Utilizing Impounded Waters in George County to Decrease the Incidence of Low Flow in the Pascagoula River, Phase 2

Final Report

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Executive Summary:

Phase 1 of this project concluded that a theoretical rectangular impoundment in George County could ameliorate nearly all of the low flow incidents in the lower Pascagoula River. The project utilized fifty years of rainfall and evaporation data and fifty years of river flow gaging data to model an impoundment as rain filled it, evaporation lowered it, overflow occurred, and the river flow was supplemented. It also simulated the impact of climate change over the same twenty year period.

Phase 2 continued this work by changing to actual planned lakes. The actual footprints were located and the soil under the lake and in the watershed were analyzed to predict water capture and loss. The general concept on which the management plan was formulated was reviewed and its application to George County was demonstrated.

The lake was located on a tributary to the Pascagoula River at the optimum distance. The foot print was determined. It was later revised into two lakes to protect an existing mitigation bank. For the purposes of the study, the two lakes were managed in simultaneous drawdown to minimize the impact on any single lake. The theoretical simulation assumed vertical sides on the lake. Since this phase used genuine locations, considerable effort went into recognizing the changing area of both the lakes and the watershed as the water level changed.

With the lakes now redefined, both the fifty year analyses were repeated. With the increased volume of these two lakes, the simulation showed not a single time in which the lakes would be unable to supply the needed water, either with or without climate change. It did, however show at least one occasion during which the lakes would be drawn down to less than half of their initial volume. Because the amount of water in the river varies so dramatically between high flow and low flow conditions, an additional analysis of the river under low flow is included to demonstrate the impact of the additional water on the river.

One more scenario was explored in which Okatibbee Lake was used to supplement the Pascagoula low flow. Analysis of stage and discharge records at Arundel and Merrill during low flow suggested a lag time of eight days from the time water is released from the lake until the time it reaches the lower Pascagoula. In addition, releases from the Okatibbee have the potential to cause flooding in the smaller tributaries. Within these conditions, it was clear that the Okatibbee could not respond quickly to low flow events, but had the potential to supplement during severe drought periods.

Phase 1 Overview:

At the completion of Phase One in 2013, a model using daily rainfall and evaporation for 50 years was used to predict the ability of a potential lake on a Pascagoula River tributary to maintain a minimum flow (7Q10) on the Pascagoula River throughout that period (Pote, et al, 2013). The report concluded that this supply would be sufficient to maintain the minimum flow in all but 79 days under the present climate regime, and all but 87 days under simulated climate change conditions over the 50-year period. Phase One also included a preliminary analysis of the size and shape a lake might take if it were actually constructed.

Concept of Sustained Flow

The impact of increased population on a watershed's runoff pattern and streamflow is well established. Pristine, forested watersheds tend to have lowered peak runoff and significantly increased base flow. When an area is settled, even such basic land uses as pastures and row crops will require ditching and drainage improvement. In certain areas of Mississippi, there is a history of channelization to reduce seasonal flooding and remove channel obstructions that create swampy areas (Speer et al., 1965). The positive result is that the land does not stay wet and boggy for extended periods. One negative result is the increased probability of downstream flooding. Another is that with the bulk of the water leaving so quickly, the base flow is decreased. As population density increases, there is also an increase in impervious surfaces (roads, parking lots, roofs), and storm drains are installed, all of which increase both the amount of runoff and the speed with which it moves into the receiving river or stream. Figure 1 shows a classic change in the shape of runoff curves pre- and post- development.

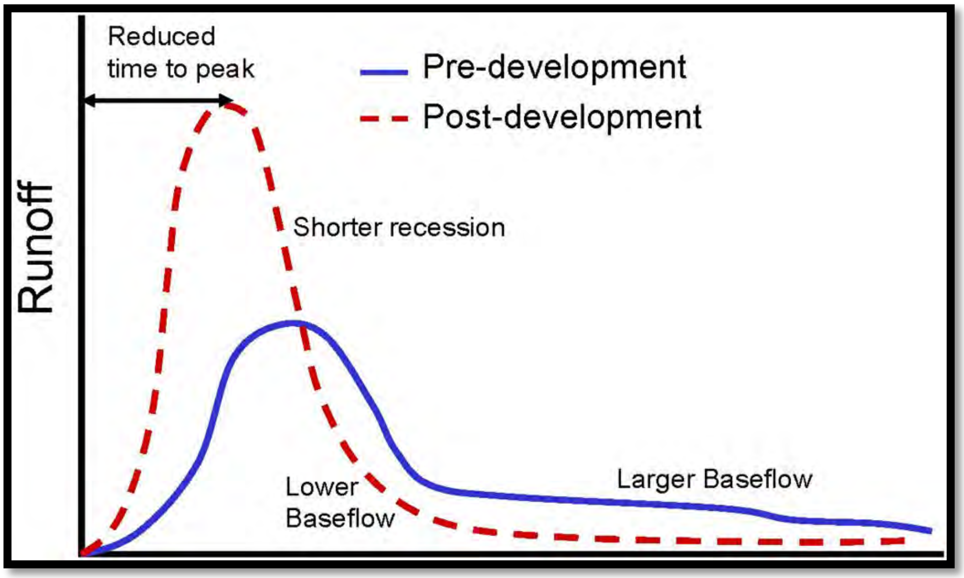


Figure 1: Runoff curves pre- and post- development.

There has typically been a great deal of awareness of the increased height of the changed runoff curve. Detention ponds to slow and hold the peak flow are commonly used in Mississippi, but on a very small scale, and primarily to reduce sediment movement. Mississippi has several lakes constructed exclusively for flood control. These, too, are intended to reduce peak flow. There has been far less attention paid to the secondary characteristic of decreased base flow caused by increased development (channelization, impervious surface, etc.) in a watershed.

In a USGS Study in the Puget Sound Basin (Konrad and Booth, 2002), flows from two watersheds were compared. One was heavily forested while the other was in a developed area. The article extensively compares the frequency and intensity of flood events, but their data show another factor just as clearly. The base flow is maintained far longer in the forested watershed (Figure 2).

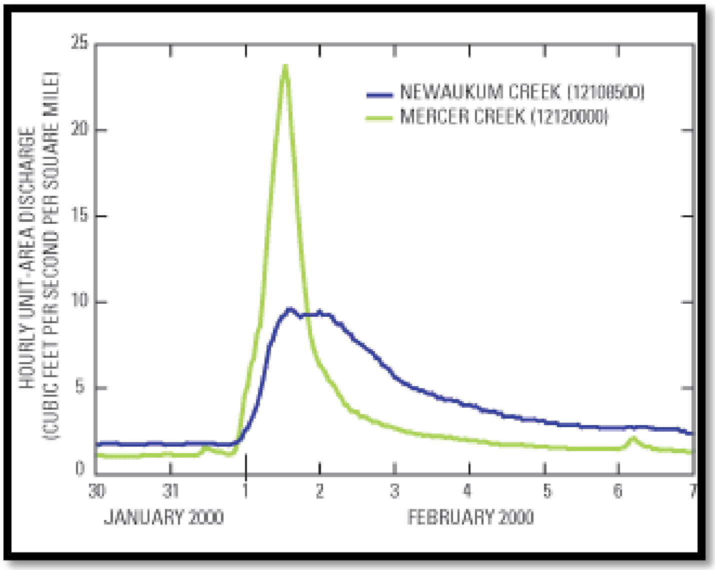
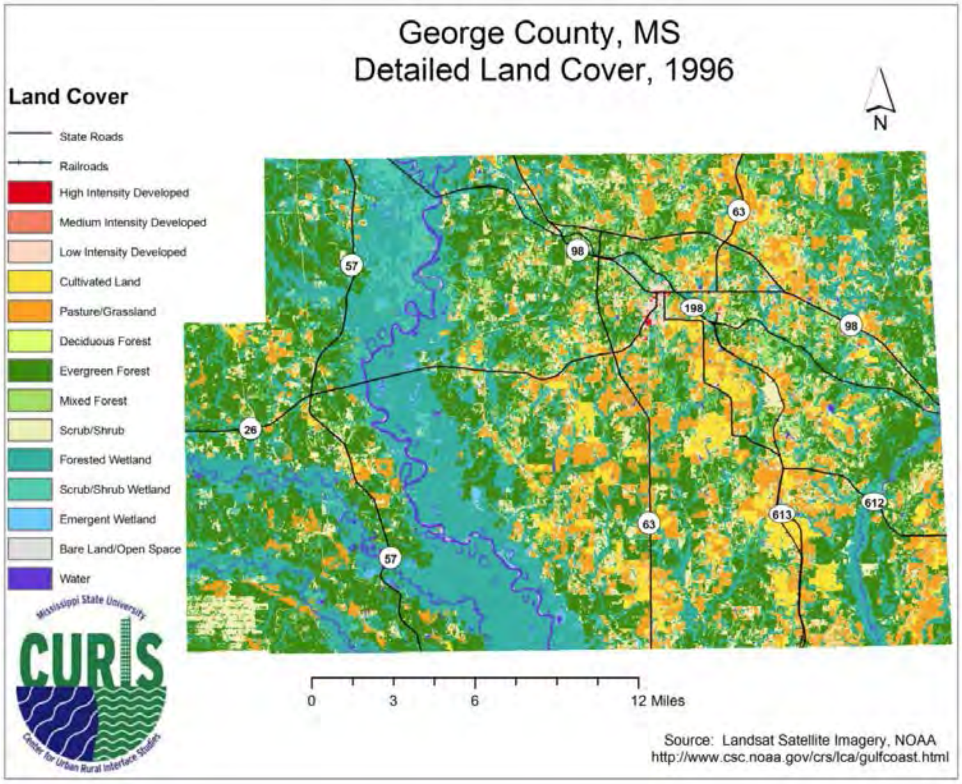


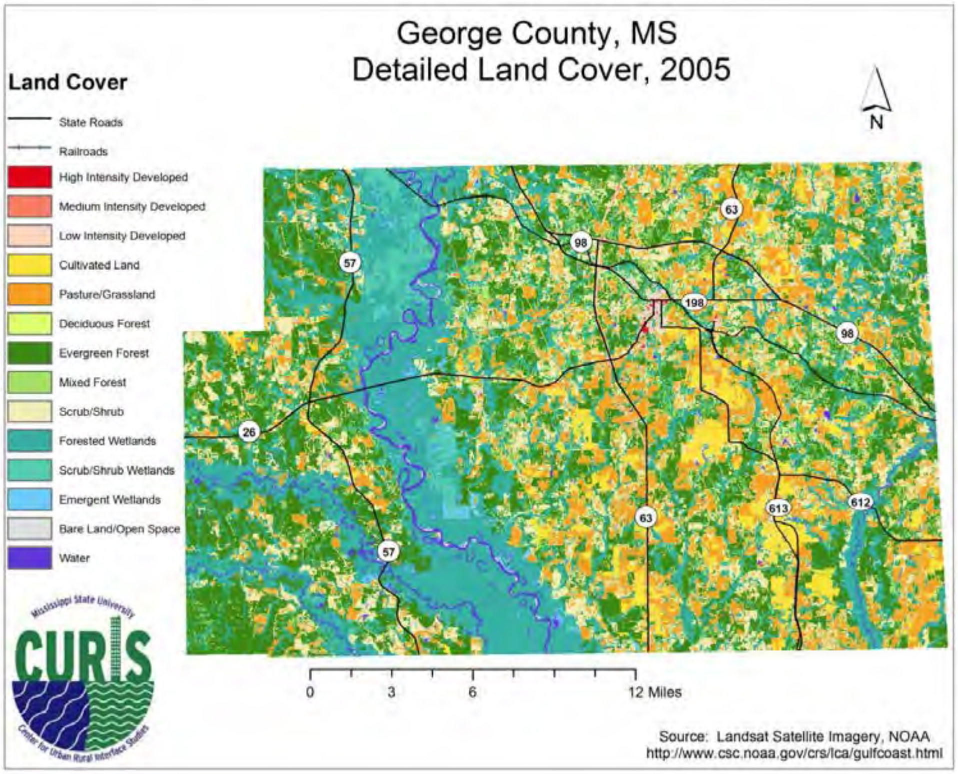
Figure 2. Flow curves for Newaukum Creek (Forested) vs. Mercer Creek (Urbanized).

Mississippi’s Pascagoula River is famous as one of the largest unimpeded rivers in the world, and the river itself is carefully protected. The Pascagoula River basin and watershed Pascagoula, on the other hand, has seen steady growth. Hurricane Katrina certainly reduced development in coastal Jackson County, but that accounts for little of the actual watershed. Much of the displaced population migrated north away from the coast, increasing the population density in George County, which has a far greater impact on the river. This growth was documented in 2009 by the Center for Urban Rural Interface Studies (2009) as shown in Figures 3 and 4. Note that the watershed, once completely forested, has changed to pasture, row crops and intensely developed areas. Each of these changes increases the incidence of flooding and decreases the base flow.



Source: Landsat Satellite Imagery, NOAA
http://www.csc.noaa.gov/crs/lca/gulfcoast.html

Figure 3. George County, MS Detailed Land Cover, 1996.



Source: Landsat Satellite Imagery, NOAA
http://www.csc.noaa.gov/crs/lca/gulfcoast.html

Figure 4. George County, MS Detailed Land Cover, 2005.

The loss of base flow in natural streams has been named as one of the primary causes of decreases in fish populations, including endangering some species and causing the extinction of others. This has increased the interest in protecting the base flow in natural streams via regulation.

Regulations regarding minimum flow originated with the concept of protecting the stream ecosystem, but have generally been evaluated simply by a measure of what is “normal” low flow. In Mississippi, the lowest acceptable flow is a river’s 7Q10--the lowest average flow rate for any sequence of seven days in a ten-year period. Below this point, it is assumed that the ecological system is stressed and cannot accept either further decreases or effluent of any kind.

Mississippi has an average annual precipitation of approximately 55 inches per year, as measured from 1900 to 2013, but the bulk of annual precipitation falls at times during the year when evapotranspiration rates are low and flow levels are not a concern (NOAA, 2014). Building on these prior studies and concepts, this investigation focuses on the ability of a detention lake to capture and store water delivered by the climate at times when runoff and river flow are high. The captured water is then used to both increase the river’s base flow and supplement river flow when it reaches critical low periods.

Procedures:

In Phase One, a purely theoretical lake was proposed and analysis of performance was generated. This produced what would be expected of a lake of roughly those dimensions in that location. As a final entry, a lake was actually proportioned and shown. In Phase Two, the data sets constructed for Phase One were again utilized—Pascagoula River flow based on fifty years of data and rainfall and evaporation from fifty years of serially complete and homogeneous climatological records. The lake was changed dramatically.

The site for the lake was moved from the Pascagoula River itself. Also, it needed to be in the lower reaches of the river to minimize response time and reduce losses in transit. Once chosen, yet another change was made. The for-profit Big Cedar Creek Wetlands Mitigation Bank was permitted in the proposed lake’s footprint. The original footprint was reduced and a second Upper Lake on Little Cedar Creek was evaluated. Figure 5 shows the two proposed lake footprints and the watersheds of the two lakes.

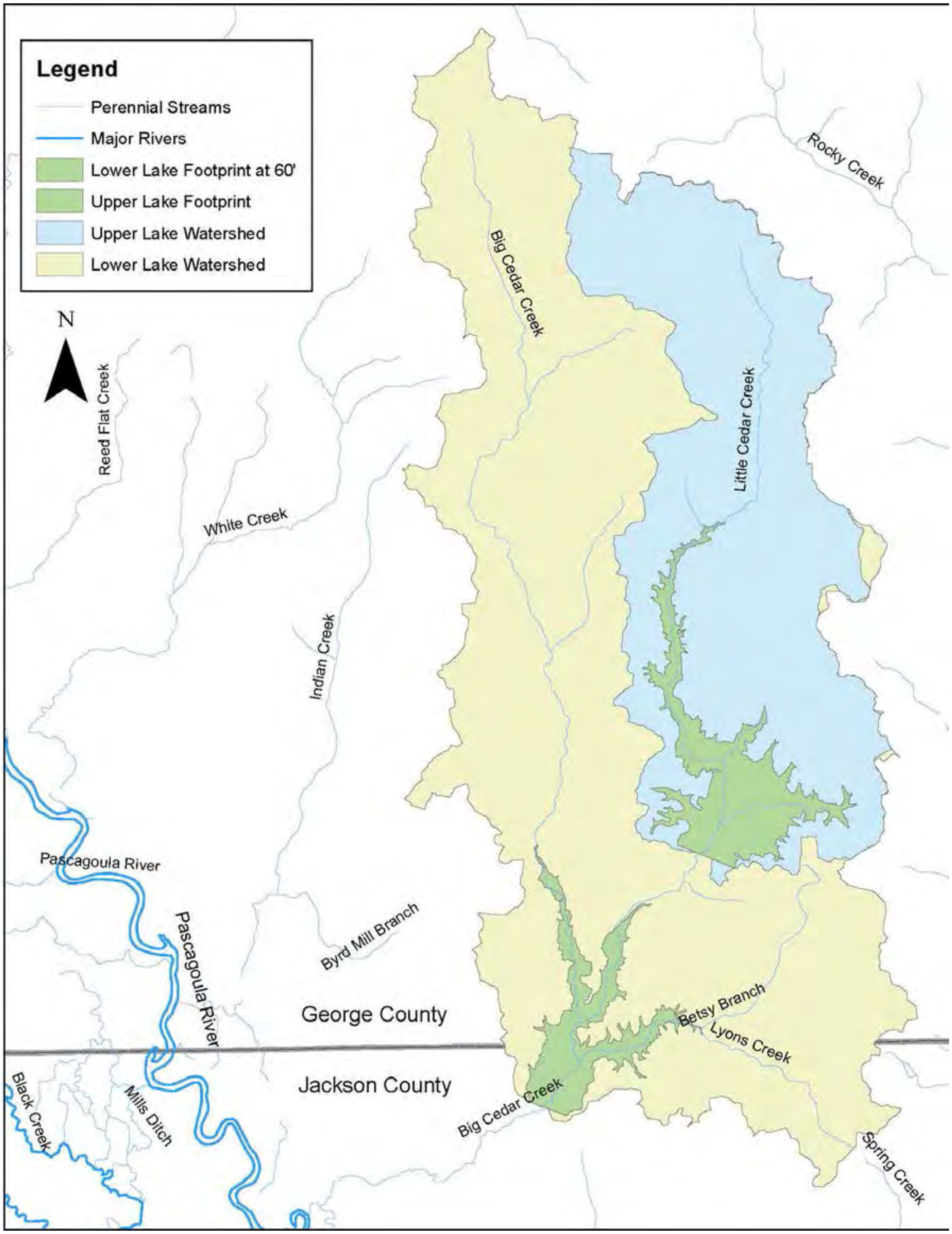


Figure 5. Proposed lake footprints and watersheds for proposed lakes.

For the purposes of the model, it was assumed that the two lakes would be used simultaneously. If water was needed, the Lower Lake would provide it, but water from the Upper Lake would be released until the elevation changes in the two lakes were equal.

Therefore, the simulations assumed the two lakes operated as one, with a combined water surface area of 2,868 A and geometry provided by GIS analysis using DEM data. This geometry provided a combined lake-full volume of 41,452 A-F. The drainage basin was assumed to be 39,743 A with a rainfall-runoff coefficient of 0.6 because of the nature of the basin's land cover and soil types.

A major change made in the model to accommodate the more realistic lakes was a recognition that as a lake loses volume, its area shrinks. Also, as the lake area decreases, the area of the watershed increases. In order to account for these changes, a series of elevations of the lakes were delineated to calculate the lake basin volume and area change for each ten feet of drop in the lake. Using regression analyses, equations were developed to match this sequence, producing equations in the form of Area = f(Volume). These were used in the model to establish changes in the area of the lakes and drainage basin on a daily basis.

These calculations were performed first for the Lower Lake and then the Upper Lake. Finally, since the two are treated in the model as a single lake in terms of drawdown, the specifications of the two lakes were combined and analyzed together, producing a single equation that predicted the lake area given the volume lost or gained daily (Table 1). Each day in the simulations, the calculated lake area is subtracted from the total watershed area to produce the land surface area draining into the lake. Climatological contributions to the water balance of the lake are thus applied to the constantly changing areas of the lake and drainage basin as calculated on a daily basis. The equations developed are shown in Table 2.

Table 1. Calculated lake elevations and surface areas.

Elevation	Upper Area	Volume	Lower Area	Volume	Combined Areas	Volume
0	1,715	31,428	1,153	10,024	2,868	41,452
-10	1,681	30,229	1,124	9,659	2,805	39,888
-20	1,647	28,639	1,097	8,583	2,744	37,222
-30	1,613	27,010	1,069	7,507	2,682	34,517
-40	1,579	25,822	1,042	7,085	2,621	32,907
-50	1,547	24,477	1,015	6,663	2,562	31,140

Table 2. Prediction equations for upper, lower, and combined lakes.

Area = 0.023667 Volume + 968.9136 Upper

Area = 0.03536 Volume + 790.628 Lower

Area = 0.027882 Volume + 1703.40 Combo

The predicted lake surface areas were graphed against the calculated lake surface areas to test goodness of fit of the equations. Figures 6, 7, and 8 show these results.

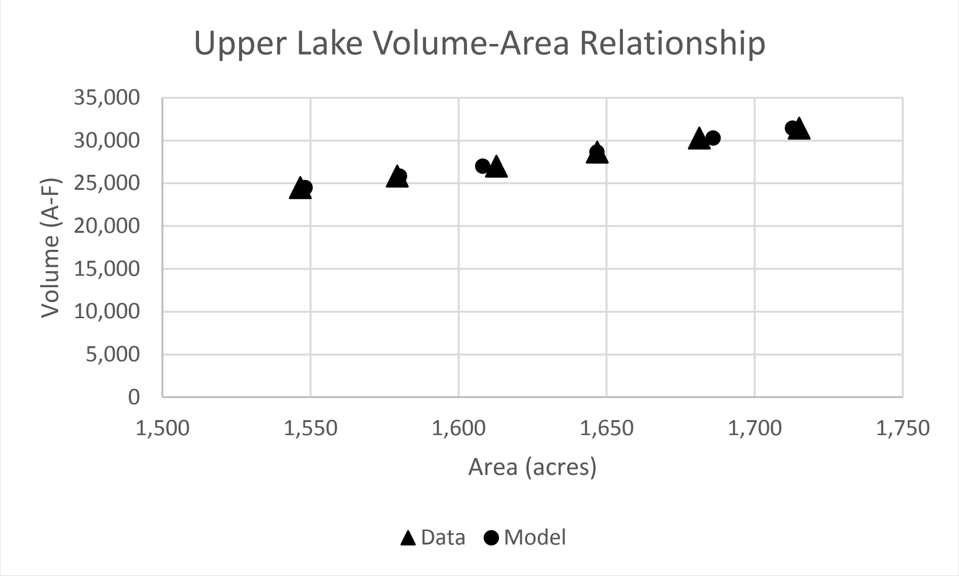


Figure 6. Calculated vs predicted lake areas, Upper Lake (R^2 = 0.997).

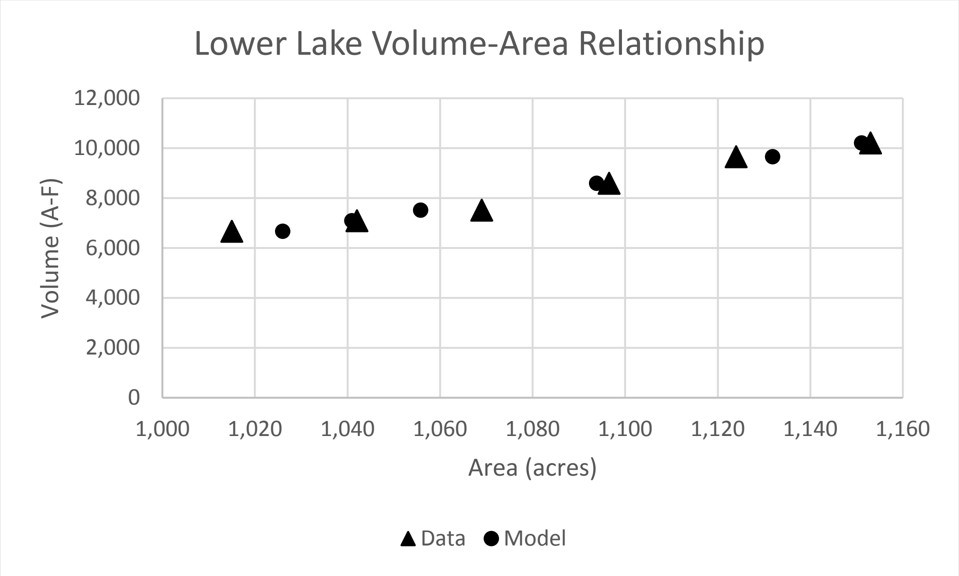


Figure 7. Calculated vs predicted lake areas, Lower Lake (R^2 = 0.972).

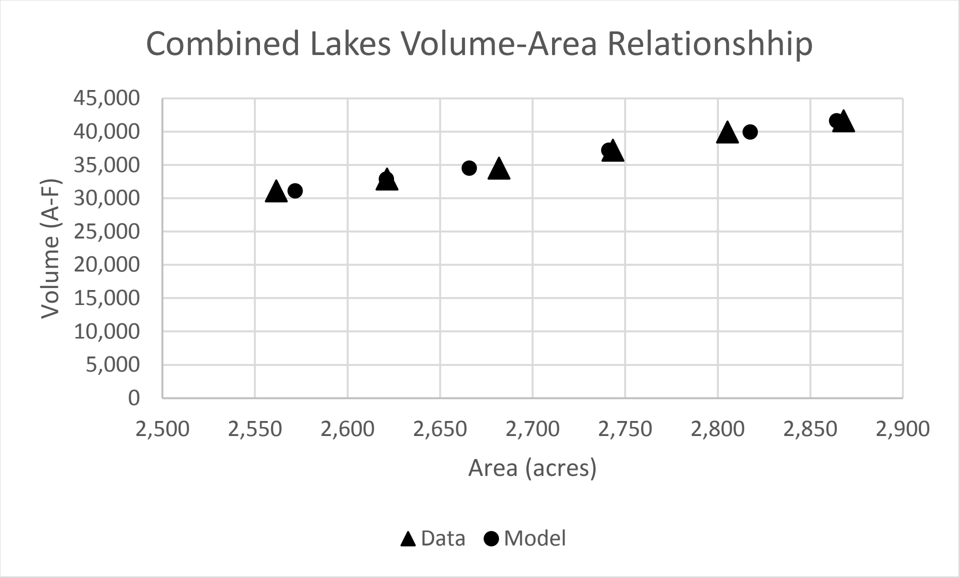


Figure 8. Calculated vs predicted lake areas, combined lake (R^2 = 0.992).

With these changes, the procedure was much like that used in Phase One. The method of analysis is a daily simulation of the lakes' volume if they had been operated over the fifty-year period 1961-2010 using climate and river flow data recorded over that period. The simulation of the lake volume uses the following inputs and outflows:

- Inputs: Runoff from rain in the watershed and rain directly into the lakes.
- Losses: Evaporation when greater than precipitation (P-E), infiltration, overflow, and management water used to supplement river flow.
- Rules of operation: When the river falls below the 7Q10 (917 cfs, 1,819 A-F/d), sufficient volume is released from the lakes to raise the river flow back to that level. This does not stop until the lakes have lost all of their volume.

The analysis required several data sets. These included information on the soils and hydrogeology, rainfall data for fifty years, evaporation data for the same period, and river stage records for the same location for the same fifty year period. The following were available:

- Rainfall: Precipitation was taken from the National Weather Service Cooperative climate record at Merrill, MS, the nearest climate record site. The data were checked for accuracy and completeness of record.
- Evaporation: The nearest two sites were Fairhope, AL and Starkville MS. These were compared and were very close in value, with Fairhope having a slightly lower cumulative value because of its coastal location. Since evaporation changes rapidly from the coast to more inland environments, and the lake location is several miles inland, the Starkville

data were used, making the simulation slightly more conservative (higher evaporation rates than likely exist in reality).

- Soil and geo-hydrology: Dr. Darrel Schmitz, who developed much of this information, performed all of the analyses necessary to provide such factors as percent of lake volume lost to infiltration and percent runoff from the basin.
- River stage and flow rates: Two locations with very complete records were available. One (Merrill) was near the lake location, the other (Graham Ferry) was nearer Mobile. Since the Merrill site is nearer the point where demand is most critical, it was selected as the location which would trigger supplemental water from the lake.

Results

The analyses showed that with the existing climate and the size and volume specifications of the envisioned lake and the system of letting the lake supplement river flow when needed, there was not a single day in fifty years when the lake would not have been able to keep the river at or above the 7Q10. Figure 9 shows the results of the 50-year analyses. When the combined lake is used to supplement river flow, it seldom drops below a volume of around 40,000 A-F (of a total volume of 41,452 A-F), remaining near or above 90% of capacity most often.

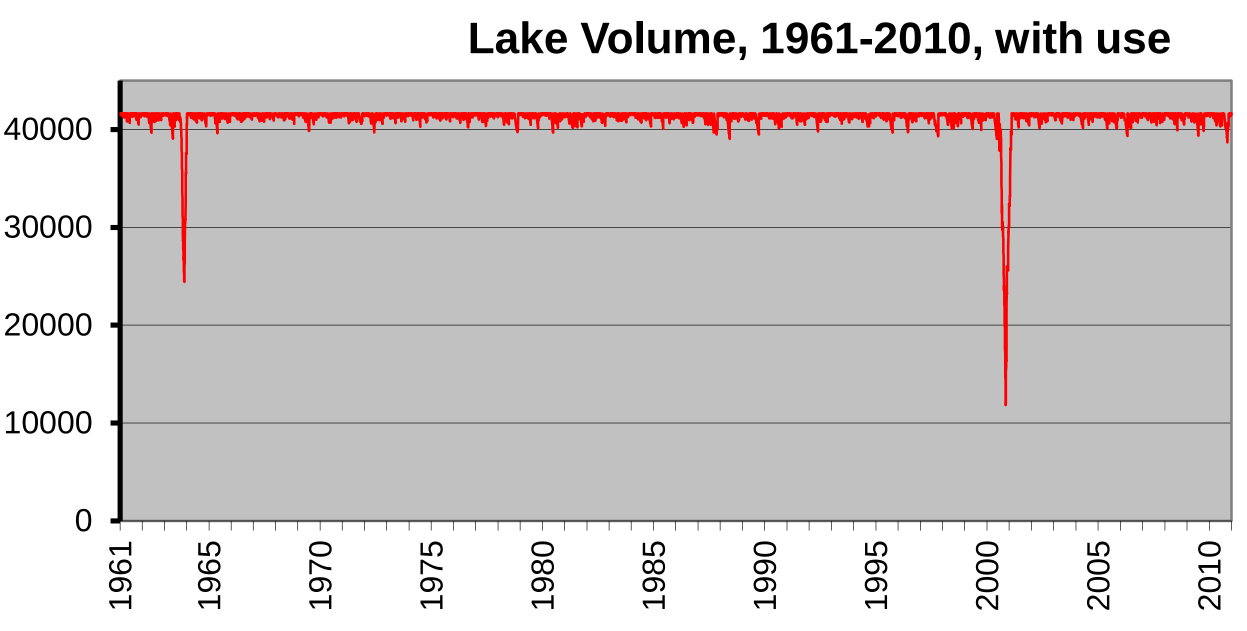


Figure 9. Merrill Lake simulated daily volume during the 50-year period 1961-2010.

The lake dropped to about one third of its lake-full volume only one time over the 50 year period, and that was during the sustained drought of 2000 (Figure 10). Specifically, during the drought of 2000 (the worst conditions during the 50 year period with back-to-back drought years), the river fell below 7Q10 and required supplemental water from the lake on 101 days. The lowest volume reached in the lake at this point (November 4, 2000) was 12,119 A-F, about 29% of capacity, and required the addition of a total of 32,892 A-F over this period. The only other notable period of lake volume decrease occurred during 1963 (see Figure 11). During this period, the lowest volume reached in the lake (on November 22, 1963) was 24,420 A-F, about 59% of capacity, and required the addition of 14,756 A-F of water over that period.

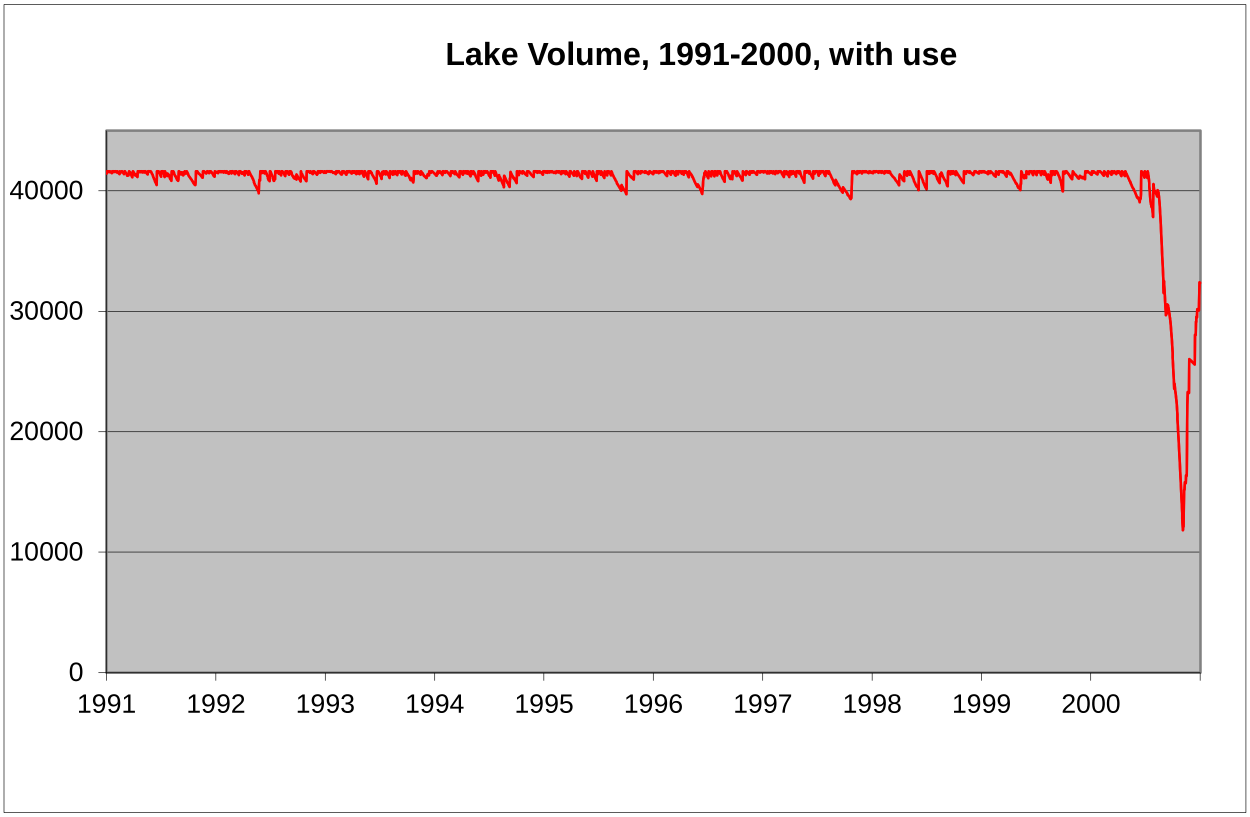


Figure 10. Lake George simulated daily volume during the 1991-2000 decade.

These results indicate that the idea of a lake supplementing the river flow to provide 100mgd is sound. In this simulation, the climate of the region sustained the lake full enough to provide the needed supplemental water on all occasions. The conclusion is that the climate and landscape of the area will support a lake of the modeled size, and that lake will store enough water to supplement the river when required.

Climate Change

The simulations were repeated using the climate change scenario developed in Phase One. This process decreased rainfall by 1.57%, increased evaporation by 9.73%, and decreased river flow by 1.57% so that all matched Tetra Tech's predictions for climate changes for this location by the year 2050. Although more water was required, there was still not a single day in fifty years when the lakes would not have been capable of keeping the river at or above the 7Q10. Figure 11 shows the lake drawdowns associated with the 1963 and 2000 drought events. The worst case was in 2000 between July 9 and November 7 when water was added from the lake to the river on 101 days. A total of 32,892 A-F was added during this period, and the lake volume fell to its lowest point of the 50-year period (about 11,000 A-F, or 27% of full volume).

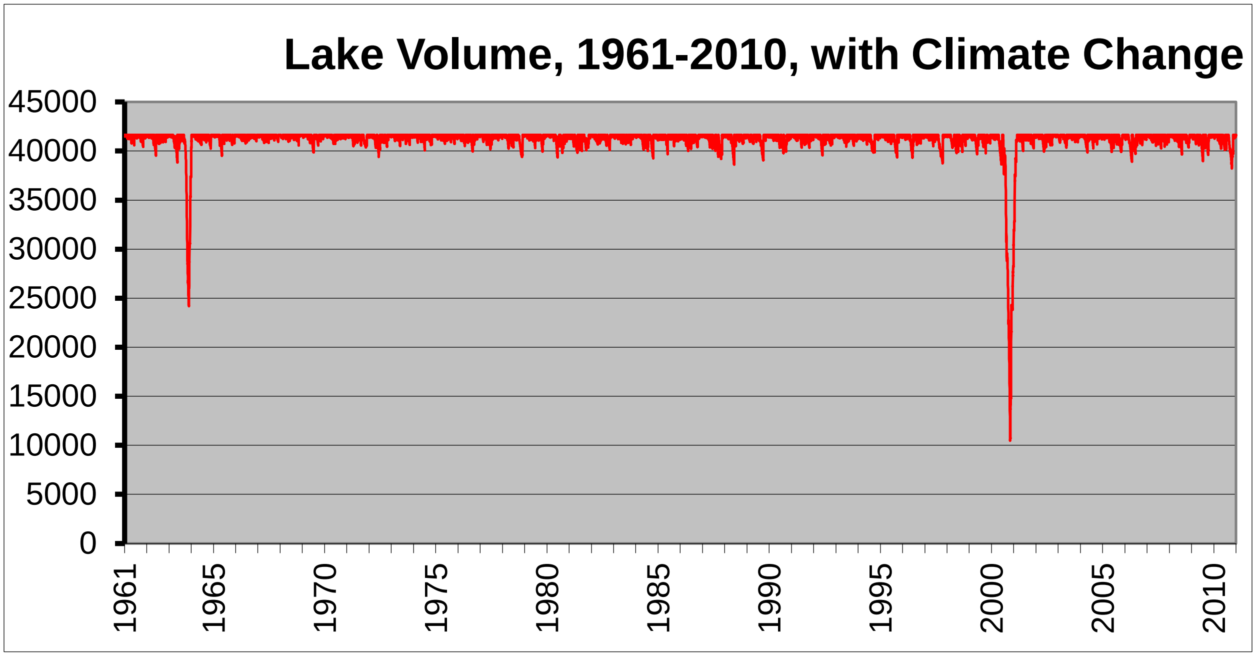


Figure 11. Lake George simulated daily volume during the 50-year period with climate change.

These results indicate that under the climate change scenario envisioned, the idea of a lake supplementing the river flow to provide 100mgd is still sound. In this simulation, the altered climate of the region still sustained the lake full enough to provide the needed supplemental water on all occasions. The conclusion is that a slightly drier and warmer climate and the resulting landscape of the area will support a lake of the modeled size, and that lake will store enough water to supplement the river when required.

Low Flow in the Pascagoula

In order to more completely examine the options for managing the Pascagoula River's low flow conditions, additional analysis was performed using the stage record of the river prior to any addition of lake water. For the purposes of this study, the extreme years were redefined. "Driest" year was the year in which the lowest flow of the year was the lowest flowrate of all fifty years, "wettest" year was the year in which the lowest flow for the year was the largest flowrate of the fifty, and the "average" year was the year in which the lowest flowrate was close to the average lowest flow for all fifty years. In reality, five years were very close to the same number. The one used was the one in which the highest flowrate and the lowest were most different.

Figure 12 Shows the driest year, 2000. The huge difference between the flow during wet times and dry times is immediately apparent. In the lower figure, the low flow period is put on a new scale to show its relationship with the 7Q10. It should be noted that during low flow, the river level stays very close to the 7Q10 level, occasionally dipping well below it.

Figure 13 demonstrates flow during the "wettest" year, 1975. No re-scaling is necessary to see that the river stays above the 7Q10, although even in this year, it gets relatively close at one point.

Figure14 is the "average" year. This year clearly shows why this type of analysis is so demanding. Although the year begins with high, variable flows, it hovers just barely above the 7Q10 during the dry period, not quite crossing it, but never getting much above it.

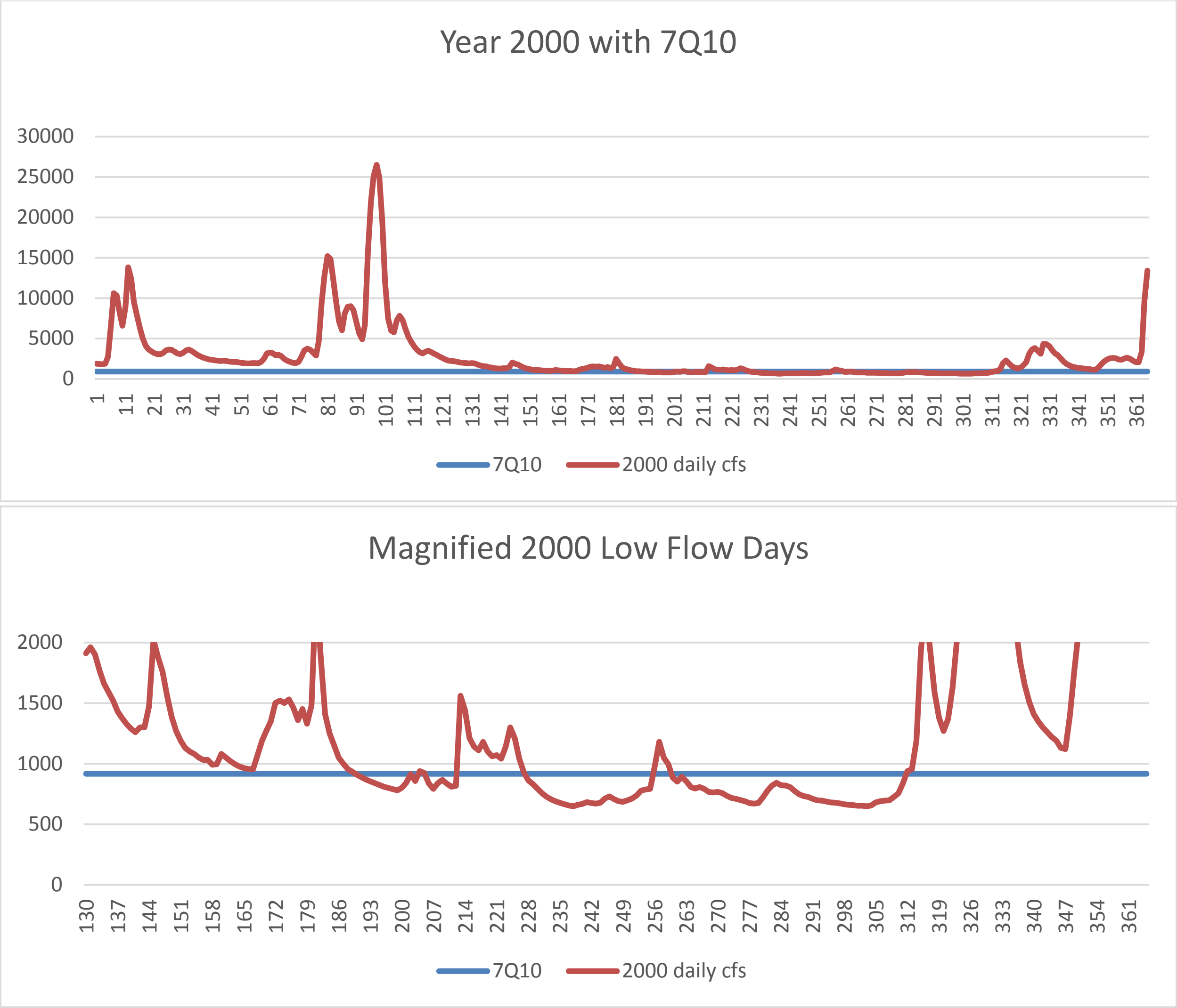


Figure 12. River flow in the driest year (lowest flowrate recorded). Second part is an expanded view of the driest period.

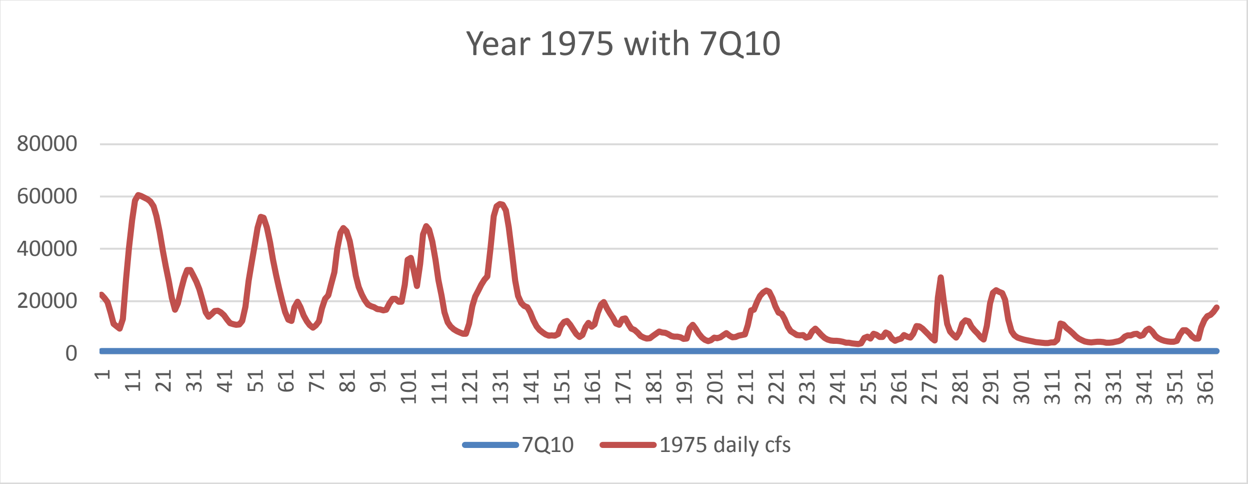


Figure 13. River flow in the wettest year, or year with the highest minimum flow.

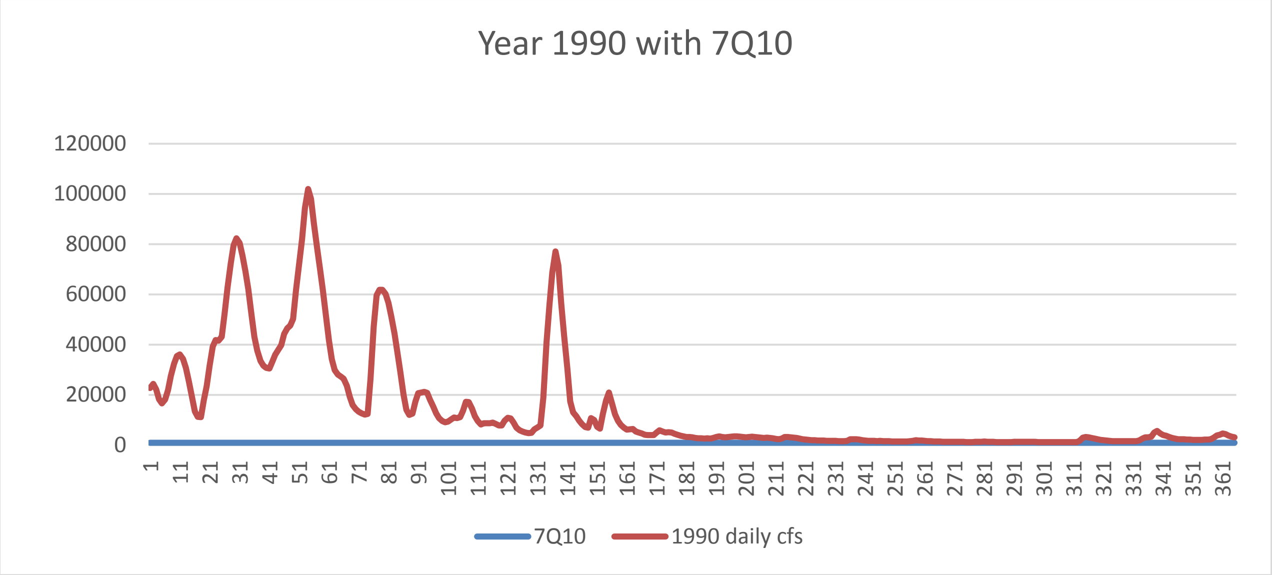


Figure 14. River flow in an average year. During the driest period, the flow never fell below the 7Q10, but stayed extremely close to it.

In future analysis for this watershed, it will be very important to treat low flow periods separately from the general record, since with the river so low, comparatively small variations constitute a large percent of the remaining flow.

PART II: Potential for use of existing Okatibbee Lake

In the second part of this task, simulations were run to use Okatibbee Lake to supplement the water provided by the new lakes. Achieving this involved several unique issues. First, a good management model had to be found. Several management models were examined. In one, the amount of water taken from Okatibbee Lake was based on the flow rate of Okatibbee Creek at Arundel, the first gaging station south of Okatibbee Lake. This proved unsuccessful, since the creek's flow almost never fell below its 7Q10 (12 cfs, 24 A-F/d). The next attempt involved using the lake to add exactly what would normally have been released from the lower lakes. This option raised the possibility of flooding, since Okatibbee Creek has such a small flow, so there was a realistic chance of producing a manmade flood. The decision was made to cap the amount of water added to the stream from Okatibbee Lake so that the added water never produced a flow rate in the top 10% of natural flow rates. This model references the prior Merrill model to check to see if the lower lakes have been triggered. When they are, Okatibbee Lake adds enough water to Okatibbee Creek to bring its flow rate to 90% of the optimum depth.

Two additional issues also had to be resolved. When a river is at low flow, it usually gets water from the aquifer. In the case where the level in that river has been artificially raised, it will lose water to the aquifer, but the amount lost was not certain. Fortunately, releases from Okatibbee Lake have actually been performed in the past, and it has been established that roughly half of the water released actually reaches the lower Pascagoula. This was determined in 2007 when Mississippi Department of Environmental Quality (MDEQ) asked the Pat Harrison Waterway District (PHWD) to release water from Okatibbee Reservoir 251 miles upstream to augment flow on the lower Pascagoula River. It was estimated that the released water took at least five days to reach the lower river, and about 50% of the water was lost.

Finally, in an attempt to improve upon the estimated time required for the release above Arundel to reach the Merrill Station, several options were attempted. These included calculating stream velocity at several points, and finding total distance traveled. Initially, the option of looking at how long a peak flow measured at Arundel took to reach Merrill was considered inappropriate, since peak flows travel faster than the small amounts planned to be added from the lake. However, the hydrologic records from three low flow years (1999-2001) provided three separate occasions when a small event occurred and moved roughly the appropriate amount of water from Arundel to Merrill. These three events required 9, 7 and 8 days respectively. The model was consequently set to assume an 8 day travel time between these two points. For example Figure 15-A shows the entire year's record of river flow at both Merrill and Arundel for the year 1999. Figure 15-B shows the first analyzed event between Julian day 340 and 360, illustrating a nine day travel time between the peak at Arundel and the subsequent peak at Merrill. Figures 16 and 17 show the other two analyzed events in the years 2000 and 2001, illustrating travel times of seven and nine days respectively.

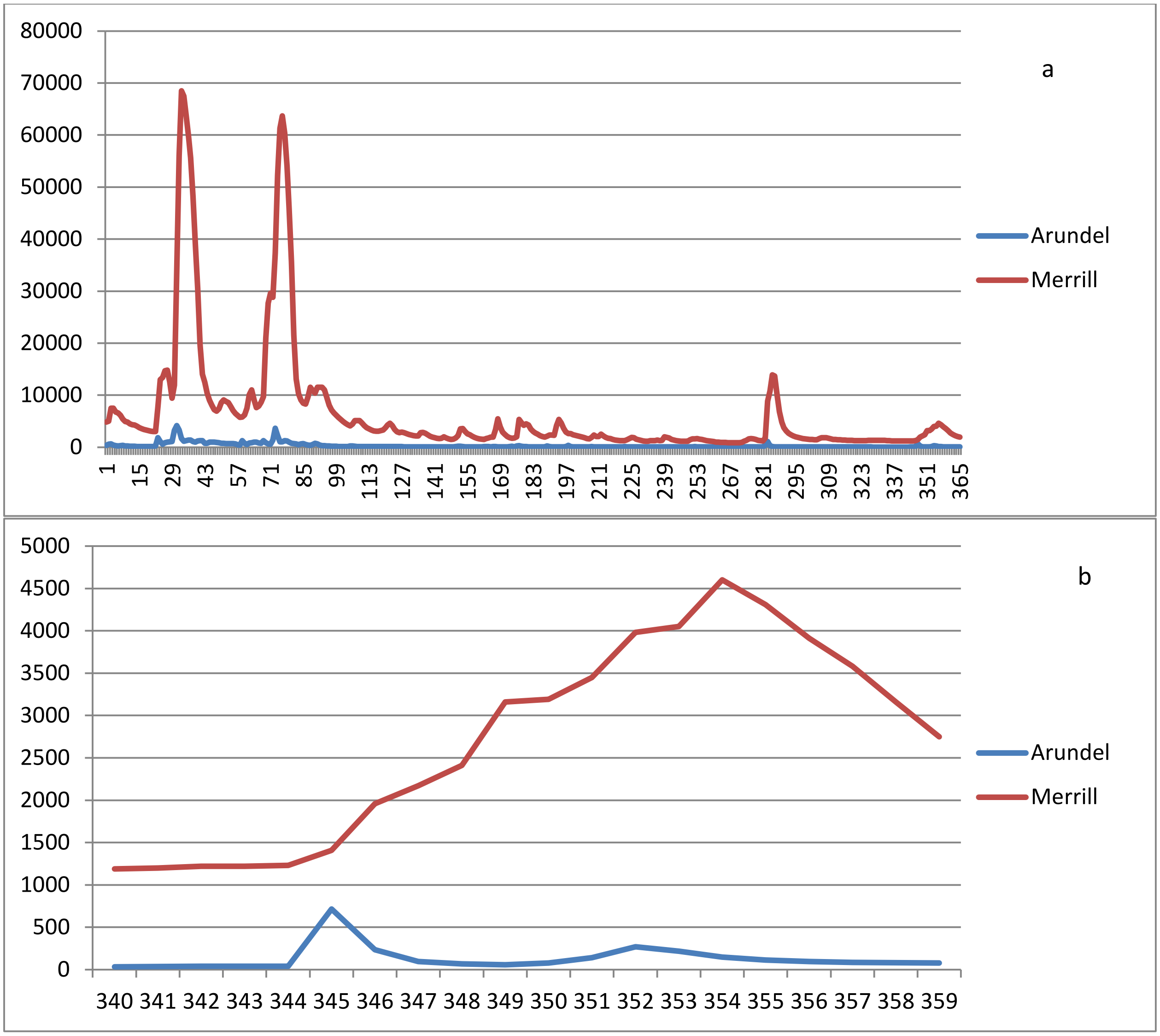


Figure 15. 1999 River flow at Arundel and Merrill demonstrating peak flow travel time of nine days.

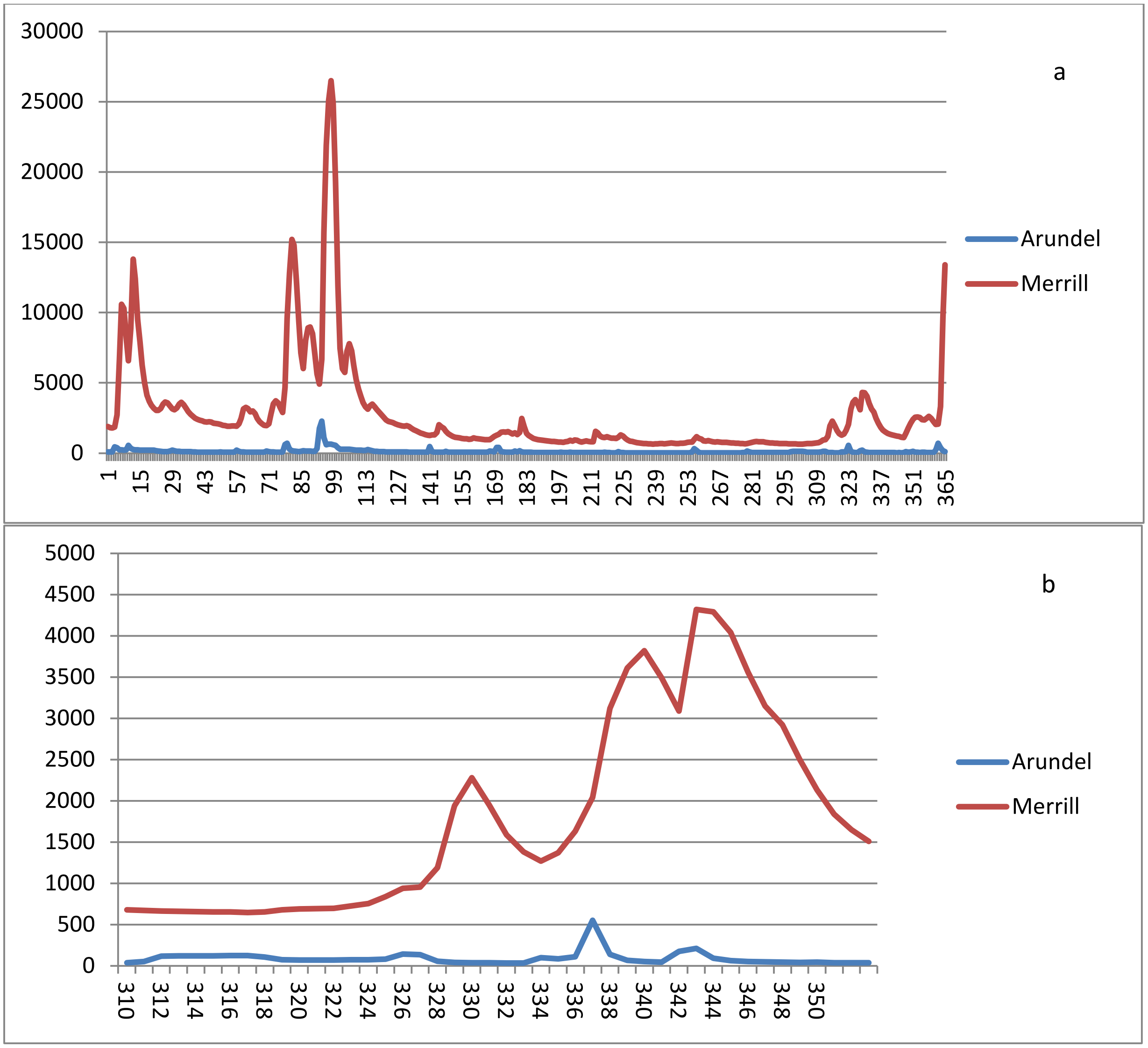


Figure 16. 2000 River flow at Arundel and Merrill demonstrating peak flow travel time of seven days.

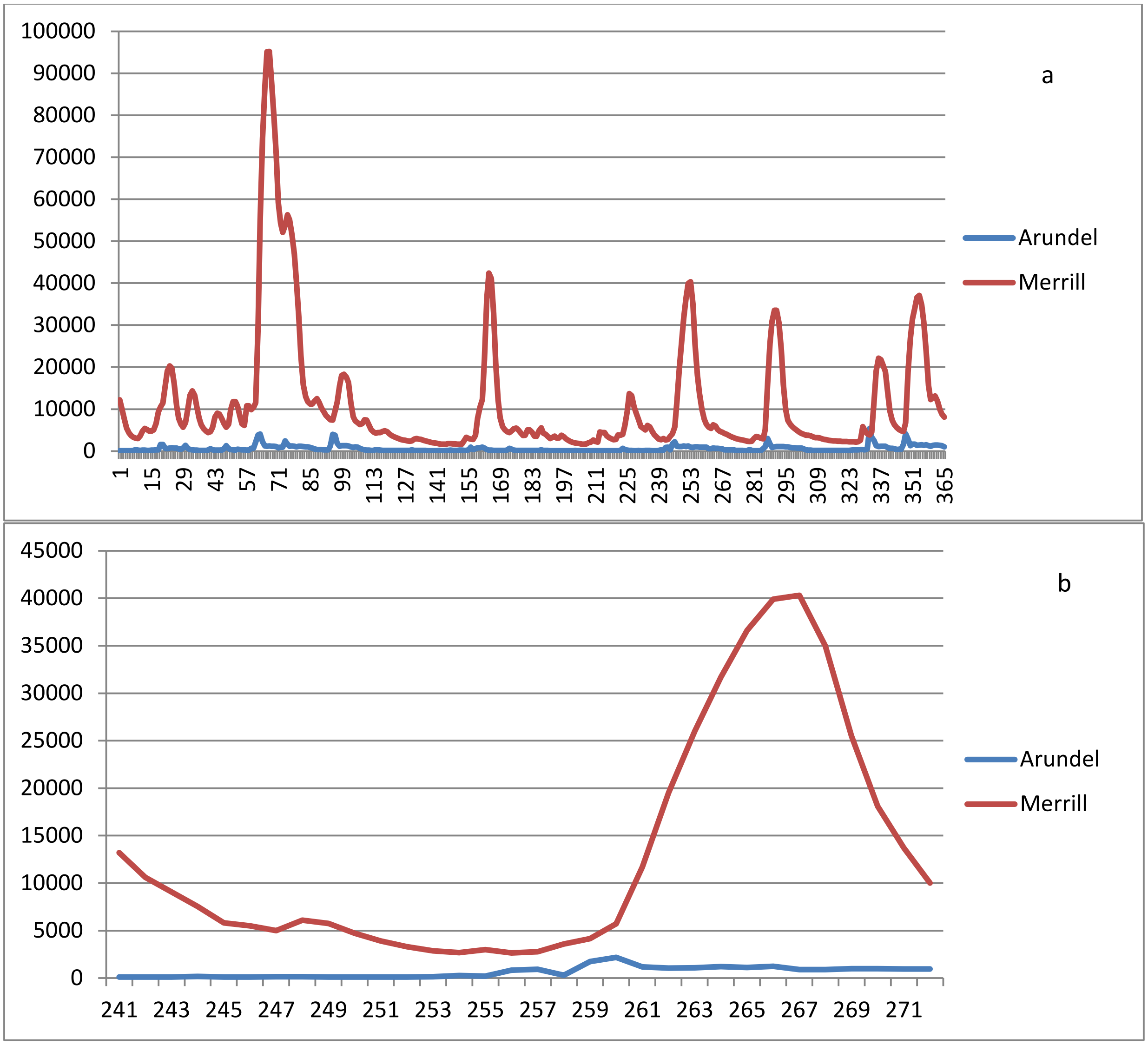


Figure 17. 2001 River flow at Arundel and Merrill demonstrating peak flow travel time of eight days.

A final limitation for this part of the task was that the record for Okatibbee Creek at Arundel begins in 1968. Therefore, the simulation analyses for part II began in 1971 and include only forty years of data, rather than the fifty-year period used in part I. Additionally, a new precipitation record was needed. The National Weather Service climatological record for Meridian, MS was selected and inspected for continuity. Using the evaporation record from the MSU site, new data sets for daily P-E were constructed for use in the new model.

The Okatibbee model used the same inputs and outflows as the Merrill model, described above, but with the Meridian daily P-E and the Arundel daily discharge. The model also referenced the river stage at Merrill and released from Okatibbee Lake the amount of water required to keep the flow above the 7Q10 there (limited by the ten-percentile flood flow at Arundel), then only added half that amount eight days later at Merrill (to account for the time lag and loss during transit from Arundel to Merrill).

In order to demonstrate the inconsistencies in performance when using Okatibbee to supply needed supplemental water, an exaggerated 7Q10 was used in the simulation. The results are shown in Figure 18 and in expanded scale in Figure 19. While withdrawals from the Lake George can supply precisely the amount of water needed to raise the flowrate as required, withdrawals from Okatibbee Lake are time lagged, sometimes missing the low flow period entirely, and sometimes adding water when it is no longer needed.

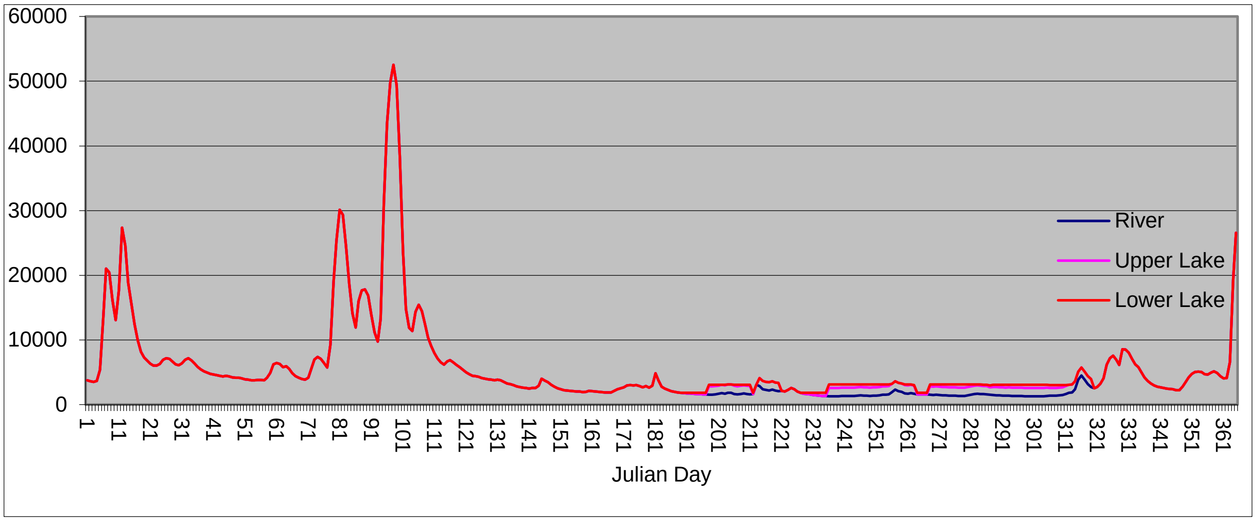


Figure 18. Low flow with exaggerated 7Q10 to demonstrate combined flow of Okatibbee and Lake Georges.

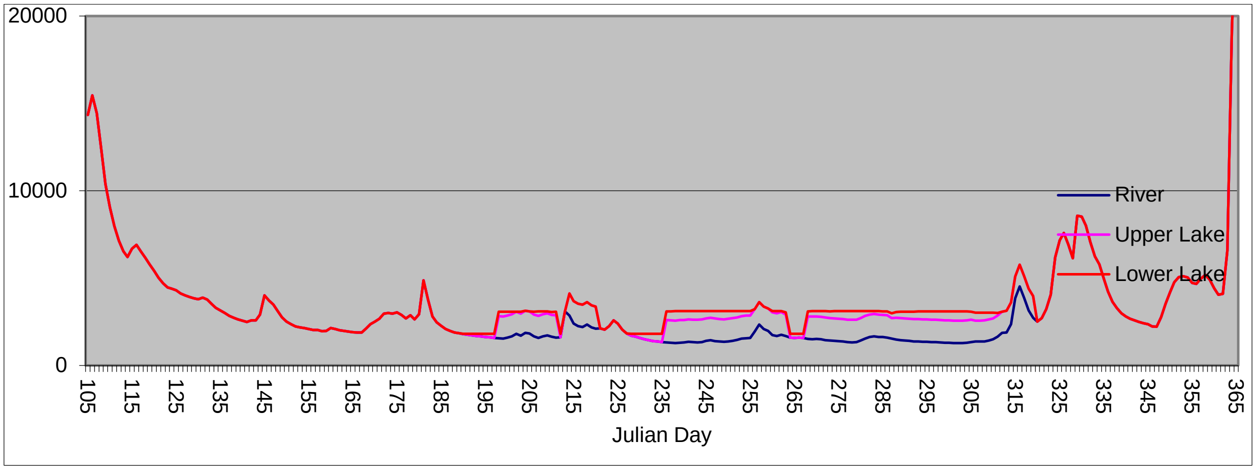


Figure 19. Duplicate of Figure 21 with expanded view of driest period.

Results of the 40-year simulation are shown in Figure 20. There were no days in the period when Okatibbee Lake could not supply the needed water. However, there are two primary problems. First, the amount that can be added at any given time is limited due to the small normal flow in the receiving water. Any major release has the potential to generate a man-made flood event. Of course roughly half of that amount will be lost to infiltration during its flow to the mouth of the river. Second, the time lag of eight days creates a particular problem. Many years have a long period when the flow hovers very near the 7Q10, occasionally crossing over it, then returning as a small rainfall occurs. During these years, the lag between needing the extra flow and actually receiving the extra flow is so great that it is not likely to be present when it is needed and is likely to show up when it is not needed. The only time when it would be of real use would be during a very long, sustained drought, and even then it would be a small contribution.

On the positive side, Okatibbee is large enough compared to this demand that using it according to the described management limits would have little negative impact on the lake.

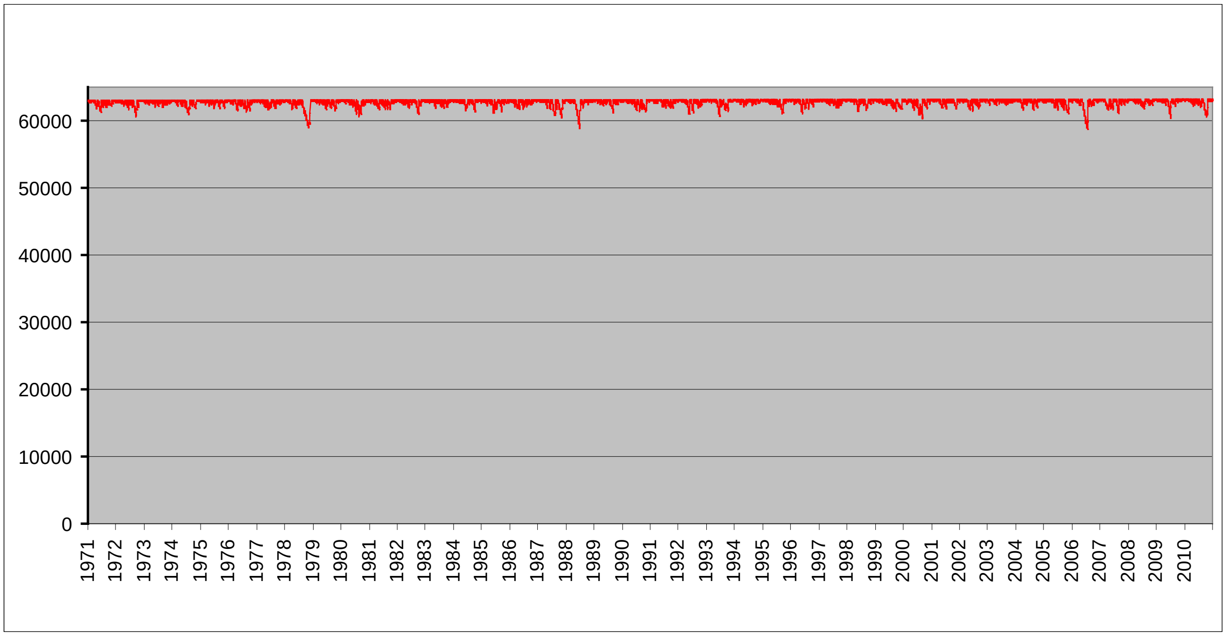


Figure 20: Okatibbee Lake simulated daily volume during the 40-year period 1971-2010

Conclusions:

The second phase of this project involved several additional steps.

First was selecting an actual site for the lake, identifying its geometry, depth and volume. In the end these analyses ended up producing two lakes, each with its own characteristics. In order to be sure that the model accurately described changes in geometry due to changes in water volume, both lakes were subjected to extensive analysis of how the lake surface area changes as water is either added or lost. Of course, reduction in lake surface area would result in gain to the area of the rest of the watershed and a gain in volume, hence lake area would result in a decrease in the area of the rest of the watershed. With actual lakes defined, this more accurate description of the relationship was added to the model.

These lakes had more volume than the previous theoretical lake and a significantly increased watershed. As a result, the model predicted no cases where the lakes would not be able to restore flow to the minimum 7Q10 throughout the entire 50 year period.

As in the first phase, the true fifty year weather and river records were modified to reflect the predictions for 2050 as produced by Tetra Tech. Even with climate change included, the fifty year record showed no cases in which the lakes were unable to maintain the 7Q10.

This portion of the study shows that the lakes as proposed should be extremely effective at maintaining minimum flow in the Pascagoula River.

The second step was carried out primarily to assist in future work on low flow in the Pascagoula River. In Phase 1, a great deal of effort was spent on trying to predict stages at one location on the Pascagoula based on the stages at another location. This effort failed because the data were so dominated by high flow periods that low flow predictions were lost as “noise.”

In this step, the Wettest, Average, and Driest years were re-defined based on how low the flow went in that year. It quickly became apparent that future analyses should focus more tightly on low flow alone. In many years, including the average year, there is an extended period when the flow hovers very near the 7Q10, occasionally dropping below it. During these stages, changes are a large percentage of the remaining flow, so what would normally be insignificant variation becomes vitally important.

These results were important for the next step and will be essential in the management of the river.

The final step was examination of Okatibbee Lake to serve as the source for preventing low flow near the mouth of the Pascagoula. One of the most demanding parts of this step was determining how long it takes flow to move from Okatibbee Lake to the mouth of the Pascagoula. After several failed approaches, three low flow years were examined for a time when a small, but noticeable rainfall event occurred during low flow. These were seen to be a close simulation of adding lake water during low flow. The results were quite consistent, indicating a flow time of 8 eight days.

Using this time, the simulation shows two major problems. First, a relatively small release of water that high in the watershed can overwhelm the receiving stream, so the volume must be limited. Second, the eight day travel time severely restricts the effectiveness of the release. As previously stated, it is common for flow to stay very near the 7Q10 for extended periods, sometimes falling below it. A travel time of eight days means the response is very late and commonly arrives after the event is already past and more rain has come.

This analysis shows that releases from Okatibbee Lake are of limited value, primarily being of use during major sustained droughts.

References:

NOAA. 2014. National Climatic Data Center, Climate at a Glance, Time Series: 1895-2013. Available online at http://www.ncdc.noaa.gov/cag/.

Konrad, C.P., Booth, D.B., 2002, Hydrologic trends associated with urban development for selected streams in the Puget Sound Basin, western Washington: U.S. Geological Survey Water-Resources Investigations Report 02-4040, 40 p.

Pote, J., C.L. Wax, and M.L. Tagert. 2013. Utilizing Impounded Waters in the George County to Decrease the Incidence of Low Flow in the Pascagoula River.

Speer, P.R., W.J. Perry, J.A. McCabe, and O.G. Lara. 1965. Low-Flow Characteristics of Streams in the Mississippi Embayment in Tennessee, Kentucky, and Illinois. U.S. Geological Survey Professional Paper 448-H. Washington, D.C.: U.S. Government Printing Office.