IMPLEMENTATION OF BUILDING BLOCKS RECOMMENDATIONS AT LAKE O' THE PINES ON BIG CYPRESS CREEK

JUNE 2014

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Environmental Flows Project

The Caddo Lake Institute (CLI) initiated the environmental flow project ("Project") to restore and protect healthy flows in the Caddo Lake watershed and larger Cypress Basin in 2004 as part of the Sustainable River Program (a cooperative program between the U.S. Army Corps of Engineers (USACE) and the Nature Conservancy (TNC)). The initial goal was to seek changes to reservoir operations at Lake O' the Pines (LOTP) to maintain the ecological health of Big Cypress Creek and Caddo Lake while also meeting the water needs of people. The Project has since expanded its scope to include other major tributaries to Caddo Lake and within the Cypress Basin. The Project methodologies are consistent with the Texas Environmental Flows Program (TIFP) established by Senate Bill 2 and the Environmental Flows Planning Process Established by Senate Bill 3.

Documentation of the work of the Project can be found on the CLI website (www.caddolakeinstitute.us) including the 2005 report, *Summary Report Supporting the Development of Flow Recommendations for the Stretch of Big Cypress Creek Below Lake O' the Pines Dam,* produced by a team of experts from Texas A&M and CLI's 2010 summary report, *Environmental Flow Regime and Analysis Recommendations Report,* which includes, in Appendix A, a summary of the process.[1]

Having developed, evaluated and revised flow recommendations for Big Cypress Creek, the Project partners have now begun the process testing an implementation approach. At the conclusion of the 4th Project workshop, held in December 2011 in Jefferson, Texas, participants, including the Northeast Texas Municipal Water District (NETWMD) and the USACE, the two entities with primarily responsibility for the management of water in LOTP, agreed to implement a strategy that would provide for much of the flow recommendations for the Big Cypress Creek that had been developed through the Project. Given the multi-tiered flow regime recommendation, the implementation plan has had to include a method for deciding when various components of the flow regime will be in force e.g. how will the wet, average and dry hydrologic conditions be determined? Also, since LOTP reservoir was developed for specific purposes (providing water supply and flood control), any permanent adjustments to the reservoirs operating rules need to consider potential impacts on these purposes. The goal of this report is to inform future decisions regarding implementation by providing an evaluation of the potential costs of expected impacts on the two main purposes of LOTP, water supply and flood control.

This report will describe the current implementation plan and present the evaluation of potential impacts of implementing the recommended flow regimes. Reservoir simulation models were used to evaluate various alternatives to the current implementation plan, which has now been in place since 2012. Modifications to that implementation plan will be discussed with the goal of reducing any negative impacts on flood control or water supplies for other purposes, ensuring that, as the implementation moves forward, the costs and benefits of this proposal can be transparently evaluated.

1 Operations of Lake O' the Pines Reservoir

1.1 Current (pre-eflows) operations

Lake O' the Pines was created by the construction of the Ferrell's Bridge Dam on the Big Cypress Bayou approximately 81 miles upstream from the Red River. The project was authorized by the Flood Control Act of 1946 and additional purposes of both recreation and water supply were added during construction. The lake's normal conservation pool is 228.5 feet mean sea level (ft-msl) though it is operated to a seasonal recreational pool of 230 ft-msl from mid-May to mid-September (Figure 1). The federal authorization for the permit requires a minimum release of 5 cfs (cubic feet per second), although operations prior to the recent implementation of the eflows recommendations often included releases of 25 cfs above what was being released for downstream diversions.

[1] These and other Project documents are available at www.caddolakeinstitute.us.

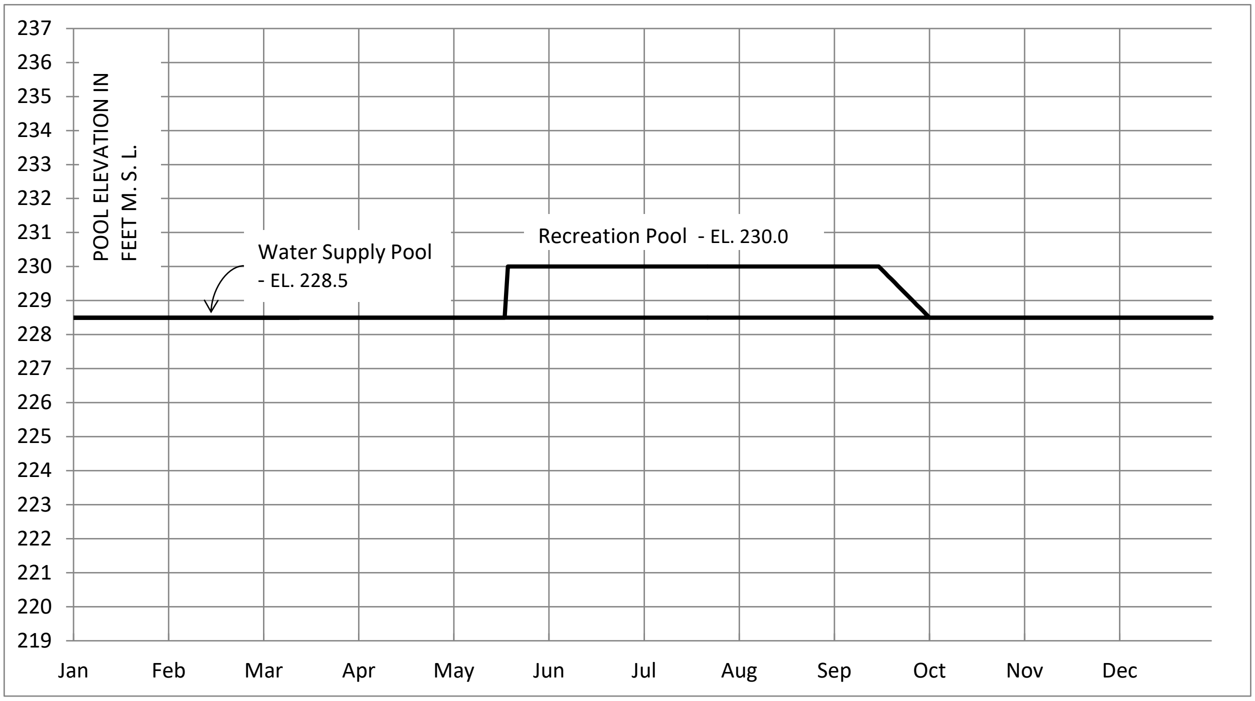


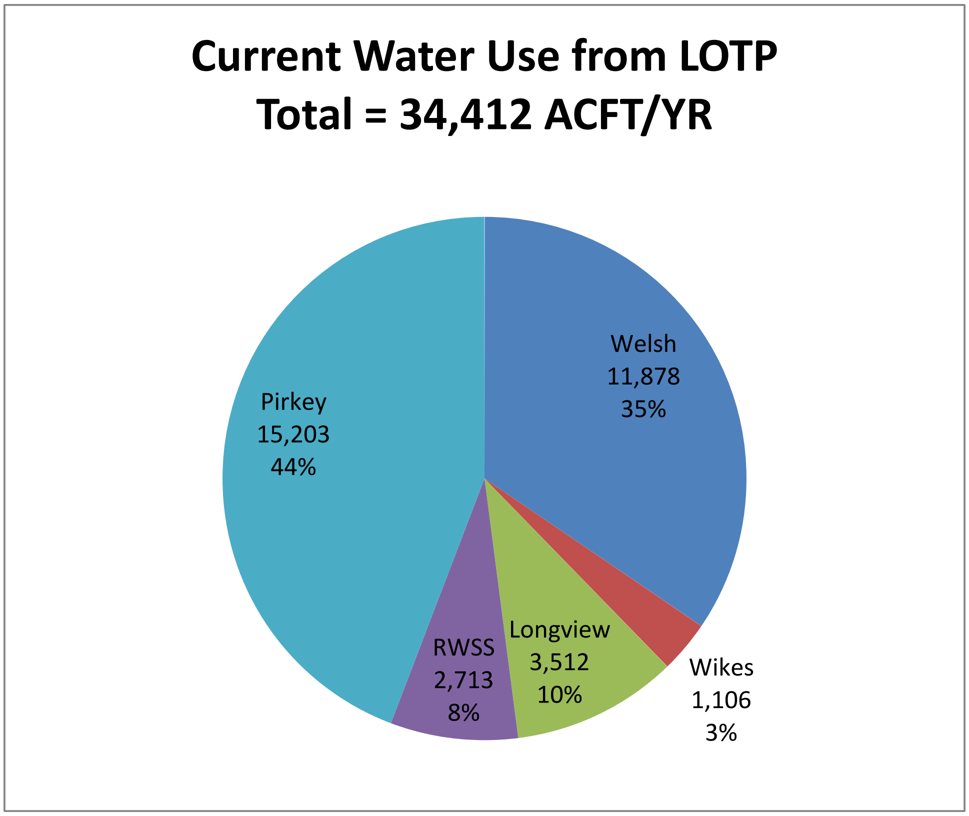
Figure 1 Lake O' the Pines Operating Rule Curve

1.1.1 Water Supply

Water supply storage exists in the conservation pool between elevations 201 ft-msl and 230 ft-msl. Intake structures are located at various points on the lake and downstream of the on Big Cypress Creek. LOTP provides water supply storage for the Northeast Texas Municipal Water District (NETMWD), which holds Texas water right number 4590. The original priority date associated with this permit is September 16, 1957. When it was issued, the authorized diversion was 161,800 acft/yr (acre-feet per year). In addition to water in LOTP, this diversion is supported by water from Bob Sandlin Reservoir located upstream of LOTP. In 1995 and 2008, the NETMWD permit (#4590) was amended to increase the interbasin transfer (IBT) allowed under this permit to 42,000 acft/yr. TCEQs WAM run 3 assumes the total diversion under this permit is 203,800 acft/yr, the combination of these two values. The firm yield of LOTP is in the range of 150,000-160,000 acft/yr.

NETMWD serves regular water supply systems (RWSS) for the cities of Jefferson, Ore City, Lone Star, Avinger, Hughes Springs, Daingerfield, Longview and Marshall. It also provides cooling water for three steam electric power plants. The estimate of current water supply provided by LOTP reservoir, based on monthly average reported diversions for the period from 2002 to 2011, is about 34,000 acft/yr. Of that amount, approximately 82% is used as cooling water by steam electric power plants. With the exception water for the of the Pirkey plant, all of this water is diverted from LOTP. Water released for the Pirkey Plant is released from the reservoir and diverted several miles downstream of the reservoir. Recently, Pirkey use has been approximately 21 cfs[2].

[2] Releases are also made downstream for the City of Marshall, which has an intake above Caddo Lake. Releases for Marshall were not included in the model used for the evaluation presented in this report.



Conjunctive use with other upstream reservoirs, the specifics of individual contracts and the inherent uncertainty associated with long term water supply planning makes an estimate of future needs from LOTP complex. However, at a meeting at the USACE district office in Fort Worth on October 27, 2011, NETMWD indicated that for the first round of model simulations a scenario that assumes an additional 100,000 acft/yr on top of the current demands would be appropriate for the analyses presented in this study. This total future water use estimate (134,000 acft/yr) is comparable to the total volume of water that NETMWD currently has under contract (148,435 acft/yr) thus this amount may be a reasonable as a long term planning value, however there is no estimate of when the actual water use might reach this level. Several of the entities supplied by the NETMWD have projected demands at only a fraction of their contract amount by 2060.

Water supply operations for LOTP include a drought contingency plan that calls for pro rata reductions applied equally to all users when storage in the reservoir drops to specific trigger levels. (Table 1)

Table 1 North East Texas Municipal Water District Drought Contingency Plan for Lake O' the Pine Reservoir

Stage	Storage	Demand Reduction
Stage 1	50%	10%
Stage 2	40%	15%
Stage 3	25%	20%

While releases for eflows were suspended in 2012 before the reservoir reached these levels, in the simulation modeling (discussed below), the same trigger levels and reductions are applied to reduce the recommended environmental flow releases.

Finally, NETMWD has the ability to call for up to 12,000 acft/yr from Bob Sandlin Reservoir, located upstream of LOTP. Although this call has never been made, for the purpose of this report and the reservoir simulation model used to test various alternatives, this call will be made if LOTP elevation drops to 40% conservation pool. At this point, the release will be made from Bob Sandlin to LOTP over 30 days. The release will only be made only once per year.

1.1.2 Flood Control

When inflows into the reservoir cause the elevation in LOTP to rise above 228.5 ft-msl (or 230 ft-msl in the summer) flood control operations are dictated by the plan of operation in USACE reservoir control manual. The plan specifies release rates at various reservoir levels above the top of the conservation pool. The objective of these operations is to evacuate the flood pool as quickly as possible while minimizing downstream flooding and if possible prevent uncontrolled spillway flows. The reservoir is limited to a maximum release of 3,000 cfs, but operators for the USACE also attempt to maintain the combined flow from Little, Black and Big Cypress Jefferson gages less than 7,000 cfs. There is also a further downstream control point at Shreveport where operations attempt to keep the stage below31 ft-msl.

Although elevations in LOTP regularly enter the flood pool (since filling in 1960 there have only been two years in which water did not enter the flood pool), an uncontrolled release over the spillway has never occurred. Floods have caused the elevation to rise to within 10 feet of the top of the flood pool four times. (Figure 2) It is also worth noting that the flood event in 1958 occurred before the reservoir had completely filled. When this event began, the water surface elevation was 208.42 ft-msl. A maximum pool elevation of 246.5 ft. msl would have resulted if the flood had occurred on a normal pool level of 228.5 ft-msl.

Analysis was performed as part of the 1987 Cypress Bayou Basin Feasibility Report (February 1987) which evaluated the potential impact of an alternative that would reallocate of 50,000 acre-feet of flood storage by raising the conservation storage elevation by 2.5 feet from 228.5 ft-msl to 231 ft-msl. This scenario assumed the dam embankment and spillway features of the dam would remain as they presently exist and the top of the flood pool remain at 249.5 ft-msl. According to this analysis, the reduction in flood control storage would increase the probability of a 249.5 ft. msl elevation from a 50-year recurrence interval to a 40-year recurrence interval. This analysis is now 30 year old and would need to be repeated but provides a ‘ballpark’ estimate of the potential impact of reducing flood control at approximately the amount that has been considered by the project.

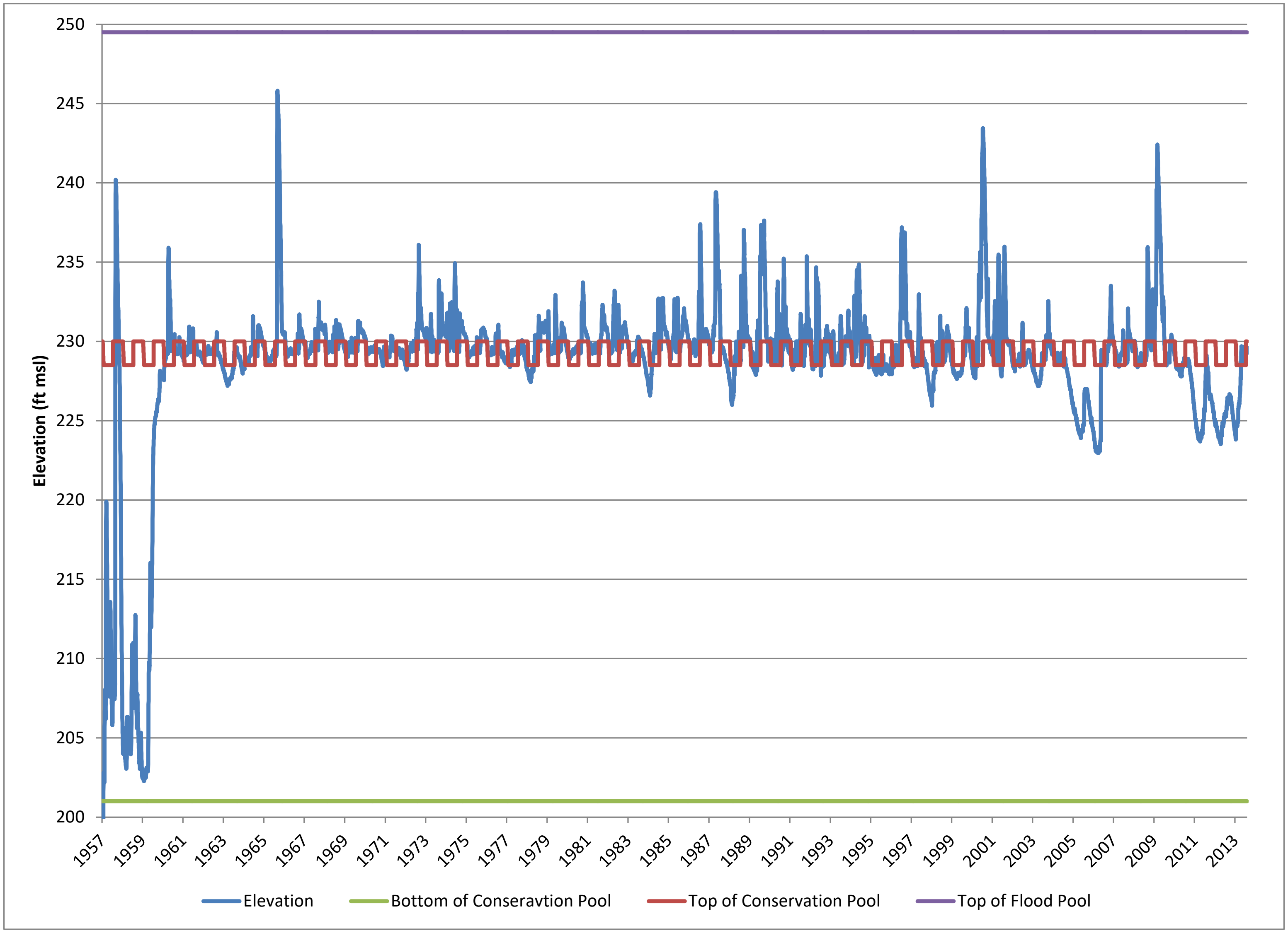


Figure 2 Lake O' the Pines Historical Elevations

1.2 Interim (eflows) operations

The implementation plan that was agreed to in 2011 defines how releases are made from LOTP to meet environmental flow needs. This plan was originally proposed by USACE and analyzed primarily by simulating the proposed operating rules using the USACE RiverWare model. According to this proposed operating plan, releases are determined based on the hydrologic condition (wet, average or dry) at the beginning of each month. Hydrological condition is defined as a combination of meteorological conditions (Palmer Drought Severity Index) and reservoir level as defined in Table 2. In this table, winter (Sep 30 – Mar 20) and summer (Mar 21 – Sep 14) correspond to the seasonal rule curve used in the UASCE reservoir control plan. The reservoir level triggers are equal to one foot below the seasonal conservation pool (above which the reservoir conditions is considered wet) and three feet below (below which the reservoir conditions is considered dry). When the reservoir elevation is between 1 and 3 feet below the top of the conservation pool the reservoir conditions is considered average. The Palmer Drought Severity Index primarily reflects long-term drought and has been used extensively to initiate drought relief. Values below -1.99 indicate drought conditions and values above 1.99 indicate moist conditions.

Table 2 Determination of Hydrologic Condition.

			Storage Triggers (Conservation Pool, Winter 228.5, Summer 230)		
			Dry	Avg	Wet
			Winter < 225 Summer < 227	Winter 225 - 227.5 Summer < 227 -229	Winter > 227.5 Summer > 229
Palmer	Dry	< -1.99	Dry	Dry	Dry
Drought	Avg	-1.99 - 1.99	Dry	Avg	Avg
Index	Wet	> 1.99	Dry	Avg	Wet

Once the hydrologic conditions are determined, base flow releases are made according to the building blocks recommendations developed in the Project (Figure 3). For example if on June 1st the elevation in Lake O' the Pines is 228 ft-msl (a wet condition) and the Palmer Drought Index is 0.13 (an average condition), and thus the hydrologic condition is determined to be average (based on the rules defined in Table 2). For all of June then a constant base flows of at 79 cfs plus any additional water to meet downstream diversions would be released from the reservoir.

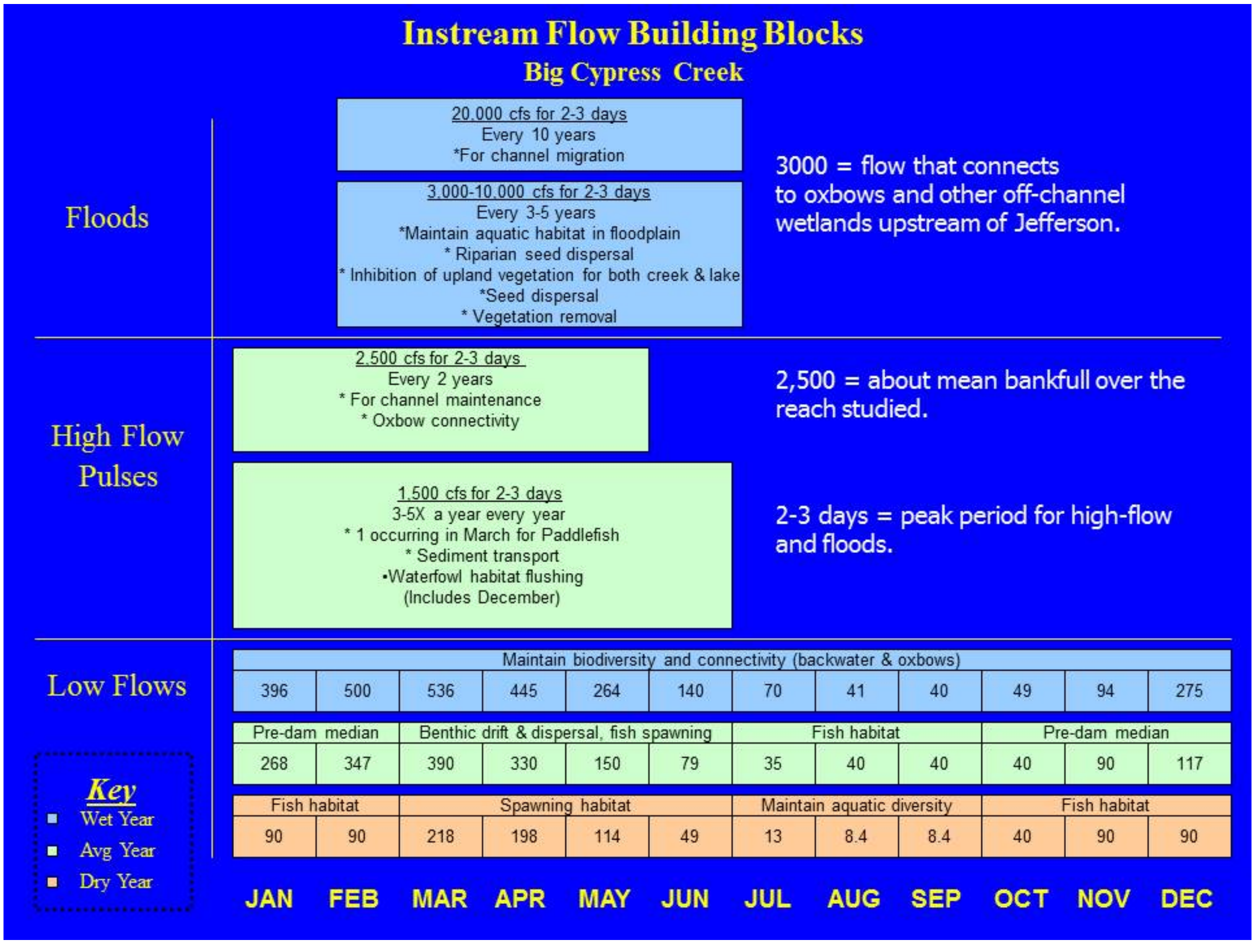


Figure 3 Big Cypress Creek Flow Regime Recommendation.

The reservoir simulation model developed by the USACE also included rules for scheduling some of the recommended pulse flow releases. Since infrastructure constraints and concerns about potential downstream flooding currently limit releases from LOTP to a maximum of 3,000 cfs, the flood releases above this level, shown in Figure 3, are not included in the current implementation plan. Additionally, although the current standards include recommendations for a 2,500 cfs pulse flow once every 2 years, these targets were also not explicitly incorporated into the release rules included in the simulation model. However, during wet and average times, releases of greater than 2,500 cfs typically occur at least once every two years as part of normal operation to evacuate the flood pool. Rather than forcing the model to make the 2,500 cfs releases, the results of the simulation model are reviewed to verify that these releases happen as part of normal operations. The recommendation for the 1,500 cfs pulses is explicitly included in the model simulation rules. In the current version of the USACE reservoir operations model, three, 1,500 cfs releases for four days are made each year (the standards call for 3-5 events per year). If these pulses do not occur because of normal flood release operations by the 15th of March, August and December, then these pulse releases are made from reservoir storage so long as the hydrologic condition is average or wet.

Actual real time implementation of the high flow pulse releases has been less strictly enforced than as simulated by the model, but it has followed this basic guidance of attempting to make high flow pulse releases when the conditions are average or wet.

1.3 Current Implementation

The USACE reservoir control staff is in the process of updating the LOTP Water Control Manual, which includes, in Chapter 7, the Water Control Plan. This Plan includes guidance as to how the storage in the flood pool will be evacuated. Up until recently, the guidance in the water control plan has been to evacuate the flood pool as quickly as possible in order to make that space available to capture the next flood event. As part of the revision to the water control manual, staff was directed to provide recommendations for changes to the guidance to be included in the water control plan that would taper off the high releases as the flood pool storage drops. These recommendations are intended to minimize the effect of abrupt changes in releases to minimize impacts on bank erosion and potential impacts to fish by stranding them in disjunctive pools as the flow rates come down. This more gradual decline in flow rates meshes well with the objectives of the Project to provide wet base flows and occasional high flow pulses. The current language being developed for inclusion in the updated water control plan will also likely recommend that, as the flood pool is dissipated, flood pool releases begin to transition into to the base wet flow rates at approximately 1 foot above the seasonally adjusted top of conservation pool. For these times, the new water control plan is likely to provide reservoir operations staff with the flexibility to increase releases if forecasts suggested that significant rains are expected. Staff will likely be authorized to make high flow pulse releases at 1,500-3,000 cfs as recommended by the Project. Based on reservoir simulation modeling it appears that these recommendations, which will likely be included in the updated water control plan, will adequately provide for the base wet and high flow recommendations of the Project.

While the base wet and high flow pulse releases are made when LOTP is close to full, base average and dry releases are made from stored water in the conservation pool. Current demands for water diversions (~34,000 acft/yr) represents about one fifth of the total available yield ~150,000 acft/yr). While modeling of the current implemental plan over the historic record appears to support the ability of making releases from the conservation pool at the base average and dry levels, recent experience in 2013 indicates that during very dry periods, LOTP can drop to elevations that create operational challenges for water intake structures in the upper part of lake. In 2013, as elevations dropped closer to 224 ft-msl, it appears that sections of the upper lake, where one intake is located, could become disconnected from the main body of the lake. Additionally, there were some concerns regarding the impact of lower lake levels on existing boat docks.

To understand better the effect of the recent implementation plan on releases and lake levels, the pattern of releases and resulting lake levels are discussed below. On January 1, 2012, LOTP reservoir elevation was 224.1 ft. msl about four feet below the top of the conservation pool. The Palmer Drought index was -4.07, which indicates a dry condition (the PDSI remained in dry for the entire year). (Figure 4) Based on the reservoir elevation and PDSI, the hydrologic conditions was determined to be in a dry state and base flow releases of approximately 125 cfs were made from the reservoir (the target release was 116 cfs = 90 cfs Jan Dry base and 26 for diversions for the Pirkey Power plant). Releases were kept at the base dry through the spring, when, in April, the reservoir level rose to within 3 feet of the top of the conservation pool and the PDSI apparently rose above -1.99. This resulted in a shift in the operations to average conditions. (Note the historical record for the PDSI currently records the PDSI in April 2012 as -2.57, which would indicate a dry condition but these records apparently have been revised from the real time reports that Corps staff read at the time). Since the releases were being managed for average conditions the Corps made a designated high flow pulse release of approximately 2,500 cfs in late April. During the summer of 2012, through the end of the year inflows into LOTP were very low with many days of zero inflows. Although the hydrologic condition was shifted to dry and the recommended releases in the summer and fall under dry conditions are quite low, the reservoir elevation continued to decline. By October 2012, LOTP elevation was below 225 ft. msl, at which point NETMWD decided to suspend the releases for eflows because of the concerns explained above. For the remainder of 2012 and through most of 2103 releases for LOTP returned to their pre eflow implementation levels of about 51 cfs (25 cfs for instream and 26 cfs for Pirkey). This resulted lower releases from November 2012 through May 2013 but, somewhat paradoxically, higher releases than those called for in the Project recommendations for June 2013 through October 2013.

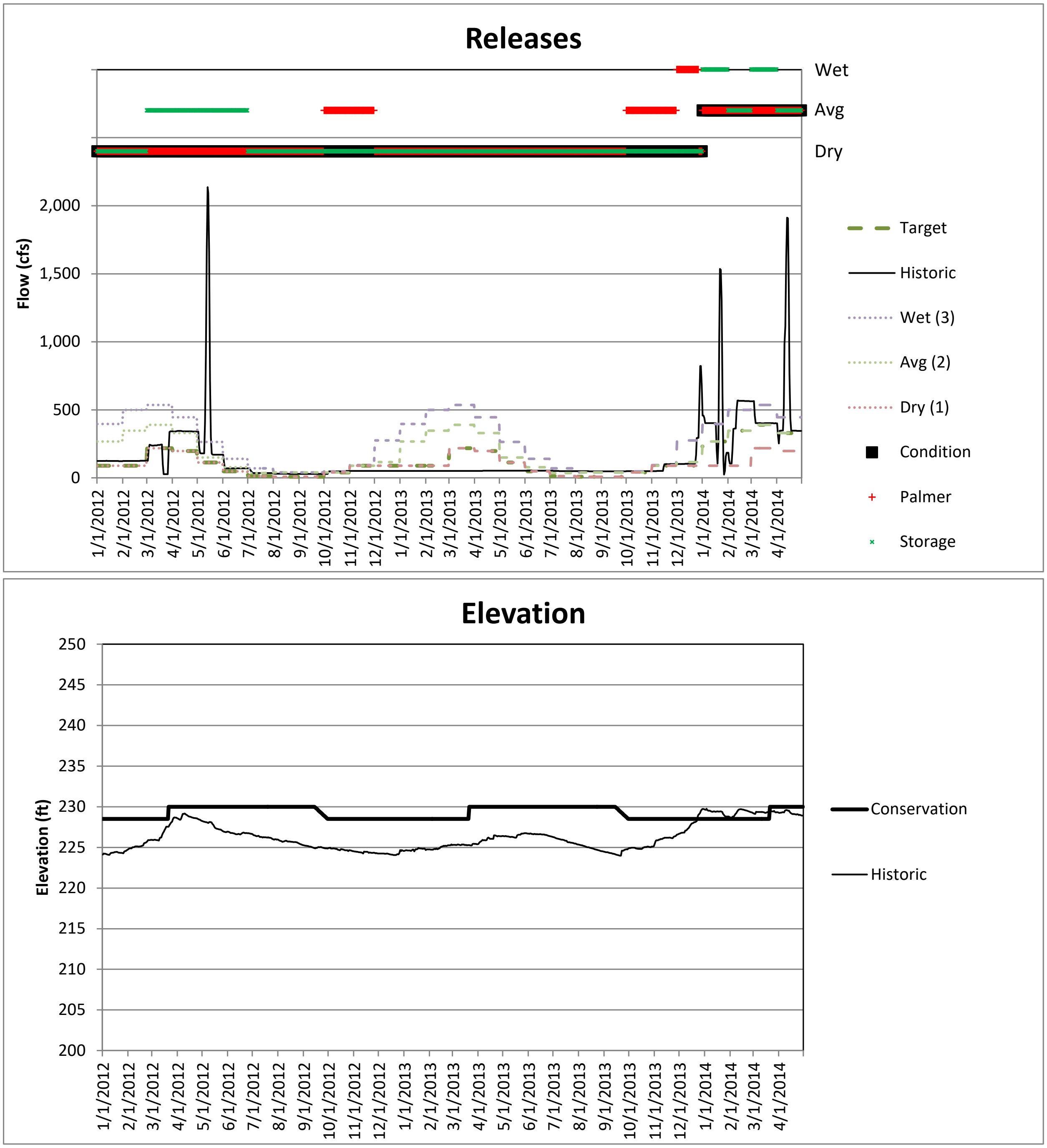
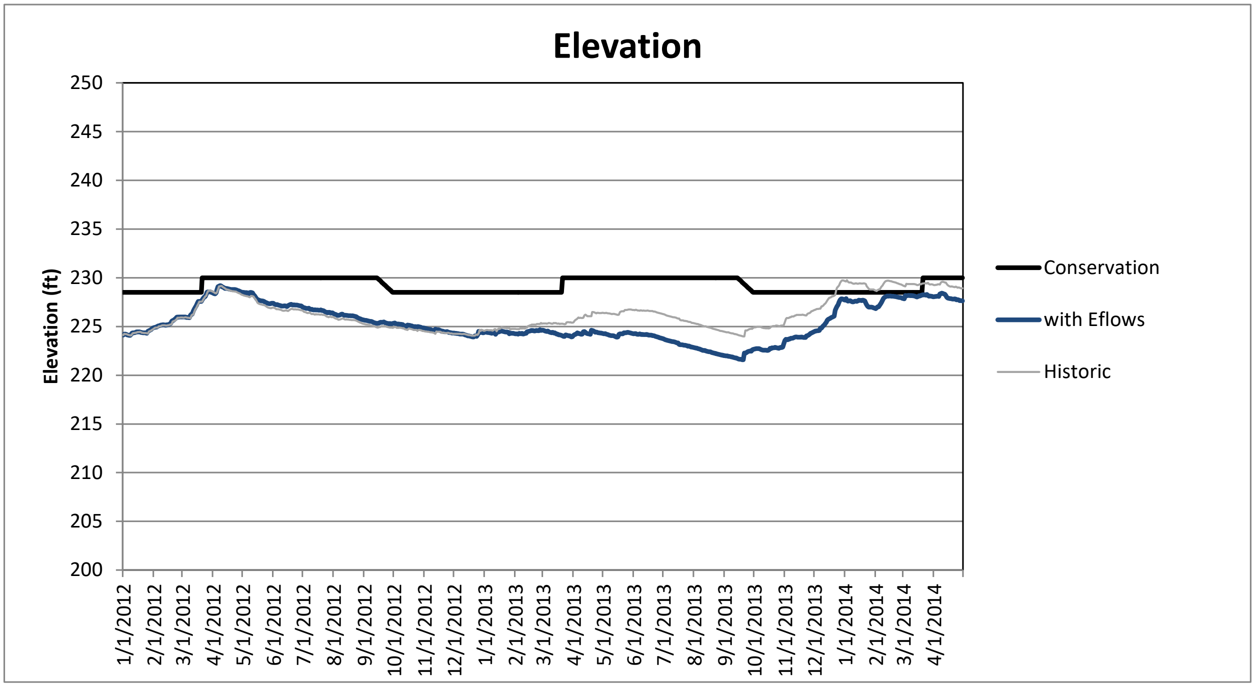


Figure 4 Implementation of the eflows regime 2012-2014

In November 2013, the PDSI shifted into the average range and reservoir levels recovered from 225 ft-msl. As a result, the eflow regime was reinstituted and since that time LOTP has been making releases according to the base average recommendations including several short duration high pulse flow releases.

The reservoir simulation model can be used to assess how the reservoir would have responded had the eflow releases not been suspended in 2012-13. Figure 5 displays the reservoir elevations and releases that would have occurred 'with eflow' recommendations. Although the eflow releases were suspended in October 2012, this suspension had little effect on reservoir levels because prior to February the base dry recommendations, which would have been in place, would have been relatively low flow rates. Thus 'with eflows' reservoir elevation trace tracks very closely with the 'historic' (or actually observed) elevation through about February 2013.



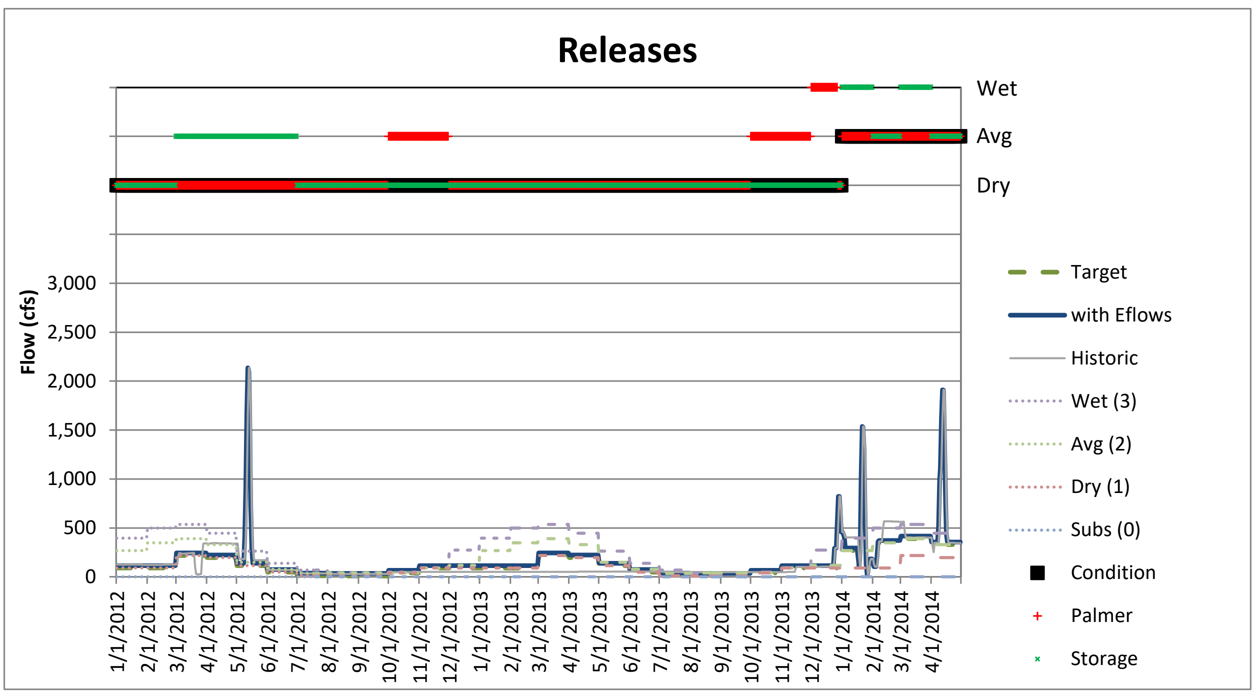


Figure 5 Implementation of the eflows regime 2012-2014 including modeling with and without eflow regimes.

After February the 'with eflows' and 'historic' lines begin to diverge. By the end of August storage in LOTP would have been approximately 2.5 feet lower had eflow released been made than it was when the eflow releases were suspended. The eflows releases would have meant that approximately 34,000 acft more of water would have been released from the conservation pool than was actually released in 2013. The reservoir would have reached a low of 222.58 as opposed to the actual observed minimum elevation of 223.96.

2 Evaluations

2.1 Framework and metrics

The objective of this evaluation section of this report is to assess how well and at what cost the current implementation plan succeeds in producing a flow regime that meet the goals of the Project. The metrics for this evaluation are derived using a reservoir simulation model to quantify how much water is needed from LOTP and how often the components of the flow regime are achieved over the long term. There are no a priori constraints that define exactly how much storage might be available and necessary for eflows and we do not know, with a high degree of certainty, the exact value the attainment frequencies required for the various flow components, therefore the tools and analysis can primarily be used to examine tradeoffs. For example, the simulation model can be used limit the amount of storage that might be available for environmental flows either explicitly by enforcing a cap on how much water can be used for eflows in a given year or implicitly by adjusting trigger levels that have the effect of reducing releases for eflows. Conversely, goals can be set for desired attainment frequencies and then implementation plan can be adjusted to meet those targets. Once this is complete, an estimate how much water it would take to achieve a specific goal can be quantified.

As discussed above, the Project is currently in the midst of a 5-year voluntary agreement to implement the eflows. This implementation plan was initially proposed based the expert knowledge at USACE and their long experience in managing LOTP. The plan was supported by reservoir modeling which produced time series figures of simulated reservoir levels and releases. Based primarily on a visual review of these figures and on knowledge about how much water is current available relative to how much is currently being used, both the USACE and NETMWD were comfortable in pursuing this plan on a voluntary basis with the understanding that deviation from the plan could be made unilaterally in response to unforeseen drought, (which incidentally is what happened). The modeling and analysis presented to the Project at the forth flows workshop in 2011 did not specifically quantify how well the implementation performed in terms of producing a flow regime that sufficiently mimics the natural pattern of flows needed to ensure the maintenance of a sound ecological environment, therefore, the first step in this evaluation provides these estimates and answers the question: Are the building blocks flow recommendations meet as frequently as they need to be and how much water does it take to implement this plan? Based on the results from this analysis, the report will suggest ways to improve on the implementation plan. Improvement in this situation means meeting the eflows recommendations with frequencies that more closely mimic the natural conditions and doing so with less impact on the established and authorized uses of LOTP to provide water supply and flood control to the region.

Finally, the ultimate goal of this effort is to chart a path, which ensures that flows protective of a sound environment, will continue beyond the current 5-year period. There are several strategies that will likely need to be considered and several steps and studies that may be needed along the way. The final section of this report (Section **Error! Reference source not found.**) of this study will conclude by describing these options and charting a path toward achieving them.

2.2 Existing and Interim Eflows Implementation Plan

For the analysis of current and proposed operations, developed to support the implementation plan that has now been in place since 2011, reservoir simulations were conducted for the period from 1938-2007 using the USACE

RiverWare model. The model includes normal operations releases for flood control subject to reservoir level and downstream constraints, reductions in all demands (water supply and environmental) based on NETMWD drought contingency plan, and a supplemental supply from Bob Sandlin Reservoir. Enhancements were made to the RiverWare model to incorporate the multi-tiered targets and the triggers discussed above. Outputs including time series of reservoir elevations and release were produced for the following four scenarios:

1. Current Demands without e-flows,
2. Current demands with e-flows,
3. Future Demands without e-flows, and
4. Future demands with e-flows.

Initial runs of future demands assuming an additional 100,000 acft/yr on top of the current demands (the number initial suggested by NETMWD) found that meeting this target and the environmental flows depleted the conservation pool. Subsequent iterations found that only an additional demand of 94,000 acft/yr could be supplied without depleting the conservation pool. Unless otherwise specified, figures with labels for future supply assume an additional 94,000 acft/yr from Lake O' the Pines.

The implementation plan also assumes that the bottom foot of the flood control pool will be used to transition from releases to evacuate the flood pool to releases for base wet conditions per the recommendations of the Project.

2.2.1 Frequency of eflows

One part of evaluating how well the implementation plan performs is to evaluate how well it meets the environmental flow targets. The flow recommendations developed for the Big Cypress downstream of LOTP are defined in terms of flow magnitude and timing (month or season) and, in the case of pulse and overbank flows, in terms of flow duration and rate of change. In order for these recommendations to be meaningful in a water management context, they also need to be defined in terms of attainment frequency; or how often the various components of the flow recommendations should occur. A recommendation of 150 cfs for a May average base flow does not provide operational guidance unless it is coupled with a recommendation for how often this flow should occur. While the Project has not explicitly defined the desired attainment frequencies, a foundational principle of the Project has been the natural flow paradigm. This principle asserts that safest and simplest approach to maintaining a sound ecological environment is to mimic the natural flow pattern as closely as possible including variability patterns (wet, dry and average years, seasonal), and associated duration and magnitude of flows. This concept also applies to attainment frequency targets. "The premise is that if a sufficiently close representation of key elements of the historical hydrology is maintained, then a reasonable approximation of the historical sound ecological environment is likely to also be maintained, while at the same time making available water for development." (SAC 2010) If a recommended flow of 150 cfs has historically occurred in May about 50% of the time, then successfully meeting this flow recommendation means that it should occur about 50% of the time in the future.

It is important to note that, just as with the development of the building blocks, the natural flow paradigm serves as a starting point assumption. Future studies including adaptive management will be used to verify, and if necessary refine, the understanding of what level of attainment is need to provide for a sound ecological environment. These future studies should also provide insight into how much deviation from the natural range of variability is acceptable.

Assuming the goal is to mimic historic - natural conditions - attainment frequencies, the next step is to decide what period of record will serve as the basis for this baseline condition. Recall that base flow recommendations developed in the Project were derived initially from outputs from a computer statistics program called the Indicators of Hydrologic Alteration (IHA), which calculates percentile flows based on historic data that has been processed to remove pulses (base flow separation). For Big Cypress the preliminary recommendations were based on specific percentile flows (25^{th}, 50^{th} and 75^{th} for dry, average and wet respectively) from 1928-1956 (Figure 6). This is the time period of available gage flow data prior to the construction of LOTP and is intended to be representative of natural flows. Similarly, a determination of appropriate attainment frequencies should also be based on a natural flow regime. Based on this line of reasoning, the appropriate period for development of attainment frequency goals would be the same as the period used to develop the flow targets, namely 1928-1956. However, the reservoir simulation model that is used to test the implementation of the eflows has a period of record from 1938-2007. Since the USACE developed a naturalized daily stream flow set for the period from 1938-2007, an alternative option would be to use this longer period of naturalized flows to developed attainment frequency targets. (Since the RiverWare model only extends back to 1938, the period from 1928-1938 must be excluded if an apples to apples comparison between attainment frequencies under managed implementation of eflows and natural attainment frequencies to be conducted.) The naturalized flow set developed for the RiverWare model includes flows for the period prior to the construction of LOTP in 1958, which are simply the recorded gage flows, and flows after the construction of LOTP, which are synthetic naturalized flows developed for the model.

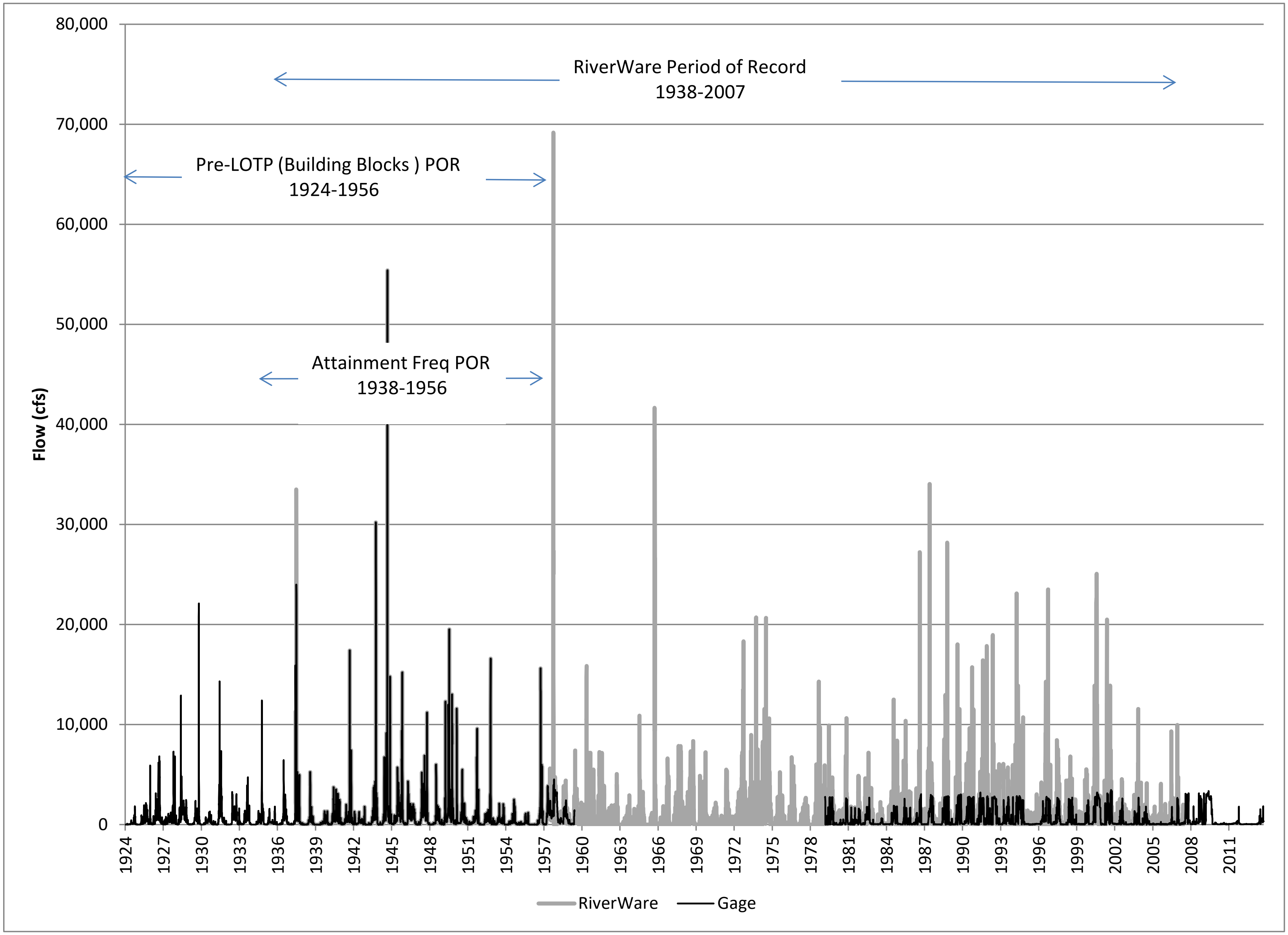


Figure 6 Big Cypress Flows

Ideally, this longer period of record (1938-2007) could be used to determine desired attainment frequencies, however, a review of the synthetic flows from 1958-2007 suggests that while these flows are maybe adequate representations of the naturalized flows at higher end of the flow regime there is some question as to whether they accurately capture the characteristics of the lower end of the flow regime. This can be seen by comparing cumulative frequency plots for the period from 1924-1954 with the period from 1960-2007 (Figure 7). Flows from these periods, if they represent the same natural flow regime, should produce similar cumulative frequency plots, excepting for natural variation within the two periods. While pulse flows greater than 1000 cfs are exceeded approximately 20% of the time in both periods, the distribution of flows in the base flow range is significantly different between the two periods. In the synthetic data set, over 20% of the days had zero flow. Since reservoir, storage is dominated by large inflow events, the differences observed at low flows, in Figure 7, may be of less concern with respect to the results produced by the reservoir simulation model. However, given the differences observed in Figure 7 it would not seem appropriate to based desired attainment frequencies based on this naturalized dataset.

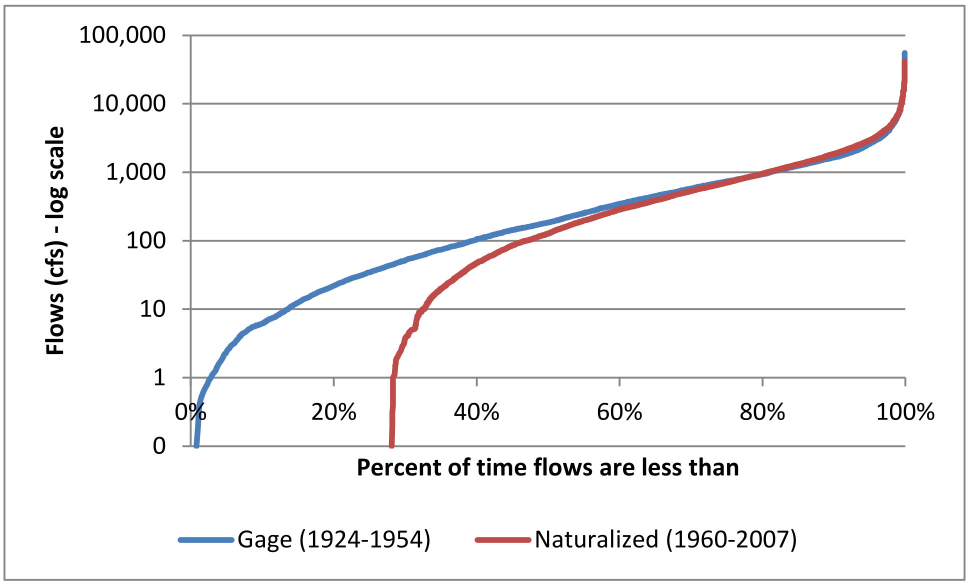


Figure 7 Cumulative Frequency of flows of gage flows for Pre-LOTP period (1924-1954) and synthetic naturalized flows for Post – LOTP period (1960-2007)

Therefore, in the following analysis, the attainment frequencies are based on flow from 1938-1954, the period of record prior to LOTP that is included in the reservoir simulation model.

Table 3 shows the percent of time that the various base and pulse flow targets are met or exceeded under natural conditions and assuming that the LOTP reservoir were operated to meet current demands both with and without the implementation the environmental flows. Under natural flow conditions, flows greater than the dry base flow would have been observed approximately 78% of the time, greater than the average base flows 63% of the time and greater than the wet base flows 53% of the time. These monthly percentiles thus form the basis of the target attainment frequencies that ought to be observed to preserve the ecological functions that these flows provide.

The green and red colors in Table 3 indicate greater than a plus or minus 10% change the percent frequency relative to natural flows. The 10% value does not have any specific merit and is used here primarily for illustrative purposes. A reasonable argument might be made that a 5% or 15% change represents an ecologically significant change, but further studies would be needed to develop scientifically defensible value. If the reservoir is operated without implementation of the environmental flow regimes (CurNoEflow), the model predicts that in 8 out of 12 of the months in the year, dry base flow targets would occur more than 10% less often than they are occurred under natural flow conditions. Notably, for average and wet base flow levels, except for the months of November and December, the operation of LOTP does not appear to have a substantial impact on attainment frequency. In fact, having the reservoir in place results in base flows being meet more frequently than they would be met under natural conditions. This apparent contradiction occurs because LOTP captures high volume, low duration floods and then, under current demands, releases that water at flow rates higher than the base flow targets over long periods. This results in more days with flow exceeding the base wet targets.

Table 3 Percent of days base flow targets in Big Cypress would be met under alternative scenarios as compared to the attainment frequencies under pre-LOP flow period assuming current demand levels.

	Base Flow Targets Percent Excedence								
	Dry			Average			Wet		
	Pre	CurNoEFlow	CurwEFlow	Pre	CurNoEFlow	CurwEFlow	Pre	CurNoEFlow	CurwEFlow
Jan	94%	83%	100%	77%	72%	89%	63%	60%	54%
Feb	99%	94%	100%	83%	82%	85%	66%	72%	69%
Mar	87%	87%	100%	77%	82%	86%	69%	75%	75%
Apr	93%	92%	100%	83%	85%	83%	75%	84%	83%
May	89%	81%	100%	82%	80%	92%	67%	76%	73%
Jun	87%	76%	100%	75%	74%	93%	59%	69%	62%
Jul	87%	62%	100%	58%	60%	85%	42%	54%	47%
Aug	70%	32%	100%	30%	30%	67%	29%	30%	39%
Sep	66%	39%	100%	32%	36%	69%	32%	36%	69%
Oct	38%	53%	100%	38%	53%	100%	33%	52%	46%
Nov	52%	35%	100%	52%	35%	100%	50%	35%	36%
Dec	77%	61%	100%	73%	56%	71%	48%	42%	42%
All Months	78%	66%	100%	63%	62%	85%	53%	57%	58%

1,500 cfs pulses, 3 per year			2,500 cfs pulse			>3,000 cfs pulse		
Pre	CurNoEFlow	CurwEFlow	Pre	CurNoEFlow	CurwEFlow	Pre	CurNoEFlow	CurwEFlow
58%	53%	53%	68%	58%	53%	68%	0%	0%

When the simulation model is run to implement the environmental flow targets (CurwEflow), results indicate that under present demand scenarios base flow targets will generally occur more often than they occurred under natural conditions. Since the model is set up to always release the base dry target, it predicts that these flows are meet or exceeded 100% of the time even though under natural conditions the flows in Big Cypress were often (22% of the time = 100%-78%) observed below these levels. Base average and wet targets also generally occur more often than they would have occurred naturally.

As discussed in Section 1.2 above, the pulse flow recommendations from the Project are only partially implemented in the operation plan. Designated releases for the lower pulses (1,500 cfs) are made up to 3 times a year when hydrologic conditions are wet or average (no pulse releases are made when the system is in a dry condition). Apparently, pulses would typically occur this often (in 53% of the years) as the result of spills even when the reservoir is not operated to meet eflows (CurNoEflow).

The 2,500 cfs target pulse release is not included in the model as part of the reservoirs operating rules and thus only occurs when required to evacuate the flood pool. This decision was made simply from a modeling expediency standpoint. The code required to update the RiverWare model to address events that occur less frequently than one per year would is complicated and a decision was made that it would be more expedient to simply run the model an evaluate whether the 2,500 cfs pulses occurred at sufficient frequencies as a result of normal flood control operations. While the existence of LOTP causes a reduction in annual frequency of 2,500 cfs pulses (from

68% of the years to 58% of the years) these pulse events still occur approximately every other year (as recommended) under normal reservoir operations without having to make explicit releases at these levels. Development of the next round of RiverWare simulations may consider these results and determine whether explicitly including rules for 2,500 cfs pulses are needed. Actual operations since 2011 have included dedicated pulse releases greater than 2,500 cfs.

As has been known throughout the Project, LOTP does not release more than 3,000 cfs, thus events above this flow rate, which occurred in 68% of the years before LOTP was constructed, do not occur under the current or proposed implementation plan.

In summary, this analysis suggests that there may be some opportunity to loosen the requirements to meet base flow recommendations under the management regime. Specifically it appears that the base dry targets do not need to occur as often as they are predicted to under the current implementation plan.

2.2.2 Drawdowns and storage

The other side of the analysis is to evaluate the impact of meeting the environmental flow targets on reservoir storage and the ability to provide water for other uses. Figure 8 shows the LOTP reservoir elevations with and without releases for eflows.

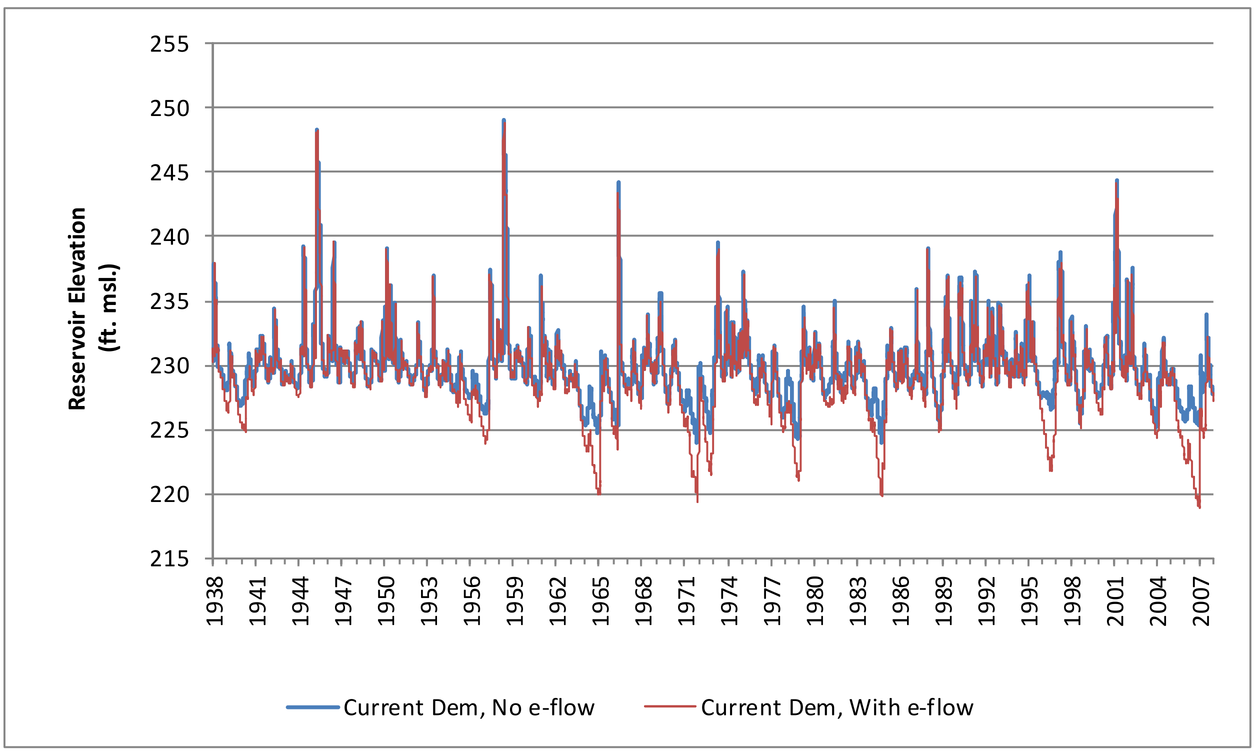


Figure 8 Lake O' the Pines reservoir trace with and without releases for eflows assuming current demand levels.

One measure of the impact of making releases for eflows is the frequency of time when the reservoir elevation would below 220 ft-msl, which is the level at which NETMWD drought management begins. Assuming the current demands, the model indicates that LOTP would always stay above this elevation. If releases were made for eflows the elevation would fall below this level four times in 70 years, however these declines are to less than 1 foot below 220 ft-msl and, with the exception of the 2007 event which last about 100 days, only remain below 220ft-msl for about one month.

Another way to look at the impact of meeting eflows has on storage is to quantify how much additional water needs to be released each year to meet the eflows targets. Figure 9 shows the maximum difference in simulated reservoir storage when LOTP is operated without and with eflows.

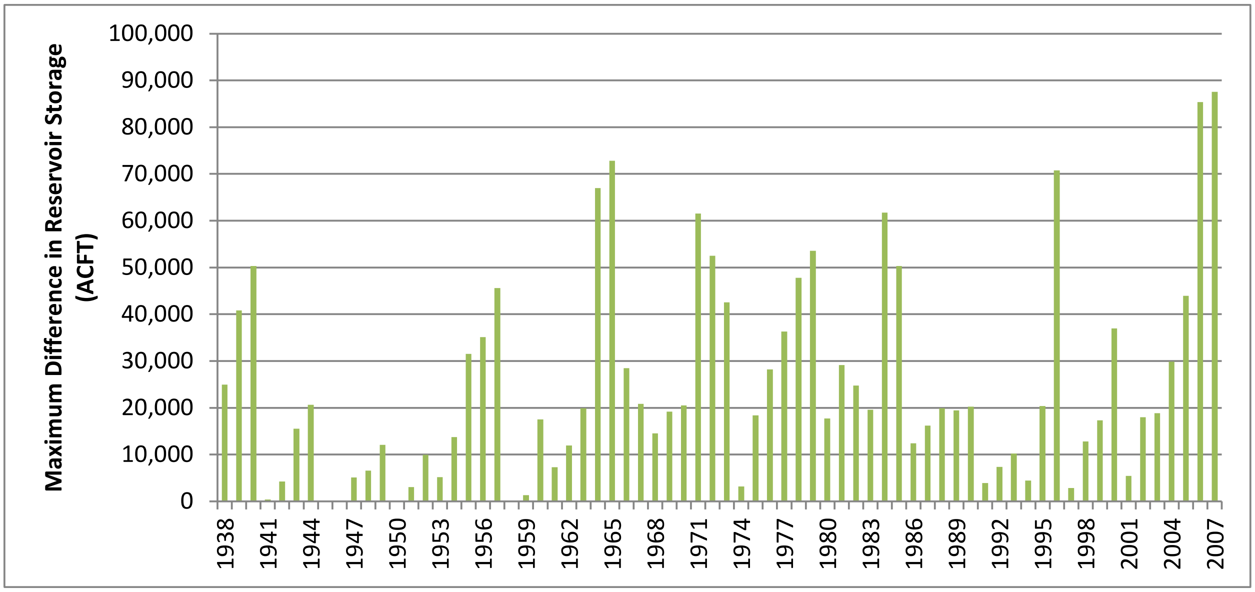
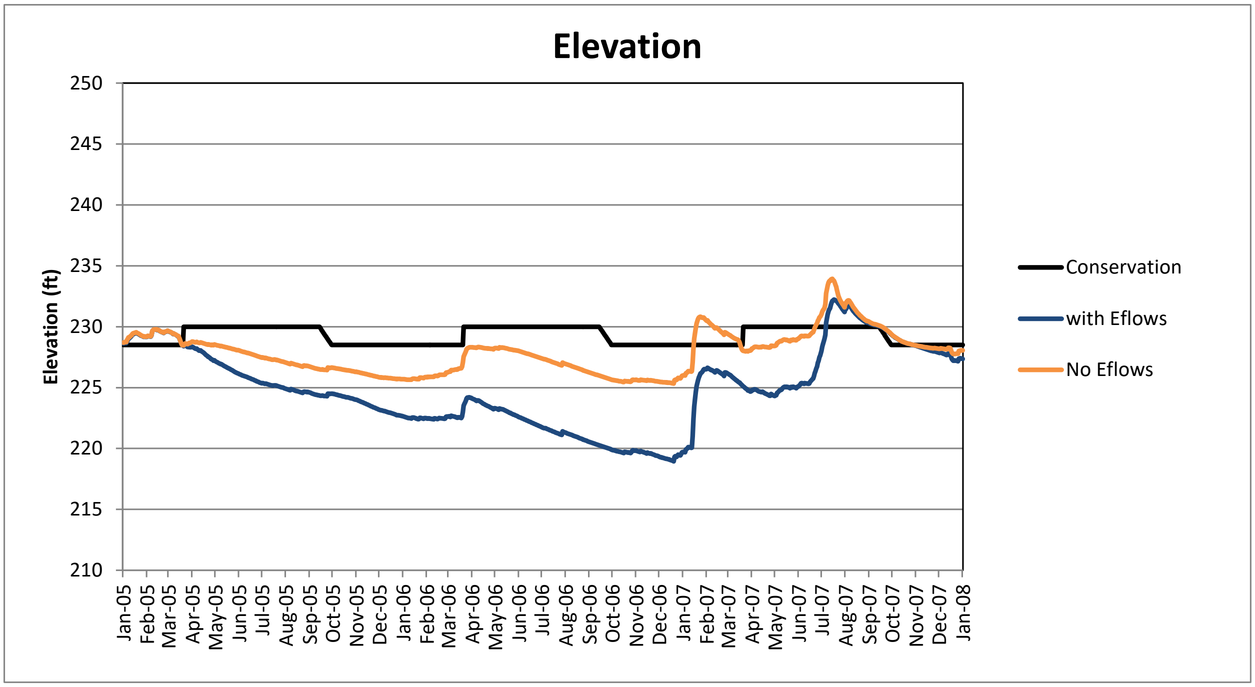


Figure 9 Effect of making releases for flows on reservoir storage.

The year with the greatest difference in storage, when comparing the 'with' and 'without' eflows simulations, was 2007. As a result of making release for eflows, the LOTP elevation would have been approximately 5 feet lower on In January 2007 than it would have been had the reservoir been operated without the implementation of the eflows. This elevation difference is equivalent to approximately 87,000 acft of storage.

The period from 2005 to 2007 involved a multiyear drought. (Figure 10) On January 1, 2005, LOTP reservoir elevation was 228.8 ft-msl or just above the conservation pool. The PDSI was -0.29, which is an average condition and, in fact, high inflows in the spring of 2005 pushed storage up into the flood pool. Since the reservoir was above the conservation pool, releases in the beginning of the month are made to evacuate the pool, whether the eflows are implemented or not. Once the reservoir level hits 229.5 ft-msl, the eflows implementation releases begin to taper down to the with eflows target (blue line in the bottom panel of Figure 10), which are equal the base average recommendation of 268 cfs, and begin to differ from the releases without eflows (orange line in the bottom panel of Figure 10), which are equal to 26 cfs. Simulated elevations in LOTP begins to diverge (top panel of Figure 10) between the 'with eflow' and 'without eflow simulations'. On March 15, a 4-day pulse flow release of 1,500 cfs is made, since the reservoir storage and PDSI criteria were both in average and a pulse event had not yet occurred in this year. The pulse event causes the reservoir elevation to drop almost one foot. Throughout April and for the rest of 2005 inflows remained very low. In November, no inflows were reported for the entire month. Low inflows persisted through 2006, until a large flood in January 2007 restored reservoir levels. Just before these high inflows, and even only having made base dry releases for almost 20 months LOTP would have been approximately 5 feet lower (at an elevation of 218.95 ft-msl) than it would have been had it not made releases for eflows. The storage would have been about 87,000 acft less as reflected in Figure 9 above.



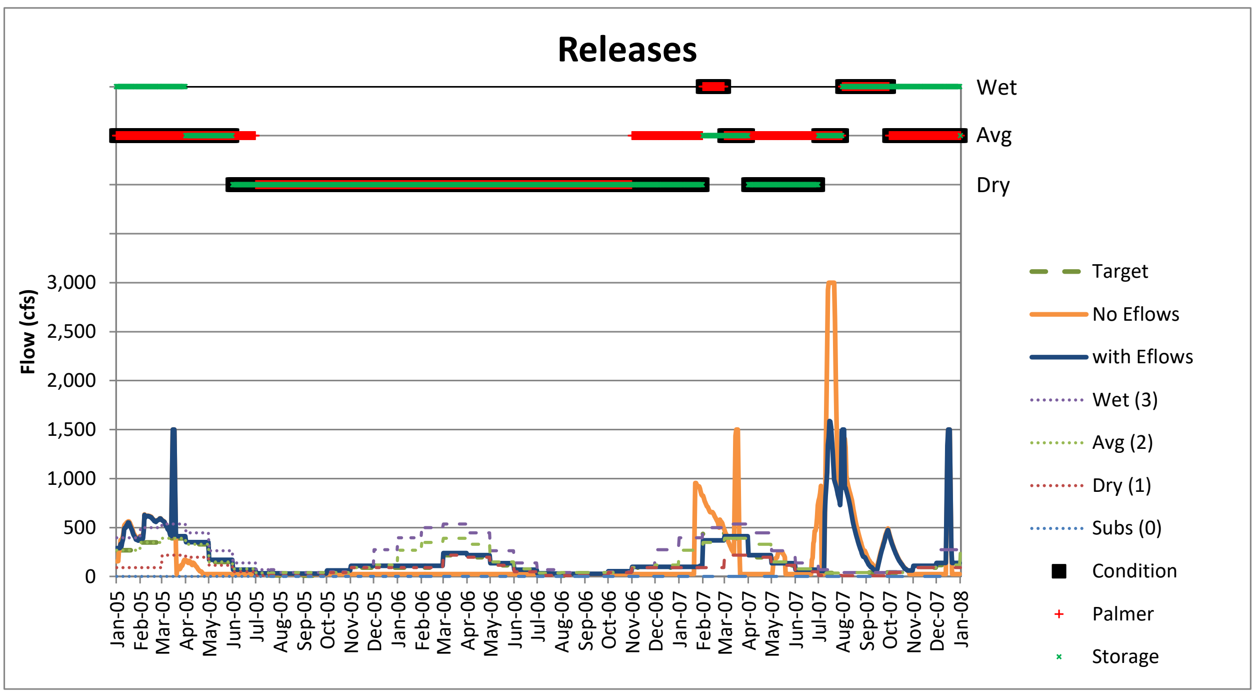


Figure 10 Reservoir Elevation (top) and Releases (bottom) with and without eflow releases

While this worst-case scenario, (the above example representing the greatest impact on reservoir storage over the period of record) is significant, the simulation demonstrates that the system can implement the eflows recommendations and meet the current water supply commitments without requiring reductions per the drought contingency plan in all but four cases.

The analysis points to components of the implementation scheme that have the most significant impact on reservoir storage. Two factors were the consistent drivers of low reservoir elevations for other periods as well.

First, was the release of designated high flow pulse at the beginning of a multi-year drought. In the above example, this pulse was made just after flood releases had been made to evacuate the flood pool and just before the system entered drought conditions. In reality (as opposed to how it is modeled), a pulse release would probably have been made to coincide with flood releases earlier in the winter/spring in 2005. The second factor and, in fact, the dominate factor in this event, and all of the other major drawdown events, is the continued release of base dry recommended flows as the reservoir level continues to decline below 224 ft-msl. This fact, coupled with the insight gained from the attainment frequency analysis (Table 3 above), might suggest that either some modification to the implementation plan or some alternative strategy such as a year round increase in the conservation pool to the current summer recreation pool level (230 ft-msl) will be needed if triggering of drought contingency plans are to be avoided. The actual operations in 2012 and the suspension of the eflow releases, also helps understand a need to consider some modifications to base flows releases.

2.3 Future Demands

In addition to simulating operations under current demand levels (~34,000 acft/yr) the RiverWare model was also used to simulate reservoir operations assuming future demand levels. The initial simulations assumed future demands of an additional 100,000 acft/yr, however these results showed that reservoir storage would be depleted during the worst drought if these demands and the recommended eflows were to be meet. Subsequent simulations determined that a maximum future demand level of an additional 94,000 acft/yr could be supplied under current reservoir allocations while at the same time meeting the eflows under the current implementation scheme.

Similar to the analysis of the current demand simulations, the RiverWare model was used to quantify attainment frequencies of the eflow recommendations and the potential impact on reservoir storage resulting from this simulation. Table 4 shows the frequency of meeting the various components of the eflows recommendations assuming future demands for water supply equal to 128,000 acft/yr (34,000 acft/yr for current levels plus 94,000 acft/yr additional demand). Here, the contrast between without implementation (FutNoEFlow) and with implementation (FutwEFlow) is more pronounced than it was under current use scenarios. Unlike the current demand scenarios in which many of the eflow recommendations, especially of the base average and wet components, would occur frequently without the need to make designated releases for them, under future demand scenarios these flows would not occur often enough without an eflows implementation plan. Even with the current implementation plan in place (FutwEFlow) base average and wet flow recommendations would occur more than 10% less often in the winter months. More troubling is that the annual attainment frequency for the of the 3-per year, 1,500 cfs high flow pulse falls from 53% under current demands (Table 3) to 37% under future demands.

Table 4 Percent of days base flow targets in Big Cypress would be met under alternative scenarios as compared to the attainment frequencies under pre-LOP flow period assuming future demand levels.

	Base Flow Targets Percent Excedence								
	Dry			Average			Wet		
	Pre	FutNoEFlow	FutwEFlow	Pre	FutNoEFlow	FutwEFlow	Pre	FutNoEFlow	FutwEFlow
Jan	94%	58%	97%	77%	51%	57%	63%	46%	40%
Feb	99%	72%	94%	83%	59%	65%	66%	51%	52%
Mar	87%	77%	94%	77%	70%	78%	69%	61%	56%
Apr	93%	83%	94%	83%	83%	83%	75%	80%	71%
May	89%	73%	96%	82%	71%	87%	67%	67%	64%
Jun	87%	59%	97%	75%	58%	81%	59%	56%	55%
Jul	87%	38%	100%	58%	37%	73%	42%	36%	39%
Aug	70%	20%	100%	30%	18%	56%	29%	18%	28%
Sep	66%	15%	100%	32%	13%	39%	32%	13%	39%
Oct	38%	25%	100%	38%	25%	100%	33%	25%	28%
Nov	52%	21%	94%	52%	21%	94%	50%	21%	27%
Dec	77%	33%	98%	73%	30%	45%	48%	24%	27%
All Months	78%	48%	97%	63%	45%	72%	53%	41%	44%

1,500 cfs pulses, 3 per year			2,500 cfs pulse			>3,000 cfs pulse		
Pre	FutNoEFlow	FutwEFlow	Pre	FutNoEFlow	FutwEFlow	Pre	FutNoEFlow	FutwEFlow
58%	42%	37%	68%	53%	53%	68%	0%	0%

Also notable from the results present in this table is the fact that, while still very high, the frequency of meeting the base dry flow targets is no longer 100% for all months. This suggest that in a fairly high percentage of the months in the spring (>5%) reservoir levels are predicted to be below 220 ft-msl and drought contingency plan reductions will be in force thus reduce recommended base dry releases. A review of the simulated reservoir storage traces for these two scenarios confirms this (Figure 11). Under future demand scenarios, reservoir elevation in LOTP would be expected to have fallen below 220 ft-msl about 14 times. This would be the case simply because of the additional demands without including releases for eflows. Including releases for eflows result in longer durations during which LOTP elevation remains below 220 ft-msl.

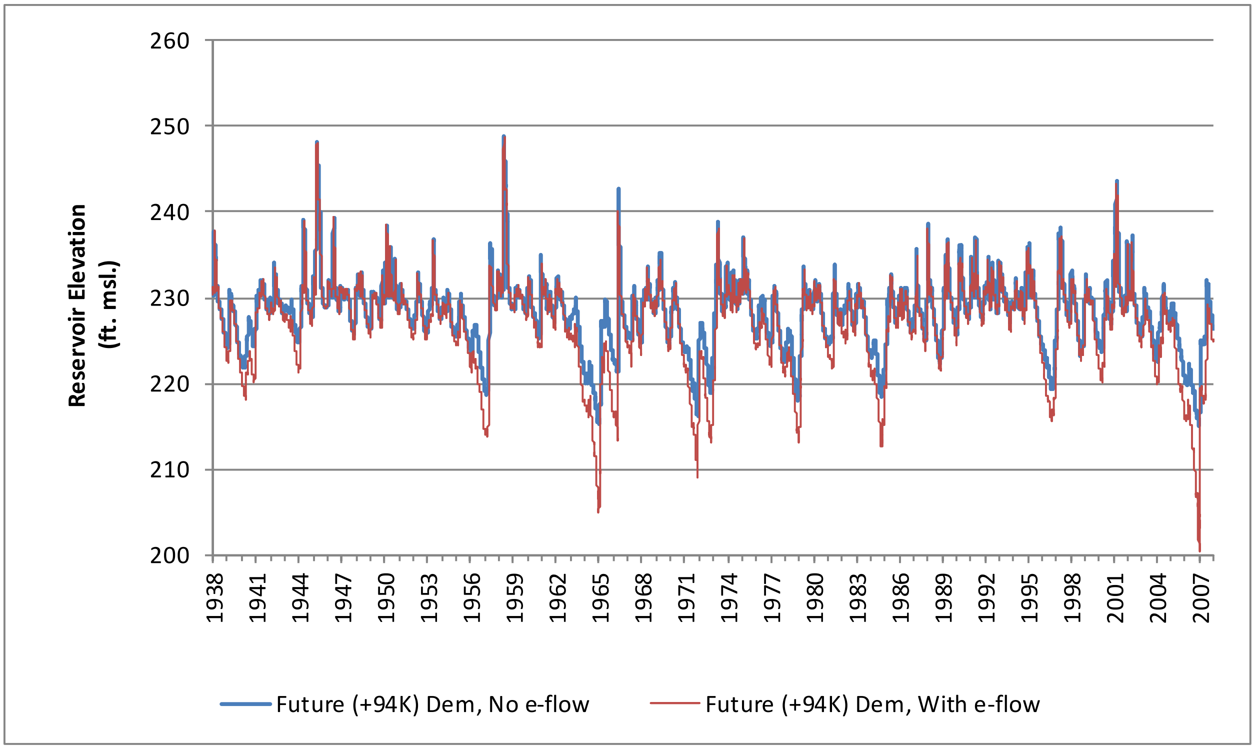


Figure 11 Lake O' the Pines reservoir trace with and without releases for eflows assuming future demand levels.

While the analysis of the current demand scenarios supports the conclusion that LOTP can be operated to meet eflow requirement with modest adjustments to the guidance language in the Corps water control manual and modest revisions to the flow regimes, such as the addition of subsistence flows for very dry periods, achieving the eflow recommendations while minimizing the impact of on water supply (i.e. minimizing the frequency of lowering storage to undesirable levels) assuming future water supply demands of approximately 128,000 acft/yr would necessitate a more proactive strategy. This future water demand scenario assumes demands that are almost four times their current levels. It is unlikely that current water supply customers will reach these water usage levels for many decades. It is conceivable that other new customers may seek supplies from LOTP however, no new large water supply alternatives that rely on LOTP are included in any state or regional water plans. This study would benefit by having estimates of short-term water use forecasts that are expected with a higher degree of certainty. It is likely that more modest growth in water use could be accommodated with modest adjustments to reservoir operations.

One option that has been considered has been to increase the top of the conservation pool to 230 ft-msl year round. Although this has not yet been modeled in the RiverWare model, a simplified version of the reservoir simulations using excel spreadsheet suggest that this is a promising approach. Available storage between 228.5 ft-msl and 230 ft-msl is approximately 28,000 acft, storage that could be used to meet both eflow and additional water supply demands. While this additional storage would not have a significant impact on the frequency of causing the elevation in LOTP to fall below 220 ft-msl, it would mean that LOTP could supply the full 100,000 acft/yr of additional demand while also implementing the eflow regime as proposed.

3 Conclusion

The implementation plan, assuming current demands, would appear to meet the desired attainment frequency of the eflow recommendations at frequencies at or above the levels observed under natural flow conditions.

According to the RiverWare simulation model, in the worst case scenario (in 2007), meeting the eflows comes at a cost of approximately 5 feet of reservoir storage and implies that the drought contingency conditions would have been triggered 4 times in a replication of historical hydrology for the period from 1938-2007, versus zero times if eflows are not implemented. There are some opportunities to reduce the frequency at which dry base flow recommendations are achieved and this could lesson these impacts on reservoir storage without significant impacts on the ecological health of the downstream watershed. Modeling (using a simplified version of the USACE RiverWare in an excel spreadsheet) was used to investigate the possibility of shifting to some form of subsistence flows during extreme drought, however, the results of this exercise suggest that, by the time a shift is made, the impacts may already have occurred. This suggests that an improved forecasting tool is needed to allow adjustment of eflows earlier, closer to the onset of major drought conditions.

The study also finds that significant increases in water supply (up to 94,000 acft/yr) can be met along with the eflow flow implementation. This additional demand will result in lower reservoir levels and a greater frequency of times when the reservoir falls below 220 ft-msl. Including releases for eflows with this additional demand would increase the duration of time that the current drought contingency plan would be in force. A proactive strategy, such as maintaining a year round conservation pool of 230 ft-msl, would help to offset impacts to reservoir levels, help to meet future water supply needs and provide the flow regime necessary to maintain as sound ecological environment.