignatius (2009) does not distinguish between the two impoundment types. Because of these assumptions, the results reported herein should be viewed as approximate ranges, providing upper and lower limits of the net evaporation losses and gains due to these impoundments.

However, the increase of potential water surface area over time was incorporated using available information on historical reservoir construction. Hindcasted values are computed by scaling present day surface areas with factors computed from ratios of present day impoundments to the number of reservoir in existence for each past decade. For some of the largest reservoirs (e.g., Lake

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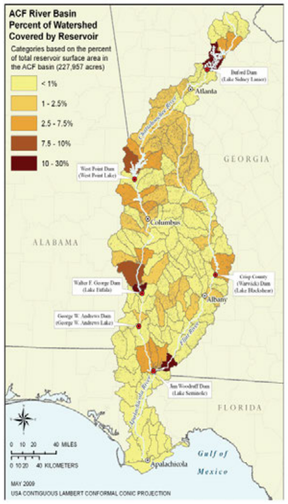
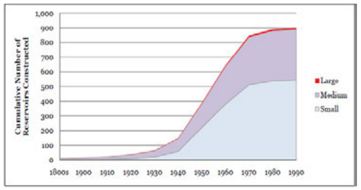
Harding and Lake Blackshear), the construction dates were known and were taken explicitly into account.



Reservoir surface area

State	Small		Medium		Large		All Sizes Combined	
	Acres	% of total	Acres	% of total	Acres	% of total	Acres	% of total
Alabama	6,555	2.9%	3,727	1.6%	14,889	6.5%	25,171	11%
Florida	3,258	1.4%	708	0.3%	6,226	2.7%	10,192	4.4%
Georgia	48,074	21.1%	24,557	10.8%	119,963	52.6%	192,594	84.5%
TOTAL	57,888	25.4%	28,993	12.7%	141,078	61.9%	227,957	100%

Lake Lanier: 38,292 (acres)



Cumulative reservoir construction over time

Figure B.1: Geographic Data of Reservoirs in the ACF Basin (A. Ignatius, MS Thesis, 2009).

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B.3 Assessment Results

Results for the entire ACF basin are presented in **Figure B.2**. The figure shows the hindcasted surface areas of the impoundments for the entire ACF basin and associated evaporation and net evaporation time series estimated by the above procedure. The figure shows that evaporation rates reach up to 1,300 cfs during the dryer months of the year. Furthermore, monthly net evaporation rates vary from -750 cfs to about 1,200 cfs. The mean annual evaporation rate (12-month moving average) is currently approximately estimated at 630 cfs, while the mean annual net evaporation is estimated at around 225 cfs.

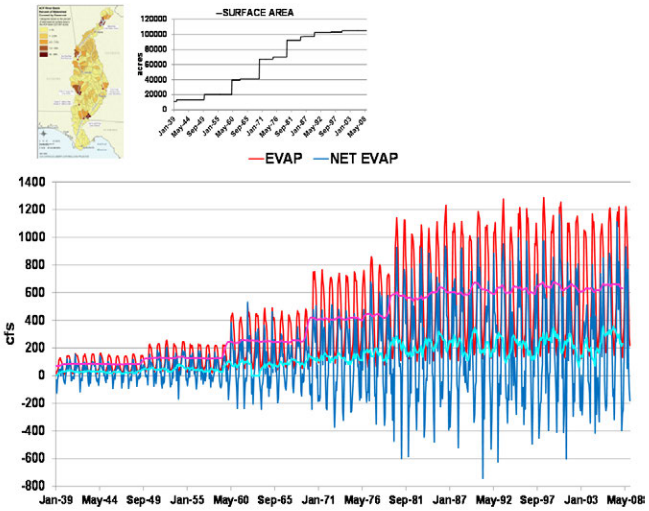

Figure B.2: Monthly evaporation and net evaporation, and associated 12-month moving average sequences from ACF impoundments (other than main stem reservoirs).

B.4 Reach-by-Reach Results

Following the same procedure, results for surface area hindcasts and evaporation and net evaporation losses were also derived for each reach. The results are shown in **Figures B.3** to **B.20** and are summarized in **Table B.1**. Among the ACF reaches, Albany, Columbus, W.F. George, and Carsonville exhibit the highest annual average evaporation losses of 123, 81, 77, and 64 cfs respectively. The same reaches exhibit average annual *net* evaporation losses of 43, 29, 35, and 20 cfs respectively. The average annual evaporation losses for the rest of the ACF reaches range from

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3 to 45 cfs, and the average annual *net* evaporation losses from 0.1 to 20 cfs. However, the monthly statistics are significantly more variable.

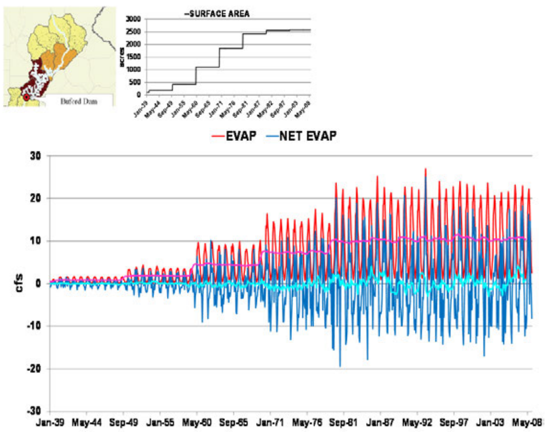

Figure B.3: Evaporation from other Impoundments for the Buford Reach.

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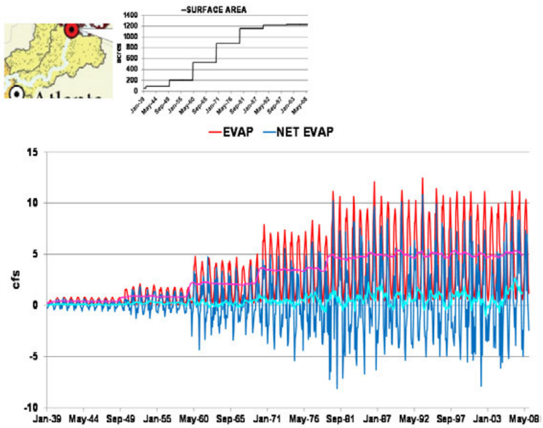

Figure B.4: Evaporation from other Impoundments for the Norcross Reach.

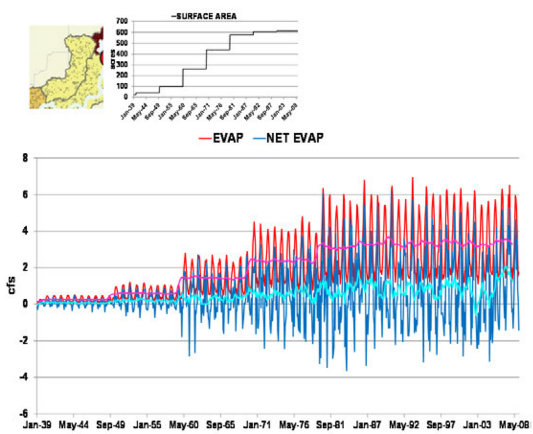

Figure B.5: Evaporation from other Impoundments for the Morgan Falls Reach.

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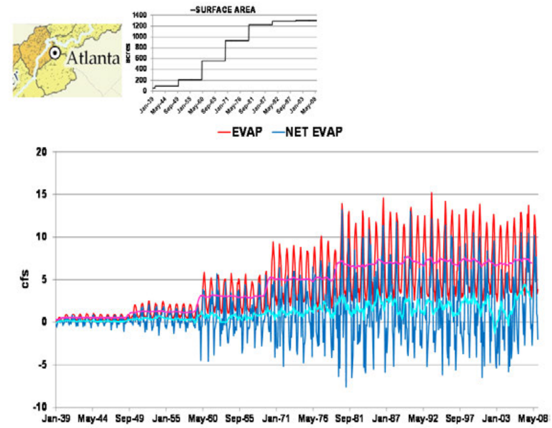

Figure B.6: Evaporation from other Impoundments for the Atlanta Reach.

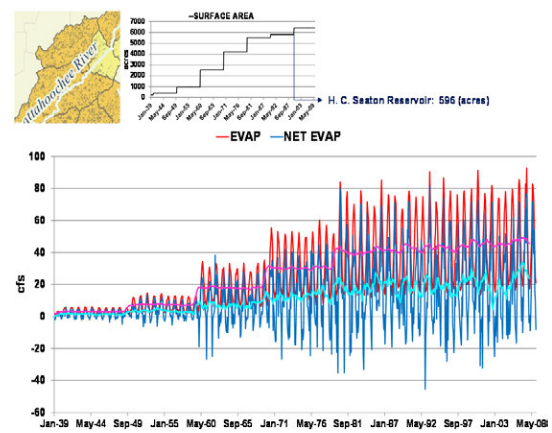

Figure B.7: Evaporation from other Impoundments for the Whitesburg Reach.

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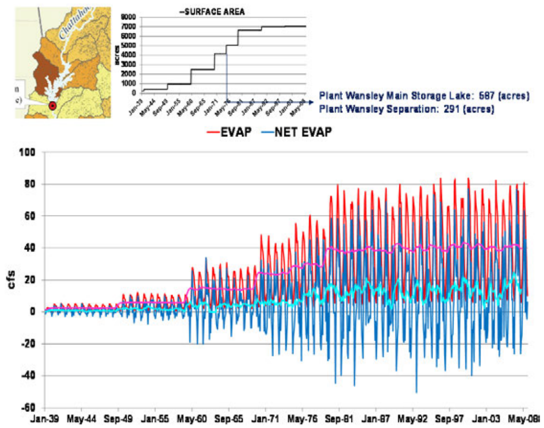

Figure B.8: Evaporation from other Impoundments for the West Point Reach.

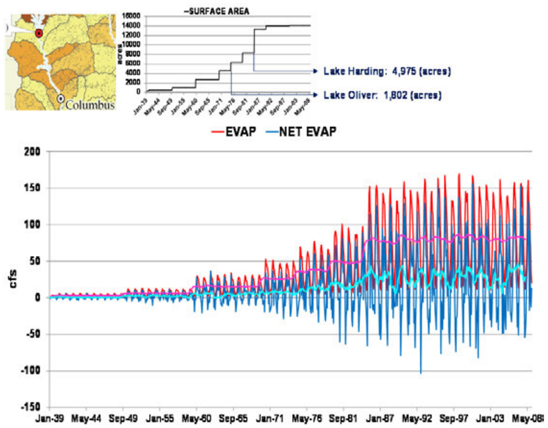

Figure B.9: Evaporation from other Impoundments for the Columbus Reach.

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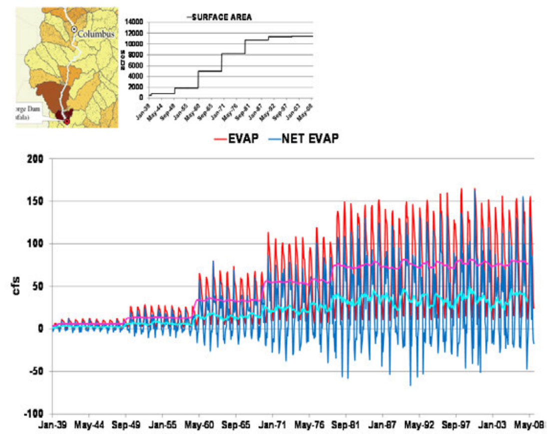

Figure B.10: Evaporation from other Impoundments for the WF George Reach.

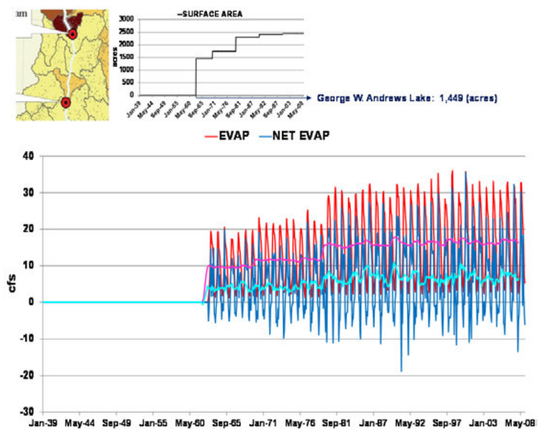

Figure B.11: Evaporation from other Impoundments for the George Andrew Reach.

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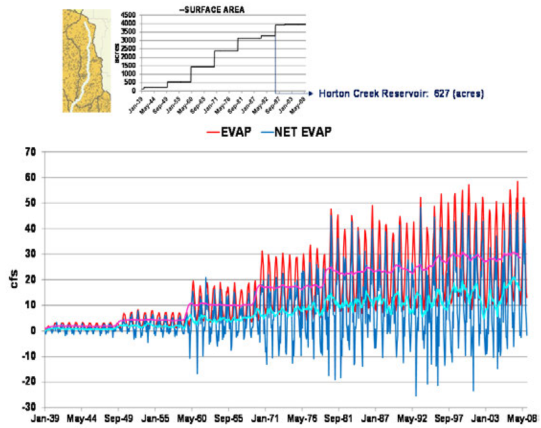

Figure B.12: Evaporation from other Impoundments for the Griffin Reach.

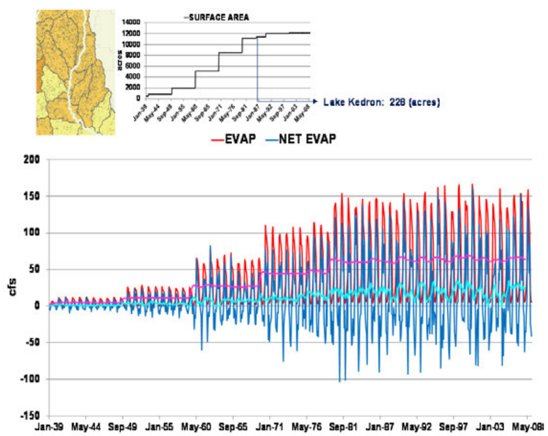

Figure B.13: Evaporation from other Impoundments for the Carsonville Reach.

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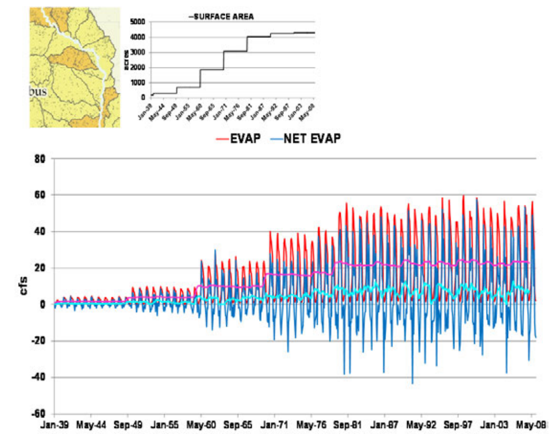

Figure B.14: Evaporation from other Impoundments for the Montezuma Reach.

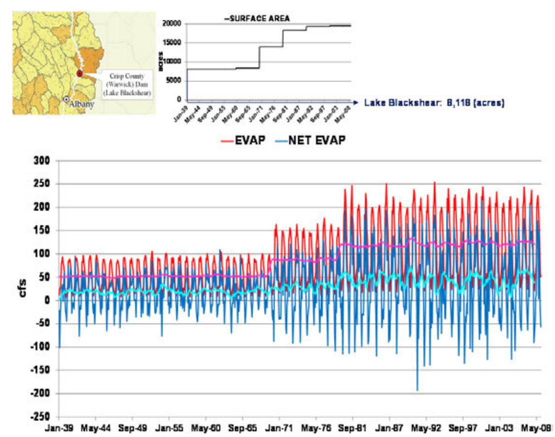

Figure B.15: Evaporation from other Impoundments for the Albany Reach.

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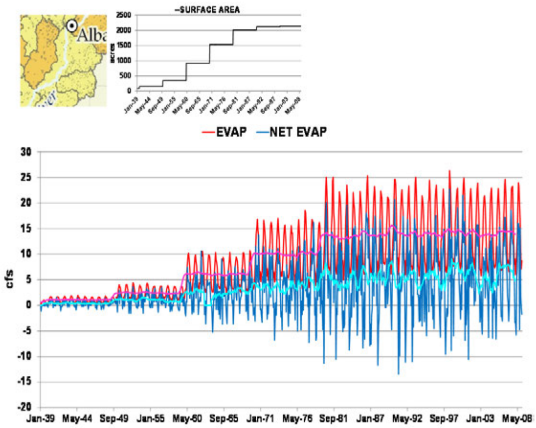

Figure B.16: Evaporation from other Impoundments for the Newton Reach.

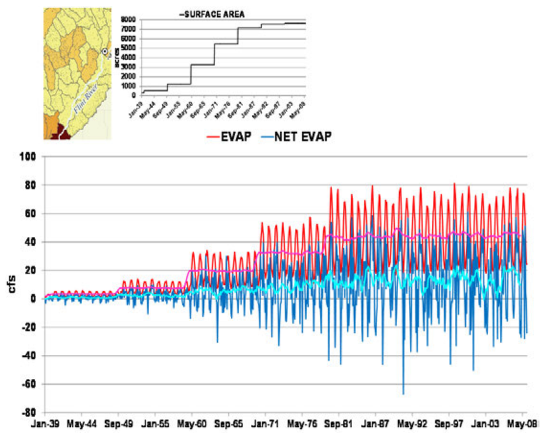

Figure B.17: Evaporation from other Impoundments for the Bainbridge Reach.

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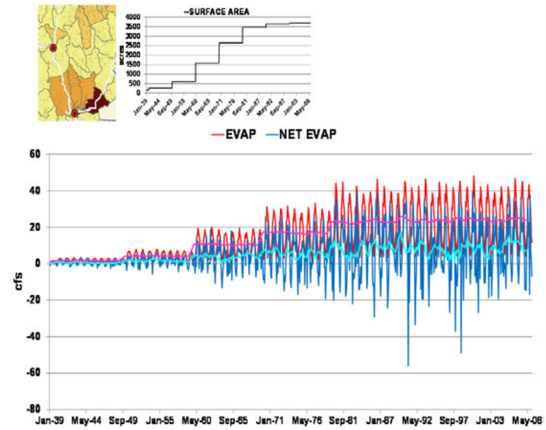

Figure B.18: Evaporation from other Impoundments for the Jim Woodruff Reach.

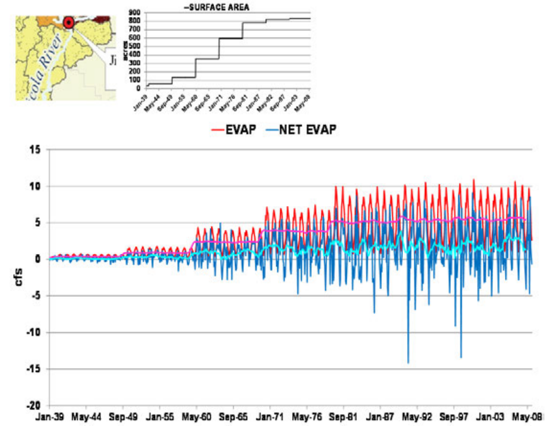

Figure B.19: Evaporation from other Impoundments for the Blountstown Reach.

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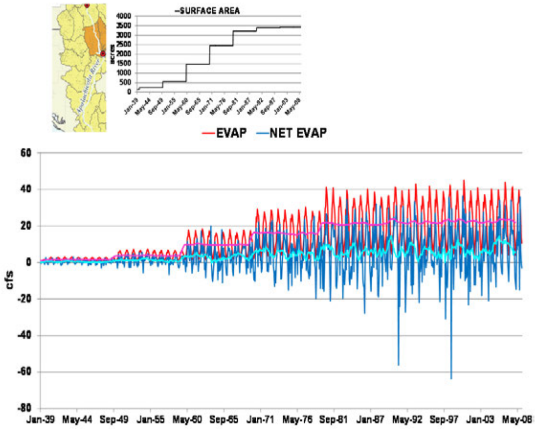

Figure B.20: Evaporation from other Impoundments for the Sumatra Reach.

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Reach	Annual Average Evaporation (1990-2008)	Annual Average Net Evaporation (1990-2008)
Chattahoochee		
Buford	10.59	0.12
Norcross	4.99	0.76
Morgan Falls	3.35	0.88
Atlanta	7.14	1.95
Whitesburg	44.63	20.25
West Point	40.41	13.29
Columbus	81.14	28.51
W.F. George	76.77	35.00
George Andrews	16.47	6.96
Flint		
Griffin	27.46	13.16
Carsonville	64.37	20.28
Montezuma	22.81	7.38
Albany	122.91	43.14
Newton	14.16	5.76
Bainbridge	44.91	13.23
J. Woodruff	23.97	8.52
Apalachicola		
Blountstown	5.45	1.84
Sumatra	22.34	6.81
ACF Basin Total	633.86	227.85

unit: cfs

Table B.1: Annual Average Evaporation and Net Evaporation from Other Impoundments.

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Georgia Department of Natural Resources
Environmental Protection Division
2 Martin Luther King Jr., Drive, Suite 1152 East Tower, Atlanta, Georgia 30334
Judson H. Turner, Director
(404) 656-4713

January 14, 2013

BY ELECTRONIC MAIL AND U.S. MAIL
Tetra Tech, Inc.
Attn: ACF WCM
61 Saint Joseph Street, Ste 550
Mobile, AL 36602-3521

Re: Notice of Intent to Revise Scope of Draft Environmental Impact Statement for Updating the Water Control Manuals for the Apalachicola-Chattahoochee-Flint River Basin To Account for the U.S. Court of Appeals for the Eleventh Circuit Ruling and a June 2012 Legal Opinion of the Corps' Chief Counsel Regarding Authority to Accommodate Municipal and Industrial Water Supply From the Buford Dam/Lake Lanier Project

Comments of the State of Georgia

Dear Sir or Madam:

The State of Georgia submits these comments in response to the Federal Register Notice of October 12, 2012 (77 Fed. Reg. 62,224) regarding the U.S. Army Corps of Engineers' (the "Corps'") proposed revisions to the scope of the Draft Environmental Impact Statement ("EIS") for the Corps' update of the water control plans and manuals (collectively, "WCM") for the Apalachicola-Chattahoochee-Flint ("ACF") River Basin.

This is the Corps' third scoping notice concerning the EIS for the ACF WCM. The Corps' prior 2010 Scoping Report expressed the Corps' intent only to consider as action alternatives reservoir operations that restricted withdrawals and releases for water supply to those allowed under a July 2009 Order of the District Court in *In re Tri State Water Rights Litigation*, Civil Action No. 3:07-mdl-1

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(M.D.Fla.)(the "MDL District Court Order"). The United States Court of Appeals for the Eleventh Circuit reversed the MDL District Court Order, and the Corps then determined that it possesses statutory authority to operate Lake Lanier to meet Georgia's projected water supply demands as set forth in the May 16, 2000 request of the State of Georgia to the Assistant Secretary of the Army (the "Georgia Water Supply Request," or "Request"). Accordingly, the Corps now must decide whether and how it will meet Georgia's future water supply needs. The Corps' deliberation over the Georgia Water Supply Request affects the scope of the EIS that the Corps must undertake for the WCM.

I. Georgia's Prior Scoping Comments and Basis for Additional Comments

The Corps first solicited comments on the scoping of the ACF WCM on September 19, 2008. In scoping meetings that followed that notice, the Corps announced that the new WCM would merely document then-current operations. Thus, the Corps would not study as an alternative accommodating Georgia's future water needs or modifying the Revised Interim Operating Plan for Jim Woodruff Dam ("RIOP"). In comments that it submitted on November 21, 2008, Georgia pointed out that limiting the scope of the EIS in this manner would violate the National Environmental Policy Act, 42 U.S.C. § 4321 et seq., ("NEPA") and the Administrative Procedure Act, 5 U.S.C. § 701 et seq. ("APA"), and would produce a deficient WCM that promptly would be rendered obsolete.

The Corps issued a second notice and request for comments on scoping in November 2009 in reaction to the MDL District Court Order. The MDL District Court Order provided that, absent congressional action or interstate agreement, as of July 19, 2012, the Corps would have to eliminate virtually all water supply withdrawals from Lake Lanier and limit releases from Lake Lanier during non-peak hydropower periods to no more than 600 cfs. The Corps announced that in light of the MDL District Court Order, in terms of water supply, the action alternative(s) for the ACF WCM would be restricted to the withdrawals and releases from Lake Lanier that were allowed under the MDL District Court Order. Georgia provided written comments stating that, notwithstanding the MDL District Court Order, the failure by the Corps to include as an action alternative operations to meet Georgia's future water supply demands would violate NEPA and produce a meaningless document. The Scoping Report that the Corps issued in March

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2010 restricted the alternatives to those that complied with the MDL District Court Order, but it did seem to acknowledge that the Corps would have to account for the serious economic implications of so restricting water supply, stating that "it is clear that the issues of greatest concern are the potential for significant impacts on socioeconomics, water resources, and biological resources." Scoping Report at 96-97.

The United States Court of Appeals reversed the MDL District Court Order in June 2011, finding that reservoir operations to support water supply—at least water supply withdrawals from the river below Lake Lanier if not also direct withdrawals from the lake—were authorized under the River and Harbor Act of 1946, and that the Water Supply Act of 1958 gave the Corps additional water supply authority. The Court of Appeals directed the Corps to reconsider the Georgia Water Supply Request, first to determine whether the Corps has authority to grant the Request, and then, if the Corps determines it has such authority, to evaluate under NEPA the effects of granting the Request. Earlier this year, the Corps formally rendered the determination that it has authority to grant the Georgia Water Supply Request.

On October 12, 2012, the Corps published notice of its intent to revise the scope of the EIS for a second time, this time, finally, to "consider a broader range of water supply alternatives, including both current levels of water supply withdrawals and increased withdrawals, from Lake Lanier and downstream at Atlanta, that have been determined to be within the Corps' legal authority." 77 Fed. Reg. 62,224.

These comments are directed at the revised scope that the Corps has proposed. Georgia will not repeat comments that it has made in response to past scoping notices. To the extent that they are not modified herein or superseded by intervening events, however, Georgia's prior comments stand, and Georgia asks that they remain in the record and that the Corps take them into consideration.

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II. Comments on Proposed Revisions to Scope

A. In Assessing All Alternatives, the Corps' Must Take Into Account Georgia's Future Water Supply Needs

Pursuant to the order of the Court of Appeals, and having determined that it has legal authority to do so, the Corps has made the correct decision to study as an action alternative allowing withdrawals from Lake Lanier and making releases from Lake Lanier to meet the projected water supply demands included in the Georgia Water Supply Request. The Corps must decide how it will accommodate Georgia's future water supply demands, and it only makes sense to coordinate the decision on Georgia's Water Supply Request with the WCM update so that the WCM reflects that decision. Thus, the NEPA analysis for the WCM update and Georgia's Water Supply request should be consolidated in a single EIS. Moreover, to avoid the delay and unnecessary expenditure of resources associated with serial updates to the WCM, the EIS should look at modifications of reservoir operations over time to meet water supply needs well into the future.

Based on the foregoing, meeting Georgia's future water supply needs should be identified within the EIS as an element of the purpose and need for the updated WCM. Within the EIS, the Corps must "specify the underlying purpose and need to which the agency is responding in proposing the alternatives including the proposed action." 40 C.F.R. § 1502.13. Georgia's future water supply needs as articulated in the Water Supply Request properly fall within this definition. As a consequence, all alternatives should be evaluated against the criterion of whether and how they accomplish the purpose of meeting Georgia's projected water needs.

Any alternatives that do not involve releases to support up to 408 mgd of withdrawal from the Chattahoochee River above the Peachtree Creek confluence and 297 mgd withdrawal from Lake Lanier by 2040 must account for the economic, environmental, and sociological effects of other water projects that the State or local water systems will have to develop to meet the shortfall. NEPA guidance issued by the Council on Environmental Quality provides that where an alternative would result in predictable actions by others, this consequence of the alternative should be included in the EIS. *See* Council on Environmental Quality, "Forty Most Asked Questions Concerning CEQ's National Environmental Policy

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Act Regulations," Question 3, 46 Fed. Reg. 18026, 18027 (1981). The substantially higher cost and environmental impact of projects to replace Lake Lanier likely render some or all of those alternatives unfeasible. The Corps does not have to include as an action alternative any alternative that is not feasible. *See Airport Neighbors Alliance, Inc. v. United States*, 90 F.3d 426, 432 (10th Cir. 1996) (finding that Federal Aviation Administration was not required to consider certain alternatives to runway expansion because implementing the alternatives would be infeasible); *Coalition for Lower Beaufort County v. Alexander*, 434 F. 2upp 293 (D. D.C. 1977), *aff'd mem.*, 584 F.2d 558 (D.C. Cir. 1978) (holding that Corps was not required to consider alternative site for pier where alternative site would have required the dredging of a three-mile channel and was foreclosed by its expense and by environmental and navigational problems).

B. Georgia Has Submitted Updated Information in Support of the Georgia Water Supply Request

The Georgia Water Supply Request included the best available information as of May 2000 on projected population growth and future water demands that would be dependent on Lake Lanier. As more than twelve years have passed since Georgia submitted the Request, Georgia has collected updated population, water use, projections for water supply use, as well as updated analysis of the effects of granting Georgia's Water Supply Request. The data that Georgia has collected confirms that Georgia's water demands from Lake Lanier will reach 705 mgd, including 408 mgd river withdrawal and 297 withdrawal from Lake Lanier, within a reasonable planning horizon of approximately 25-30 years. The State of Georgia submitted this information to the Assistant Secretary of the Army on January 11, 2013. A copy of Georgia's submission to the Assistant Secretary is attached as Exhibit A. In addition, Georgia is in the process of completing an economic analysis of the Georgia Water Supply Request. Georgia anticipates that the economic analysis will be completed by the end of the first quarter of 2013, at which time it will be provided to you for consideration for the EIS.

C. The Corps Should Study Alternatives to the Current RIOP

The State of Georgia continues to believe that the Corps should consider, as part of the EIS process for the WCM, alternatives to the RIOP. Although the Corps has modified the RIOP to be more protective of both system storage and

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affected endangered species, recent science demonstrates that the flow requirements and thresholds used in the RIOP are based on overestimations of the biological needs of the protected species in the Apalachicola River at the expense of needs upstream. This has resulted, in part, from the use of indirect or surrogate measures based on limited scientific information on biological needs; direct measures based on recent science can and should be utilized. Doing so will provide the basis for alternatives to the RIOP that offer equal or even better results for the protected species, while producing higher reservoir levels.

The State of Georgia requests that the Corps at least carefully reexamine the RIOP using better refined performance measures. Georgia suggests that the Corps apply the following principles in evaluating the RIOP and alternatives:

1. Develop objective, direct, measurable, quantifiable, and scientifically-defensible performance measures;

2. Consider performance measures in the entire ACF Basin as a whole, instead of just those in the Apalachicola River, when evaluating alternatives;

3. Use these performance measures to compare and evaluate all alternatives in a consistent manner;

4. Favor alternatives that demonstrate improved performance related to multiple purposes or interests while also achieving performance measures with the greatest efficiency of individual project and system reservoir storage; and

5. Restrain from drawing conclusions or formulating operations based on incomplete data or insufficient scientific understandings.

Using performance measures that were developed using Corps and FWS data, the State of Georgia has developed an alternative to the RIOP. We will refer to this alternative as the "Georgia Contemplation." The Georgia Contemplation reflects the goal of targeting the highest amount of sustainable Gulf sturgeon spawning habitat and largest amount sustainable flood plain connectivity during the Gulf sturgeon spawning period; optimizing the amount of preferred habitat for

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the Fat threeridge mussel; and conserving system storage to meet water supply and other authorized reservoir purposes.

Georgia EPD presented the Georgia Contemplation to the Corps, the Fish and Wildlife Service, and various ACF Basin stakeholders at a recent workshop. I have attached a narrative description of the Georgia Contemplation and slides illustrating its effectiveness in comparison with the RIOP. Georgia recommends that the Georgia Contemplation described in these attachments be considered as an alternative to the RIOP in the EIS process for the WCM.

III. <u>Conclusion</u>

Georgia requests that you give the foregoing comments and the comments expressed in Georgia' prior Comment Letters careful consideration in scoping the EIS for the update of the WCM for the Corps' projects in the ACF Basin. Please contact me if you have any questions or if I can be a resource for additional information that would assist you in this process.

Respectfully Submitted,

Judson H. Turner
Director
Georgia Environmental Protection Division

Attachments

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Memorandum

To: Judson Turner

From: Wei Zeng

Date: January 11, 2013

Subject: Alternative operation in the Apalachicola-Chattahoochee-Flint (ACF) River Basin

Introduction

The purpose of this memorandum is to summarize an alternative ACF operation that considers the diverse needs throughout the basin. Georgia EPD's Hydrologic Analysis Unit has worked in cooperation with the hydrologists at HydroLogics to develop an alternative ACF operation scheme to achieve performance measures for human, biological and environmental needs. These needs include water supply, power generation, recreation, water quality, endangered species, and other environmental needs. The Georgia Contemplation performs better than the Army Corps of Engineers' (Corps') Revised Interim Operating Plan (RIOP) in many aspects and similarly in others, and is not materially worse as to any. Thus, the Hydrologic Analysis Unit recommends that the Georgia Contemplation serve as a potential alternative to be considered in the Corps' ACF Water Control Manual update process.

In a technical workshop hosted by the US Fish and Wildlife Service (FWS) at Eufaula, Alabama in November 2012, I gave a presentation on the key provisions and results of the Georgia Contemplation to representatives of FWS, the Corps, the State of Alabama, the State of Florida, and stakeholders across the ACF Basin. Since then, we have incorporated comments from stakeholders and continued to work on improving the Georgia Contemplation.

In the following sections of this memorandum, I will describe the components of the Georgia Contemplation and the justifications for them. The ACF HEC-ResSim model used in simulating the Georgia Contemplation is based on a version distributed by the Corps in May 2011, supplemented with revisions to reflect the minor changes to the RIOP as described in the FWS's May 2012 Biological Opinion. The Corps' May 2011 model assumes year 2007 basin water use (with adjustment to intra-annual pattern). To allow for an apples-to-apples comparison, we applied the same water use assumption.

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Guiding Principles in Formulating the Georgia Contemplation

We looked at needs that the ACF system serves and compiled corresponding performance measures that quantify the success in meeting them. Having these performance measures is critical in comparing different operational alternatives.

The ACF reservoirs support water supply, hydropower generation, flood control, recreation, navigation (to a very limited extent), water quality, endangered species, and other environmental needs.

In the formulation of the Georgia Contemplation, Georgia EPD and HydroLogics (Georgia Team) used performance measures designed by FWS for Gulf sturgeon spawning and Apalachicola River flood plain connectivity. Other things being equal, FWS considers the operational alternative that provides the highest amount of habitat availability to be the best one. Without making any judgment as to the soundness of that assumption, we assumed, for the purpose of this analysis, that more habitat would be preferable.

The Georgia Team also conducted extensive data analyses to obtain information on potential Fat threeridge mussel habitat in the Apalachicola River. These analyses resulted in our suggestion to FWS that it use direct mussel habitat performance measures instead of the surrogates that FWS has used thus far. Again, without making any judgment as to the amount of habitat needed, for the purpose of this analysis, we assumed that the alternative that provides more mussel habitat would be considered a better option.

The Georgia Team also looked at the effect (if any) of various operation alternatives on Apalachicola Bay salinity. We have suggested to FWS that a direct performance measure of bay salinity be used to evaluate effects of operation alternatives, instead of merely selecting a flow target as a surrogate, as the previous Biological Opinions have done. The Georgia Team is working with other parties to further develop this potential performance measure.

The performance measures for water supply are straightforward. Meeting water supply needs in different parts of the basin, along with reservoir elevation and storage availability—which protect water supply against drought—are the best indicators of water supply success. The alternative that meets water supply needs while maintaining higher reservoir storage is considered a better option.

Following the Corps' approach in its June 2012 modeling and analyses of Georgia's Water Supply Request, the Georgia Contemplation uses the average amount of energy production and revenue as performance measures for hydropower. For the purposes of this analysis, we assumed that the alternative that generates more energy and revenue is considered a better option from the standpoint of hydropower.

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For reservoir recreation, the Georgia Team used the percentage of time when a level of recreational impact is reached in the annual primary recreational season, defined by the Corps as May 1 through September 8. The less the percentage of time at a certain recreational impact level, the better the alternative is considered to be.

There are existing water quality-related stream flow thresholds in the ACF basin. As long as there is remaining conservation storage in the federal reservoirs, the ResSim model releases from the federal reservoirs whatever water is necessary to meet these water quality requirements. Thus, an alternative that does not result in the depletion of reservoir conservation storage is considered a better option than one that uses up storage, and two alternatives both avoiding storage exhaustion are considered equally effective in supporting flows for the water quality purpose.

The fact that the ACF Basin reservoirs are generally unable to support a nine-foot navigation channel for a variety of reasons makes it difficult to gauge navigation availability. However, the Georgia Team has been working with navigation experts to try to develop some measure of navigation success with which operation alternatives can be evaluated.

The Georgia Contemplation in its current form does not assume changes to the existing rule curves in any of the federal reservoirs. As a result, the same amount of flood control storage is available as under the RIOP, and the Georgia Contemplation does not impact flood control operation. Note that since more conservation storage or seasonal conservation storage may yield better results in other performance measures, the potential of raising the existing rule curves warrants study.

The Georgia Team used all of these performance measures and tried to develop an operation alternative for the ACF Basin that performs better than the RIOP as to the performance measures collectively.

Key Aspects of the Georgia Contemplation

In this section, I discuss the following aspects of the Georgia Contemplation operations:

I. Flow in the Apalachicola River
   a. Spring (March through May, or spawning season)
   b. Summer and Fall (June through November, or non-spawning season)
   c. Winter (December through February, or refill season)
   d. Drought operation and Drought Zone operation
II. Conjunctive scheduling of peaking hydropower generation
III. Water supply
IV. Recreation

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V. Flow at Columbus, Georgia

I will refer to slides in the attached presentation. We have given presentations on the Georgia Contemplation to various federal and state agencies as well as basin-wide stakeholders in a November 29-30 modeling workshop hosted by FWS.

Flow in the Apalachicola River

The state line flow and storage formula under the Georgia Contemplation is set forth in Table 1 and summarized below.

March 1 through 31

March historically has been the wettest month in the ACF Basin, and monthly average flow in the Apalachicola River at the Chattahoochee gage during March has never been lower than 8,260 cfs. Uncontrolled inflow from the Chattahoochee and Flint Basins typically provides fairly high flow in the Apalachicola River without a specific minimum flow requirement. For purposes of this model, we used a minimum flow requirement in the Apalachicola River at Chattahoochee, Florida of 6,500 cfs for March with the knowledge that, based on the foregoing, that flow would be exceeded.

April 1 through May 31

The observation of February and March flow provides a good basis for determining subsequent flow and a sustainable level of spawning season habitat. We use cumulative February and March basin inflow (BI) to determine if the ACF Basin is likely to be under drought conditions. When cumulative BI for February and March is higher than 2.45 million acre-feet, the basin is considered to be under normal spring hydrologic conditions. When cumulative BI is lower than 2.45 million acre-feet, the basin is likely to be either in drought or approaching drought conditions.

When the basin is under normal spring hydrologic conditions, we set release into the Apalachicola River at the lower of 10,500 cfs or the moving minimum of the previous 30 days. A 10,500 cfs flow provides about 85% of all the available sturgeon spawning habitat at the amount of inundation specified in the 2012 Biological Opinion. (See Slide 63 for reference). Spawning habitat availability plateaus at a flow of 10,500 cfs and then actually declines at higher flows. (Slide 69). When the basin is under likely drought conditions, as determined by the cumulative BI, release into the Apalachicola River is set at 10,500 cfs when BI is higher than 10,500 cfs, or BI if it is lower than 10,500 cfs, but not lower than 5,000 cfs. This assures that a continuous 30-day inundation of a large portion of the spawning habitat is achieved and results

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in better spawning habitat availability for both individual days and periods of 30 continuous days than does the RIOP. (See Slides 11 and 12.)

Sub-period April 16 through April 30

When storage in the federal reservoirs is healthy, the system can afford to provide limited support to sustain a moderate level of flood plain connectivity. The Georgia Team found the following operation for boosting flood plain connectivity to be feasible without too much impact on system storage:

1. When Lanier elevation is above 1066 feet, West Point elevation is above 632 feet, and Walter F. George is above 187 feet, the Georgia Contemplation uses the following procedure to determine releases to support flood plain connectivity:
   a. Determine the minimum level of flow that has been sustained in the previous 30 days (March 17 through April 15);
   b. Compare this sustained flow with 10,500 cfs, and take the larger one; and
   c. Compare the flow obtained in step b with 22,500 cfs, and take the lower one as the level of flow to be sustained for the sub-period.
2. When Lanier, West Point, or Walter F. George is below the elevation levels specified above, the above support of flood plain connectivity will not be provided.

This approach makes good use of naturally-higher flow in the first half of April and provides limited support from storage in the second half of April to achieve sustainable flow support for flood plain connectivity for up to 30 days, which the FWS's Biological Opinion mentions to be of benefit. (See Slides 13 and 14 for results for daily and continuous 30-day duration of flood plan connectivity.)

June 1 through November 30

When flow is in the range between 5,000 cfs and 10,000 cfs, recent studies show that there is no added benefit in preferred Fat threeridge mussel habitat with higher flows (that is, 10,000 cfs is not better than 5,000 cfs). (See Slides 15 through 23 regarding mussel habitat availability.) In fact, recent bathymetric data and subsequent spatial analysis suggest that lower flows, even below 5,000 cfs, correspond to higher amount of preferred mussel habitat and can be preferable to higher flows. For the purpose of this analysis, we kept the base flow in this season to 5,000 cfs, and intentionally kept release from following BI when it rises above 5,000 cfs. The duration curve of preferred mussel habitat indicates a better performance of the Georgia Contemplation when compared to the RIOP (Slide 23).

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FWS has mentioned benefits of having pulse flows in the non-spawning season (June through November), including elevating dissolved oxygen, removing debris, and providing food sources to living organisms. Such pulse flows can be provided if triggered by higher BI and when timed so as not to use large amounts of storage.

The Georgia Contemplation maintains a 5,000 cfs minimum flow requirement as the base flow for the non-spawning season. When BI (7-day average as coded in the Corps platform model) rises above the 25th percentile for the period (roughly 7,400 cfs), a pulse flow lasting one day and corresponding to the 25th percentile daily flow can be made. (See Slide 28 for the pulse flows that could be provided by the Georgia Contemplation in a drought year such as 2000.) When BI rises above median for the period (roughly 10,400 cfs), the Georgia Contemplation could provide a pulse flow lasting one day and corresponding to median daily flow.

At the time of the Eufaula presentation, the summer pulse flow provision assumed a pulse flow followed by ramping down to 5,000 cfs, and a second pulse flow would not be made until the release returns to base flow level. We now clearly understand from exchanges with FWS, however, that brief rises in flow in the Apalachicola River do not result in mussels' upward movement, and, therefore, ramping after a brief period of higher flow is not necessary. We revised the summer pulse flow slightly to reflect this understanding. The Georgia Contemplation now triggers a one-day pulse flow with 1-day BI above its 25^{th} percentile (roughly 7,200 cfs) and median (roughly 10,500 cfs) levels for the season. Using one-day BI better enables triggering of higher pulses than 7-day average BI. Currently, we set an interval of seven days between any two consecutive pulses (meaning that a second pulse flow would not take place until seven days after the previous one and the 1-day BI meets the above stated conditions), and we found that such pulse flow operation to have very little storage impacts. We leave to the FWS to determine the appropriate interval between consecutive pulses if the FWS adopts our approach to providing pulse flows.

December 1 through February 28

December 1 through February 28 is the primary refill season for all of the federal reservoirs in the basin. The Georgia Contemplation's only minimum flow requirement in the Apalachicola River at the Chattahoochee gage is 5,000 cfs. Any BI beyond this minimum flow requirement is stored to replenish system storage, to the extent possible. As noted elsewhere, we do not believe that a minimum flow of as much as 5,000 cfs for this season or any other is justified by the biological data, thus, a lower flow requirement should be considered that will improve overall system performance.

Drought Operation and Drought Zone Operation – Any Time of the Year

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At any time when the system falls below the top of composite storage Zone 4, then the minimum flow requirement in the Apalachicola River is 5,000 cfs. (Again, while a lower flow requirement is likely preferable and deserves consideration, for present purposes we include the 5,000 cfs requirement as part of the Georgia Contemplation.) Any BI above 5,000 cfs is to be stored to the extent possible. If and when the system falls to below the top of the Drought Zone, as defined by the RIOP, the minimum flow requirement drops to 4,500 cfs, and all additional inflow is to be stored.

Compared with the RIOP, under the Georgia Contemplation there is much less time when the system falls into Drought Operation, as shown by Slide 29. For example, our modeling of the RIOP and the Georgia Contemplation shows that, under the RIOP, the ACF system would have been in drought operation in 1986-1987, 1988-1989, 2000-2002, and 2007-2008. In comparison, under the Georgia Contemplation, the system would have been in Drought Operation only in 2008. Furthermore, under the RIOP, the system would have been in Drought Zone operation for about a month at the end of 2007. Under the Georgia Contemplation, the system storage would have been healthy enough to avoid falling into the Drought Zone Operation, with its 4,500 cfs minimum flow.

<u>Conjunctive Scheduling of Peaking Hydropower Generation</u>

Under the RIOP, peaking hydropower generation takes place regardless of flow delivery in the Apalachicola River or balancing among upstream and downstream reservoirs. In effect, peaking power generation becomes another dominating flow requirement in excess of the flow requirements in the Apalachicola River.

In the Georgia Contemplation modeling, the Georgia Team chose to make power generation conjunctive with the flow delivery needs, instead of its being a second flow requirement. In effect, a volume of water needed for flow delivery is determined before a schedule is determined, and hydropower then can be scheduled to release this amount of water. This conjunctive scheduling of power generation resulted in only a 1% reduction in the amount of energy generated by the ACF system, including the Georgia Power reservoirs in the basin, and a 3% reduction in revenue (Slides 35 and 36).

The Georgia Team has experimented with ways to mitigate even this small impact. When more flexibility is given at times when system storage is very healthy or when the probability of refill is very high, we observed a bridging of the small gap in both energy and revenue.

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Water Supply

All water supply needs are met in the Georgia Contemplation model. Furthermore, the major storage reservoirs in the basin, Lanier, West Point, and Walter F. George, remained much healthier than under the RIOP for the entire period of simulation (Slides 37 through 45).

Recreation

Under the Georgia Contemplation, there is much less impact to recreation when compared to the RIOP. The Georgia Contemplation eliminates the Water Access Limit (WAL) at Lanier and West Point and substantially reduces the time when the reservoirs are at Recreation Impact Level (RIL) and Initial Impact Level (IIL). (See Slide 46.)

Minimum Flow at Columbus, GA

After receiving comments from stakeholders, the Georgia Team revised the Georgia Contemplation slightly by adding an alternative 1,350 cfs daily minimum flow requirement at Columbus, Georgia when the system storage is in the top three zones. When the system is in composite storage Zone 4, this flow requirement is decreased to 1,150 cfs. Under the Georgia Contemplation, this alternative flow requirement can be sustained without negative storage implications to system storage and with very little effect on individual reservoirs, assuming the system is operated as suggested in the overall Georgia Contemplation. This slight revision does not materially affect results of the Georgia Contemplation.

Potential Additional Changes

Basin Inflow Determination

While the Georgia Team used BI as calculated by the Corps ResSim model as a factor determining the flow requirement in the Apalachicola River, Georgia EPD believes there is a better way of determining BI by tracking flow observed in the Apalachicola River at Chattahoochee, FL and adding considerations of storage change in Lanier, West Point, Walter F. George, and Jim Woodruff. (Positive storage change represents a net increase in total composite conservation storage, and negative change represents a net decrease.) This eliminates the need for tracking releases made at a number of reservoirs and routing these releases to the downstream reservoirs, and the potential error associated with measuring and mathematical routing of the releases.

Minimum Flow at Atlanta, GA

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The Georgia Contemplation assumes that a minimum flow of 750 cfs in the Chattahoochee River at the Peachtree Creek confluence will be maintained for water quality purposes. This can be refined further to reflect lower flow requirements that may be implemented.

Potential Rule Curve Revisions

Using the Georgia Contemplation as the basis, the Georgia Team conducted preliminary study of revising rule curves to make larger amount of storage available for conservation operation. This resulted in even better performances for sturgeon spawning habitat availability (Slide 49), sustained flood plain connectivity (Slide 49), and reservoir storage levels. We believe other performance measures can also be improved. It is our belief that this option needs to be studied.

Summary

The Georgia Team formulated the Georgia Contemplation using a variety of performance measures throughout the basin. The Georgia Contemplation is superior to the RIOP in most of the performance measure categories. We encourage the Corps to adopt our approach, and to consider the Georgia Contemplation as an alternative to the RIOP in its Water Control Manual update process. Georgia EPD's technical team and its partners are ready and eager to work with the Corps in this process.

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Table 1 - State Line Flow and Storage Formula				
Months	**Total Storage in Reservoirs**	**Basin Inflow (BI) (cubic feet/second) or Other Conditions**	**State Line Flow (SLF) (cubic feet/second)**	**Basin Inflow to be Stored[2] (cubic feet/second)**
March	Zones 1, 2, and 3	NA	>=6,500 cfs	Entire or partial BI above SLF, subject to available Storage Capacity[3]
April 1 – May 31	Zones 1, 2, and 3	Cumulative BI in February and March > 2.45 million acre-feet	Maintain Q = min (10,500 cfs, min(observed moving 30-day flow))	Entire or partial BI above SLF, subject to available Storage Capacity
		Otherwise if BI > = 10,500 If BI < 10,500 and >= 5,000 If BI < 5,000	>= 10,500 >= BI >= 5,000	
In sub-period April 16 – April 30		Lanier > 1066', and West Point > 632', and Walter F. George > 187'	Maintain Q = min (22,500 cfs, max(10,500, min(observed March 17 – April 15 daily flow)))	Entire or partial BI above SLF, subject to available Storage Capacity
June - Nov	Zones 1, 2, and 3	BI>= 10476 & previous seven days' Chattahoochee gage flow <5100	>= High Pulse flow (June 14850, July 15500, August 14400, September 11200, October 10100, November 10500), No rise & fall rate limit.	Entire or partial BI above SLF, subject to available Storage Capacity
		BI>= 7181 and < 10476 & previous seven days' Chattahoochee gage flow <5100	>= Small Pulse flow (June 11600, July 11500, August 11100, September 8620, October 7420, November 7980), No rise & fall rate limit.	Entire or partial BI above SLF, subject to available Storage Capacity
		Other situation	>= 5,000	Entire or partial BI above 5,000 cfs, subject to available Storage Capacity
Dec - Feb	Zones 1, 2, and 3	NA	>= 5,000	Entire or partial BI above 5,000 cfs, subject to available Storage Capacity
At all times	Zone 4	NA	>= 5,000	Entire or partial BI above 5,000 cfs, subject to available Storage Capacity
At all times	Drought Zone	NA	>= 4,500	Entire or partial BI above 4,500 cfs, subject to available Storage Capacity

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Contemplated ACF Operati
Alternatives and Suggeste
Performance Measures

Georgia EPD
Hydrology Unit
January 2013