TECHNICAL MEMORANDUM

TO: Sulphur River Basin Authority

FROM: Jon Albright

SUBJECT: TM 1-2 2016 Yield Analyses

DATE: October 31, 2016

PROJECT: Sulphur River Basin Feasibility Study
SBG15591

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1 Introduction

This memorandum provides the results of yield modeling done by the Sulphur Basin Group (SBG) under Work Order #2, 2016 Support Services for the Sulphur Basin Feasibility Study. Task 1 of the 2016 work includes:

- Review of updated U.S. Army Corps of Engineers (USACE) RiverWare models
- Incorporation of environmental release criteria developed by other contractors in the RiverWare model and determination of yields, referred to as the 2016 Yields in this document
- Development of demand scenarios that
  - Identify the location of potential demands in the Sulphur Basin, and
  - Develop operational criteria to meet those demands

Modeling conducted as part of this task is intended to inform planning-level decisions about potential project configurations and should not be construed to be definitive projections or form the basis of any future permitting work without additional review/modification. Estimates of project yields are different than in previous studies due to updates to the RiverWare model, extensions of the period-of record-hydrology, and revisions to estimates of environmental flow requirements. As the studies progress, and additional refinements are made to the analysis, yield estimates would be expected to continue to evolve.

Review of the USACE RiverWare models under this task order focused primarily on identification of the specific differences between the Corps of Engineers' approach to RiverWare modeling, which is dominated by concerns related to flood operations, and modeling efforts focused on identifying reservoir yield. In part, this effort was undertaken to reconcile discrepancies between initial Corps of Engineers' estimates of Lake Wright Patman yield at the Ultimate Rule Curve and work performed by SBG to estimate the same parameter. The differences noted as a result of this evaluation are documented in SBG Memorandum dated April 22, 2016

SUBJECT: *Draft Memorandum – Recommended 2016 Yield Modeling Assumptions for RiverWare Modeling*. This memorandum also documents modeling protocols for future yield modeling at Wright Patman that have been mutually agreed to between the Corps of Engineers and the project sponsors. This memorandum has been incorporated as Attachment A.

Updated estimates of likely environmental flow requirements were received by SBG from other contractors in August 2016 and have been incorporated into yield estimates for various project scenarios[1]. Table 1 is a summary of the 2016 Yields, which were calculated for Lake Wright Patman reallocation, Marvin Nichols Reservoir, and combinations of Lake Wright Patman reallocation and Marvin Nichols Reservoir. In general, compared to the 2015 work, the 2016 Yields are lower for Marvin Nichols and higher for Lake Wright Patman. These differences are almost entirely the result of the new environmental flow releases developed for the 2016 Yields. Other differences are minor and are discussed in Attachment A.

In addition to the 2016 Yields, this study uses the location of potential future demands in the Sulphur Basin to examine the possible benefit of operating the major reservoirs in the Sulphur Basin as a system. The 2016 System Yields are described in Section 4 of this memorandum.

1.1 Need for Water

Project sponsors have identified a supply goal of 604,000 acre-feet per year from the Sulphur Basin. Based on the project development contract between the Sulphur River Basin Authority (SRBA) and project proponents in the Dallas/Fort Worth Metroplex area, 20 percent (120,800 acre-feet per year) would be reserved for use by in-basin sponsors while the remaining 80 percent (483,200 acre-feet per year) would be available for export. Looking at Table 1, only one project combination, Patman reallocation to 242.5 feet and Nichols at 328 feet (Run 9), fully meets the supply goal.

1.2 Previous Studies

The 2016 Yields are updates to the following studies:

- *The 2014 WAM Yield Studies.* These yields use the Sulphur Basin WAM as modified by SBG (SBG WAM) to determine project yields using a variety of assumptions and combinations of projects. The yields are summarized in the January 2014 *Sulphur River Basin Overview Final Report.*

- *The 2014 Hydrologic Yield Studies.* This study uses both the RiverWare Model and SBG WAM to determine hydrologic yields. (Hydrologic yields are yields determined without applying the Texas priority water rights such that water is allocated in upstream to downstream order). The report also includes an investigation of the differences between the two models. The results of this study are summarized in the August 2014 *Technical Memorandum on Hydrologic Yields*.

[1] The RPS/Carollo report is not available to SBG at this time.

Table 1: Summary of 2016 Yields

Run	Reservoir Elevation (feet)		Priority Assumption	Environmental Flow Releases	Wright Patman Yield			Marvin Nichols Yield		Total New Yield (ac-ft/yr)
	Wright Patman	Marvin Nichols			Total (cfs)	Total (ac-ft/yr)	New (ac-ft/yr)	(cfs)	(ac-ft/yr)	
1	232.5	n/a	Standard	Patman only	460.0	333,253	153,253	n/a	n/a	153,253
2	242.5	n/a	Standard	Patman only	669.3	484,883	304,883	n/a	n/a	304,883
3	252.5	n/a	Standard	Patman only	954.4	691,427	511,427	n/a	n/a	511,427
4	n/a	328.0	Standard	Nichols only	n/a	n/a	n/a	541.5	392,297	392,297
5	232.5	328.0	Reallocation junior to Nichols	Patman & Nichols	360.0	260,807	80,807	524.3	379,836	460,643
6	232.5	328.0	Reallocation senior to Nichols	Patman & Nichols	457.0	331,080	151,080	396.0	286,887	437,967
7	235.0	328.0	Reallocation junior to Nichols	Patman & Nichols	402.75	291,777	111,777	527	381,792	493,569
8	238.0	328.0	Reallocation junior to Nichols	Patman & Nichols	459.75	333,072	153,072	527	381,792	534,864
9	242.5	328.0	Reallocation junior to Nichols	Patman & Nichols	561.5	406,786	226,786	523.5	379,256	606,042
10	242.5	328.0	Reallocation senior to Nichols	Patman & Nichols	667.8	483,796	303,796	360.4	261,096	564,892

Notes:
Standard Priority means that water is passed according to the priority of existing water rights (Chapman, Ralph Hall, Patman) with new projects (Patman reallocation, Nichols) junior to the existing projects.
Reallocation junior to Nichols has the Standard assumptions plus the assumption that Marvin Nichols senior to the reallocation of Lake Wright Patman.
Reallocation junior to Nichols has the Standard assumptions plus the assumption that the reallocation of Lake Wright Patman is senior to Marvin Nichols.
New Yield refers to the total yield less the 180,000 acre-feet per year already authorized for diversion from Lake Wright Patman.

- *The 2015 Yield Updates.* These yields use the RiverWare model to update and supplement the 2014 WAM Yields of Wright Patman and Marvin Nichols. This study included an analysis of the impacts of different assumptions on project yields. The results of this study are found in the October 2015 memorandum *Revised Patman and Nichols Yield Modeling*.

One of the key findings of the 2014 and 2015 studies is that the recent drought in the Sulphur Basin has reduced the yield of the proposed projects. This finding, along with the environmental flows, has significantly reduced the available supply from the proposed projects.

1.2.1 Differences from Previous Studies

For the 2016 Yields, there are four main factors that are different than previous studies:

- *Environmental flows*. The 2016 Yields include environmental flows developed by RPS/Carollo for this study. These environmental flows will be different than previous studies, which either did not include environmental flows explicitly in the modeling, or used “Lyons Method” flow requirements. Environmental flows would be applied to Marvin Nichols and to reallocated Wright Patman storage above the Ultimate Rule Curve. A description of the environmental flows used for this analysis may be found in the RPS/Carollo report on the flows.

- *Hydrology for Lake Ralph Hall*. The 2016 study uses slightly different hydrology for Lake Ralph Hall. The modified hydrology begins in June 1942 and ends in September 1949. Since this change is before the 1950s drought it has little if any impact on yields. This change was adopted so that SBG’s modeling matches the USACE's modeling.

- *Lake Patman low-flow releases.* Most previous runs have used a combination of 10 cfs and 96 cfs low-flow releases from Lake Wright Patman. USACE has, in numerous team meetings, indicated that they intend to drop the summer 96 cfs release when Ultimate Rule Curve operations are implemented, and the operating rules in the RiverWare model they have provided for our use are consistent with that stated intent. After consultation with the USACE and the project sponsors, it has been agreed that all new modeling will assume only the 10 cfs low-flow release. For reallocation scenarios, this release would be made when the reservoir is at or below the Ultimate Rule Curve and above 220 feet (the bottom of the conservation pool). Above the Ultimate Rule Curve, the environmental flows would apply. However, when above 220 feet, the minimum elevation of the conservation pool, releases from the reservoir are never allowed to be less than 10 cfs.

- *Senior priority for Lake Patman reallocation.* Previous studies have all assumed that the reallocation of Lake Wright Patman would be junior to a new reservoir at the Marvin Nichols site. The 2016 study includes some scenarios that have the reallocation senior to Marvin Nichols in order to evaluate the potential impact of that assumption on yields.

Other assumptions are the same as in previous studies.

1.3 Description of Models

There are two main models that were used to develop the 2016 Yields:

- A RiverWare model of the Sulphur and Cypress River Basins developed originally by the USACE (USACE Model), and

- A "MiniWAM" using the Water Rights Analysis Package (WRAP) model, incorporating the USACE hydrology that was used to develop priority and environmental flow releases that were incorporated in the USACE model. The USACE RiverWare model does not include information relative to priority releases or water rights issues. The "MiniWAM" was developed to address that gap and reflect the important effect of State legal requirements on project yields.

Additional information on these models may be found in Section 2, Section 3.1 and Attachments A and B.

2 Review of Revised USACE Model

The 2016 Yields use a RiverWare model of the Sulphur and Cypress Basins initially developed by the USACE, with priority and environmental flow releases developed by SBG using the MiniWAM. The USACE provided the first version of this model to SBG in December 2013 for use in the 2014 Hydrologic Yield Studies. The USACE RiverWare model was modified by SBG to include proposed projects (Parkhouse I and II, Marvin Nichols, Talco and Wright Patman reallocation), priority pass-throughs and environmental flow releases. These features can be turned on and off for various modeling exercises. The basic structure of the RiverWare model has remained unchanged since it was first provided by the USACE. However, both SBG and the USACE have modified the inputs and modeling assumptions over the course of the Sulphur Basin Feasibility Study. As with any modeling exercise, changes to modeling inputs and assumptions can have a significant impact on the modeling results. As inputs and assumptions used in the modeling have evolved over the course of this study, the results have also evolved.

The 2016 Yields use hydrology obtained from the USACE in March of 2016. This hydrology is almost identical to the hydrology obtained from the USACE in March 2015, which was used for the 2015 Yields. The March 2016 hydrology slightly changes the estimated flows at Lake Ralph Hall prior to October 1949, the beginning of the historical period for the North Sulphur gage. Since these flows are before either the 1950s or 2006-2007 drought, the change does not impact the yields of any of the projects considered in the 2016 study.

In the interim between the 2015 Yield Updates and the 2016 studies, there were several iterations of hydrology and modeling assumptions. As a direct result of these iterations, SBG developed the April 22, 2016 *Draft Memorandum – Recommended 2016 Yield Modeling Assumptions for RiverWare Modeling*, which is included as Attachment A of this memorandum. This memorandum describes the preferred assumptions that are to be used for Sulphur Basin Feasibility Study modeling, and gives guidance for making and documenting alternative assumptions. The document also gives a brief history of how modeling assumptions have changed over the course of the study.

3 2016 Yields

The 2016 Yields use modeling assumptions that are consistent with the practices used in state-sponsored Regional Water Planning. These assumptions are outlined below and described in more detail in Attachments A and B. The most important of these assumptions are the priority operation of the water rights associated with the projects, low-flow and environmental releases, and reservoir storage sedimentation characteristics. The individual impact of each of these factors on reservoir yields has been evaluated in previous studies, with the most recent evaluation in the 2015 Yield updates. Since these factors have already been quantified in previous studies, we will not repeat that analysis here. SBG has verified the validity of the 2015 results using the most recent model, and has found the differences to be minimal.

One factor that has changed since the 2015 Yield update is the environmental flows. The 2015 Yields used environmental flows based on the Lyons Method, while the 2016 Yields use preliminary environmental flow releases developed for this analysis using Texas Commission on Environmental Quality (TCEQ) environmental flow guidelines. Selected 2016 Yields are compared to equivalent runs from the 2015 update in the sections on stand-alone and combination yields.

3.1 Methodology

The 2016 Yields use three modeling scenarios:

1. Stand-alone yields of Wright Patman reallocation scenarios
2. Stand-alone yields of Marvin Nichols Reservoir with Wright Patman operating at the Ultimate Rule Curve
3. Combination yields of Wright Patman reallocation and Marvin Nichols

Each of these scenarios was modeled using both the USACE Model and the MiniWAM.

The scenarios use the following assumptions:

- *Priority releases from Lake Chapman for the senior portion of Lake Wright Patman's existing water rights.* Lake Chapman is junior to the existing conservation storage in Wright Patman and the diversion of the first 60,000 acre-feet of water. The remaining 120,000 acre-feet of diversion from Patman is junior to Chapman's water right. Priority releases are determined using the MiniWAM and incorporated in the USACE model.
- *Priority releases from the proposed Lake Ralph Hall and Marvin Nichols for Wright Patman's existing water rights.* The State of Texas has issued a water right for Lake Ralph Hall and this proposed project is included in all of the modeling. This right is junior to the existing Wright Patman water right. Marvin Nichols is included in all scenarios except the stand-alone Patman reallocation scenarios. Any water

right issued for Marvin Nichols would also be junior to the existing Wright Patman water right. Accordingly, releases from Ralph Hall and Marvin Nichols in accordance with Patman's senior water rights have been estimated in the MiniWAM and incorporated in the USACE model.

- *Low-flow releases from Lake Wright Patman.* A minimum release of 10 cfs is always required from Lake Wright Patman any time the reservoir is operating in its conservation storage. This 10 cfs release is a requirement of the existing storage contract between the USACE and the City of Texarkana.

- *Environmental flow releases.* A new set of proposed environmental flow releases have been developed by RPS/Carollo for the 2016 Yields. WRAP code for environmental flow releases from Marvin Nichols and Patman provided by RPS /Carollo has been incorporated into the MiniWAM. The WRAP code in the MiniWAM is used to develop a series of releases that are incorporated into the USACE model. Consistent with applications in Texas water rights, the environmental flows releases are limited to the inflow into the reservoir. The environmental flows apply to Marvin Nichols Reservoir and the diversion and storage associated with the reallocation of Lake Wright Patman. The environmental flow releases are modeled so that they are senior to the proposed projects. As a result, for combination modeling, flows from Marvin Nichols will be passed to meet both the environmental flow releases at the Nichols site as well as at Wright Patman. This assumption is consistent with water availability analyses performed by the State of Texas for a new water right application. For stand-alone projects, only the environmental flows at the proposed site are included in the modeling. So for stand-alone analyses of Marvin Nichols, the environmental flows for Wright Patman are not included in the modeling.

- *Current storage in existing reservoirs.* The 2016 Yield modeling uses current storage conditions for existing reservoirs. Some storage in these projects will probably be lost due to sediment accumulation before new projects are implemented. The impact of sedimentation on project yield has been previously examined in the 2014 WAM Yield Studies. Once the timeline for the development of the new projects has been established, additional modeling may be needed to quantify the potential impact of sedimentation on project yields.

3.2 Environmental Flow Releases

The environmental flow releases used for the 2016 Yields were developed by RPS /Carollo. Table 2 and Table 3 summarize the environmental flow criteria. RPS /Carollo also developed the WRAP code implementing the flows that was incorporated into the MiniWAM. The environmental flow releases were provided to SBG on August 15, 2016. Additional information on the environmental flows may be found in the RPS/Carollo report[2].

[2] The RPS/Carollo report is not available to SBG at this time.

Table 2: Environmental Flow Releases for Lake Wright Patman

Season	Subsistence	Base Low	Base High	Pulse
Winter	2.7 cfs	32 cfs	435 cfs	4 per season Trigger: 6,823 cfs Volume: 44,310 af Duration: 7 days
Spring	2.7 cfs	36 cfs	304 cfs	3 per season Trigger: 6,823 cfs Volume: 40,530 af Duration: 7 days
Summer	2.7 cfs	10 cfs	41 cfs	2 per season Trigger: 303 cfs Volume: 1,916 af Duration: 6 days
Fall	2.7 cfs	11 cfs	87 cfs	2 per season Trigger: 5,357 cfs Volume: 43,555 af Duration: 8 days

Definitions of seasons, subsistence flows, base low, base high and pulse flows may be found in the RPS/Carollo report.

Table 3: Environmental Flow Releases for Marvin Nichols Reservoir

Season	Subsistence	Base Low	Base High	Pulse
Winter	1.5 cfs	17 cfs	241 cfs	4 per season Trigger: 3,789 cfs Volume: 23,136 af Duration: 7 days
Spring	1.5 cfs	20 cfs	168 cfs	3 per season Trigger: 3,789 cfs Volume: 21,162 af Duration: 6 days
Summer	1.5 cfs	5.6 cfs	23 cfs	2 per season Trigger: 168 cfs Volume: 1,001 af Duration: 5 days
Fall	1.5 cfs	6.1 cfs	48 cfs	2 per season Trigger: 2,975 cfs Volume: 16,940 af Duration: 7 days

Definitions of seasons, subsistence flows, base low, base high and pulse flows may be found in the RPS/Carollo report.

3.3 Stand-Alone Yields

The stand-alone yields represent the individual yields of either Wright Patman reallocation without Marvin Nichols upstream or the Marvin Nichols Reservoir project without Patman reallocation. Yields of combinations of Nichols and Patman may be found in Section 3.4.

3.3.1 Wright Patman Reallocation

Table 4 shows the stand-alone yields for Lake Wright Patman reallocation to elevations 232.5, 242.5 and 252.5 feet. The total yield of the project is given in both acre-feet per year (ac-ft/yr) and cubic feet per second (cfs). The "New Yield" in the last column is the total yield less the 180,000 ac-ft/yr already permitted for diversion from Lake Wright Patman. All runs assume that Lakes Chapman and Ralph Hall pass water to the senior portions of Patman's water right. However, these projects will be senior to the reallocation so no additional priority pass-throughs are needed from Chapman or Ralph Hall. These runs apply only the Patman environmental flows.

Note that none of these options meet the supply goal of 604,000 acre-feet per year.

Table 4: Wright Patman Stand-Alone Yields

Run	Reallocation Elevation (feet)	Total Yield (cfs)	Total Yield (ac-ft/yr)	New Yield (ac-ft/yr)
1	232.5	460.0	333,253	153,253
2	242.5	669.3	484,883	304,883
3	252.5	954.4	691,427	511,427

Note: New yield is the total yield less the 180,000 ac-ft/yr already authorized for diversion from Lake Wright Patman

Table 5 compares the new yield for elevations 232.5 and 242.5 feet to yields from the 2015 Yield updates. Like the 2016 Yields, the 2015 Yield numbers use the same hydrologic period of record and have a 10 cfs minimum release from Lake Wright Patman. The main difference between the two runs is that the 2015 Yields use the Lyons Method environmental flows rather than the 2016 RPS /Carollo environmental flows. (Additional information on the Lyons Method flows can be found in the October 2015 memorandum *Revised Patman and Nichols Yield Modeling.*) The environmental flow requirements are essentially "debits" from the yield. Because the 2016 estimates of environmental flow requirements are lower for Wright Patman than the 2015 estimates, that is, the "debits" are smaller, the currently-predicted yields are higher. At 232.5 feet, the yield is about 16% higher, and at 242.5 feet the yield is about 6% higher.

Table 5: Comparison of Patman 2016 New Yield to Previous Study

Run	Reallocation Elevation (feet)	2016 New Yield (ac-ft/yr)	2015 Lyons Yields (ac-ft/yr)	Difference (ac-ft/yr)
1	232.5	153,253	131,700	21,553
2	242.5	304,883	287,445	17,438

Note: New yield is the total yield less the 180,000 ac-ft/yr already authorized for diversion from Lake Wright Patman

3.3.2 Marvin Nichols Reservoir

Table 6 shows stand-alone yield of Marvin Nichols Reservoir at elevation 328.0 feet. The maximum storage elevation for Marvin Nichols in previous studies has been 328.0 feet. Since the largest increment of Nichols is necessary to meet supply goals, lower elevations were not evaluated in the 2016 Yields.

Table 6: Marvin Nichols Stand-Alone Yields

Run	Maximum Elevation (feet)	Storage Volume (ac-ft)	Total Yield (cfs)	Total Yield (ac-ft/yr)
4	328.0	1,532,031	541.5	392,297

The 2015 Yield for Marvin Nichols using the Lyons environmental flows at elevation 328 feet was 464,200 acre-feet per year, or about 71,903 acre-feet per year more than the yields with the 2016 environmental flows. This is a more than 15 percent reduction in yield. The difference in the yield is entirely the result of the new environmental flows, which are larger in the 2016 estimates than in the previously-developed Lyons method estimates.

3.4 Combination Yields – Wright Patman Reallocation and Marvin Nichols Reservoir

Table 7 shows the combination yields for Lake Wright Patman reallocation and Marvin Nichols Reservoir. Reallocation assumes a flat top of conservation at elevations 232.5, 235.0, 238.0 and 242.5 feet. In all cases Marvin Nichols is assumed to have a top of conservation at 328.0 feet. The yields in Table 7 all consider

Marvin Nichols to be senior in priority to the Wright Patman reallocation. In other words, *the runs assume that Marvin Nichols does **not** pass water to meet new Patman diversions over 180,000 acre-feet per year or to refill storage emptied by the new diversions associated with reallocation. Marvin Nichols **does**, however, pass water for the existing 180,000 acre-feet per year authorized at Patman and filling of storage emptied by diversions under this water right.* This assumption is consistent with other yields determined previously in the Sulphur Basin Feasibility Study. An alternative scenario where Wright Patman reallocation is senior is discussed in Section 4.2 of this report.

Table 7: Combination Yields for Lake Wright Patman Reallocation and Marvin Nichols Reservoir

Run	Wright Patman Elevation (feet)	Marvin Nichols Elevation (feet)	Lake Wright Patman Yield [a]			Marvin Nichols Yield		Total New Yield [b] (ac-ft/yr)
			Total Yield (cfs)	Total Yield (ac-ft)	New Yield (ac-ft/yr)	Yield (cfs)	Yield (ac-ft/yr)	
5	232.5	328.0	360.0	260,807	80,807	524.3	379,836	460,643
7	235.0	328.0	402.75	291,777	111,777	527	381,792	493,569
8	238.0	328.0	459.75	333,072	153,072	527	381,792	534,864
9	242.5	328.0	561.5	406,786	226,786	523.5	379,256	606,042

a New Yield for Lake Wright Patman is the Total Yield of the reservoir less 180,000 ac-ft/yr already authorized for diversion from the reservoir.
b Total New Yield does not include the 180,000 ac-ft/yr already authorized from Lake Wright Patman.

Note that only one of these projects, Patman reallocation to elevation 242.5, meets the supply goal of 604,000 acre-feet per year.

Table 8 compares the 2016 Yields for the Nichols/Patman combination to yields from the 2015 Yield update with similar assumptions. The most significant difference between the 2016 and 2015 Yields is the environmental flows, which for the combination project scenarios are larger in the 2016 estimates than in the previously-developed Lyons estimates. The new 2016 environmental flows reduce the yield by about 11% for Patman reallocation to 232.5 feet and 7% for reallocation to 242.5 feet.

Table 8: Comparison of 2016 Combination Yields with New Environmental Flows to 2015 Yields with Lyons Environmental Flows

Elevation (feet)		2016 Yields (acre-feet/year)			2015 Lyons Yields (acre-feet/year)			Difference (acre-feet/year)
Patman Reallocation	Nichols	New Patman	Nichols	Total	New Patman	Nichols	Total	
232.5	328	80,807	379,836	460,643	50,886	464,228	515,114	-54,471
242.5	328	226,786	379,256	606,042	186,629	464,199	650,828	-44,786

As shown in Table 7, the yields for Marvin Nichols are slightly higher for reallocation scenarios 235.0 and 238.0 feet compared to the reallocation at 232.5 and 242.5 feet. This change in yield is due to the complex interaction in the model of the following factors:

- Assumptions regarding the reservation of flow for Patman's senior water right, and
- Differences in the timing and duration of events when Patman is full and spilling.

Wright Patman's current water right uses the Ultimate Rule Curve to define conservation storage, which is shown in Figure 1. Note that with the Ultimate Rule Curve, on the ascending limb of the curve between April and May, storage volume increases by over 100,000 acre-feet. On the descending limb of the curve between August and December, the conservation storage is reduced by the same amount, but at a slower rate. In the WAM model, on the ascending limb of the curve water is appropriated by Patman's senior water right to fill the increasing storage. This is in addition to the water appropriated for diversions under the existing right and water appropriated to offset evaporative losses.

With reallocation to a conservation storage at a fixed elevation, in April and May there are times when the water appropriated by Patman's senior water right cannot be fully used. There simply would not be room in the conservation storage to store all of the water that would have been appropriated under Patman's existing rights. As a result, some of this senior water is "released" for appropriation by more junior rights or environmental flows. When this situation happens during the critical period[3] for Marvin Nichols (one of those junior rights), it changes the amount of water available to Nichols, therefore affecting Nichol's yield. A more detailed discussion of this modeling issue may be found in Attachment C.

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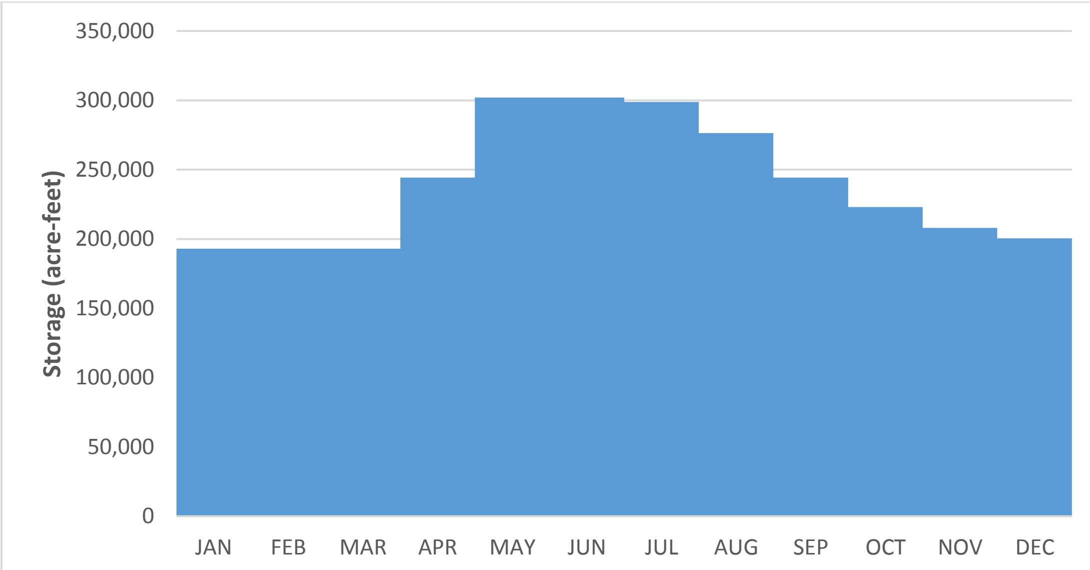
[3] In this document, the term "critical period" refers to the sequence of historical hydrology that determines the yield of the reservoir. The end of the critical period is the date in a yield simulation on which the lowest storage in the reservoir occurs. The beginning of the critical period is the date prior to the lowest storage just after the reservoir was last full. The critical period usually occurs during the drought of record for a particular basin, but depending on reservoir size and operation it can also occur during other droughts.

Figure 1: Ultimate Rule Curve Storage Volumes



Storage volumes based on the current storage in Lake Wright Patman.

4 Operation with Alternative Assumptions

This section examines three considerations that have not been examined in previous studies:

- The location of in-basin demands that could be met from the proposed projects, and how those demands could be met from the proposed projects in a way that enhances the yield of the system.
- Operation that facilitates the ability of International Paper to meet the terms of their discharge permit.
- A permitting scenario where the reallocation of Lake Wright Patman is senior to Marvin Nichols. Previous studies have assumed that Nichols would be senior to or have the same priority as Patman reallocation.

4.1 Alternative Demand Scenarios

Previous studies have focused only on the yield of the proposed projects, without regard to the purpose of the water use (for example municipal, industrial or irrigation), or the location where the water would be used. The 2016 study examines how the supplies from the proposed projects might be distributed to meet needs in the Sulphur Basin and adjacent areas, and examines potential operational scenarios that could increase the reliable supplies from the combination of Patman reallocation and Nichols Reservoir. For the 2016 study, two demand scenarios were developed based on needs from the 2016 Region D water plan:

- *Scenario 1 – Sulphur Basin Only* looks at only needs in the Sulphur Basin. According to the Region D plan, there will be a need for an additional 93,706 acre-feet per year by 2070.

- *Scenario 2 – Expanded Demand Scenario* adds needs that are in areas adjacent to the Sulphur Basin or along the delivery pipeline.

More details on the demand scenarios may be found in the July 2016 Draft Memorandum *Demand Scenarios Based on 2016 East Texas (D) Regional Water Plan*.

The July 2016 memorandum identifies potential demands that could be met from the proposed projects but does not identify a specific source for the demands. For purposes of synthesizing project operations within the model, it was necessary to apportion the demands to either the Marvin Nichols or the Patman component. Table 9 shows how we treated this assignment process in this set of model runs based on which source was most proximate to each specific demand.

Table 9: Assumed Distribution of Demand Scenarios 1 and 2 to Potential Sources of Water
(Values in acre-feet per year)

County	Type of Use	County	Assigned Source	2070 Scenario 1	2070 Scenario 2
Bowie	Municipal	Bowie	Patman	14,915	17,216
Bowie	Manufacturing	Bowie	Patman	2,235	2,251
Bowie	Irrigation	Bowie	Patman	1,881	4,140
Cass	Manufacturing	Cass	Patman	62,676	62,827
Hopkins	Municipal	Hopkins	Nichols	88	255
Hopkins	Irrigation	Hopkins	Nichols	2,126	2,126
Hopkins	Mining	Hopkins	Nichols	422	639
Hunt	Municipal	Hunt	Nichols	1,520	26,446
Hunt	Irrigation	Hunt	Nichols	33	146
Hunt	Steam Electric Power	Hunt	Nichols	0	28,213
Hunt	Mining	Hunt	Nichols	0	0
Lamar	Municipal	Lamar	Nichols	45	116
Lamar	Manufacturing	Lamar	Nichols	951	951
Lamar	Steam Electric Power	Lamar	Nichols	0	10,568
Lamar	Irrigation	Lamar	Nichols	2,360	18,302
Morris	Municipal	Morris	Patman	0	170
Morris	Manufacturing	Morris	Patman	0	2,763
Red River	Municipal	Red River	Nichols	591	591
Red River	Manufacturing	Red River	Nichols	9	9
Red River	Irrigation	Red River	Nichols	3,091	4,125
Titus	Municipal	Titus	Nichols	763	2,229
Titus	Manufacturing	Titus	Nichols	0	5,440
Titus	Steam Electric Power	Titus	Nichols	0	91,555
			Total	93,706	281,078

Table 10 and Table 11 summarize the total demands by source and type of use for Scenarios 1 and 2, respectively. This table does not include the 180,000 acre-feet per year already permitted from Lake Wright Patman. For the purposes of this study, it was assumed that the existing Patman supplies are fully committed and the future demands would need to come from the new projects.

Table 10: Scenario 1 – 2070 Demands by Source and Type of Use
(values in acre-feet per year)

Type of Use	New Patman	Nichols	Total
Municipal	14,915	3,007	17,922
Manufacturing	64,911	960	65,871
Irrigation	1,881	7,610	9,491
Steam Electric Power	0	0	0
Mining	0	422	422
Total	81,707	11,999	93,706

"New Patman" represents needs in addition to the 180,000 acre-feet per year already authorized for use from Lake Wright Patman.
Demands do not include water for export out of the basin.

Table 11: Scenario 2 – 2070 Demands by Source and Type of Use
(values in acre-feet per year)

Type of Use	Patman	Nichols	Total
Municipal	17,386	29,637	47,023
Manufacturing	67,841	6,400	74,241
Irrigation	4,140	24,699	28,839
Steam Electric Power	0	130,336	130,336
Mining	0	639	639
Total	89,367	191,711	281,078

"New Patman" represents needs in addition to the 180,000 acre-feet per year already authorized for use from Lake Wright Patman.
Demands do not include water for export out of the basin.

4.1.1 Comparison to 2016 Yields

The first set of analyses compares the demand scenarios to the 2016 Yields. Project sponsors have agreed that for the full development of the basin (604,000 acre-feet per year), that 20 percent of that supply would be reserved for local in-basin use (120,800 acre-feet per year). The remainder would be available for export out of the basin. In the 2016 Yields for the Patman/Nichols combination, the only one that meets this requirement is Patman reallocation to elevation 242.5 feet and Marvin Nichols at elevation 328.0 feet. For this analysis, the combination with Patman reallocation to elevation 232.5 feet is also presented for comparison. In this case, the 20% local reserve would be 92,129 acre-feet with 368,514 acre-feet available for export. These two supply goal scenarios are shown in Table 12.

Table 12: Goal Supply from the Sulphur Basin
(Values in acre-feet per year)

Scenario	Total New Yield	In-Basin Reserve (20%)	For Export (80%)
Full Supply Goal	604,000	120,800	483,200
Smaller Patman Reallocation	460,643	92,129	368,514

Table 13 compares the 2070 demands for Scenario 1 to the new yield of the combination project with Patman at 242.5 feet and Nichols at 328 feet. The 2016 Yield assumes priority passage of water to senior rights, the 2016 environmental flows, and a minimum release of 10 cfs from Lake Wright Patman. With Scenario 1, there is about 29,136 acre-feet of water that has not been assigned to a demand. About 27,000 acre-feet of this unassigned water is the unused portion of the 20% reserved for in-basin use. The remainder is the yield in excess of 604,000 acre-feet per year.

Table 13: Comparison of Scenario 1 2070 Demands to 2016 New Yield – Patman at 242.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	226,786	379,256	606,042	New firm supply using 2016 Yield assumptions
Sulphur Basin Only Demands (Scenario 1)	81,707	11,999	93,706	Region D in-basin demands as noted in July SBG Memorandum
Available for Other Uses	145,079	367,257	512,336	Remaining supplies after meeting Scenario 1 demands
Export Supplies			483,200	80% of 604,000 ac-ft/yr
Surplus (+) or Deficit (-)			29,136	Unassigned supply

Table 14 makes the same comparison as Table 13 but uses the Scenario 2 expanded demands. In this case, there is over 158,000 acre-feet of demand that cannot be met from these sources.

Table 14: Comparison of Scenario 2 2070 Demands to 2016 New Yield – Patman at 242.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	226,786	379,256	606,042	New firm supply using 2016 Yield assumptions
Expanded Demands (Scenario 2)	89,367	191,711	281,078	From July SBG Memorandum - Includes demands in adjacent areas
Available for Other Uses	137,419	187,545	324,964	Remaining supplies (+) or deficit (-) after meeting Scenario 2 demands
Export Supplies			483,200	80% of 604,000 ac-ft/yr
Surplus (+) or Deficit (-)			-158,236	Unmet demand

Table 15 compares the Scenario 1 Demands to the 2016 Yield of Patman at 232.5 feet and Nichols 328 feet. Note that the total in-basin need in Scenario 1 is only slightly more than the 20% reserve supply of 29,136 acre-feet per year, and that this scenario could almost --but not quite-- meet the in-basin needs and provide 80% of the supply for export.

Table 15: Comparison of Scenario 1 Demands to 2016 New Yield – Patman at 232.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	80,807	379,836	460,642	New firm supply using 2016 Yield assumptions
Sulphur Basin Only Demands (Scenario 1)	81,707	11,999	93,706	Region D in-basin demands
Available for Other Uses	-900	367,837	366,936	Remaining supplies after meeting Scenario 1 demands
Export Supplies			368,514	80% of 2016 Yield
Surplus (+) or Deficit (-)			-1,578	Unmet demand

4.1.2 Meeting Demands Using Alternative Operation

The 2016 Yields described in previous sections all assume that the reservoirs make releases of inflows based on the priority system, with junior water rights passing water for senior water rights. The modeling is consistent with water availability analyses that are performed for new Texas water rights and as part of the state-sponsored regional water planning. However, it has been our experience that the priority system does not guarantee efficient use of water supplies. The major existing and proposed water supply projects in the Sulphur River Basin provide a good opportunity for operating these reservoirs as a system. Some of the out-of-basin sponsors of the Sulphur Basin Feasibility study also get water from Lake Chapman and the proposed Lake Ralph Hall, so this analysis includes these two reservoirs as part of a hypothetical four-reservoir system. Additional supplies could be generated by using programmed releases from upstream reservoirs (Chapman, Ralph Hall or Nichols) only when needed to “firm up” supplies in Lake Patman, rather than the continuous passage of water in accordance with a water availability analysis. The analyses in this report are only a look at the hydrologic feasibility of this type of operation and do not address institutional/procedural or cost implications. Implementation would require more study, and would require agreement among the various users of the projects to implement the operation.

The 2016 alternative operation analysis uses the following alternative assumptions:

- *Sulphur Basin Only or Expanded Demands split out by type of use.* Each type of demand in Scenarios 1 and 2 is distributed using seasonal patterns based on the type of use for each demand. Unassigned supplies or supplies exported out of the basin use a constant demand, which is the assumption that has been used in previous yield studies for the Sulphur Basin Feasibility Study.

- *Use of programmed releases of water from Marvin Nichols to firm up supplies from Wright Patman.* The alternative operation relies on releases of inflows and stored water from Marvin Nichols when needed to firm up supply rather than passage of inflows for Patman’s senior rights. Nichols releases may also be used to firm up new Patman supplies as needed. There are no releases for downstream use from either Ralph Hall or Chapman, other than the constant 5 cfs release required from Lake Chapman.

- *2016 Environmental Flows.* The analysis uses the same environmental bypass flows used for the 2016 Yields, except that Marvin Nichols does not pass water to meet Patman’s environmental flow requirements.

These assumptions were incorporated into the modified USACE RiverWare model of the Sulphur Basin. The programmed releases from Marvin Nichols to firm up Lake Patman were determined by iteration.

Table 16 compares the available supply from the Marvin Nichols/Wright Patman combination project, using the alternative operation, to the Scenario 1 demands. To generate these supplies, the model makes a deliberate release of 150 cfs from Marvin Nichols when Nichols has more than 150,000 acre-feet of water in storage and Patman is below elevation 224.0 feet. The release is set to the maximum of either 150 cfs or the environmental flow release.

Table 16: Comparison of Scenario 1 Demands to 2016 System Yield – Patman at 242.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	218,599	419,609	638,208	Yield with alternative operation
Sulphur Basin Only Demands (Scenario 1)	81,707	11,999	93,706	Region D in-basin demands per SBG Memorandum dated July 2016
Available for Other Uses	136,892	407,610	544,502	Remaining supplies after meeting Scenario 1 in-basin demands
Export Supplies			483,200	Established target
Surplus (+) or Deficit (-)			61,302	Unassigned supply

Table 16 shows that the combination Nichols 328/Wright Patman 242.5 project's yield under alternative operations would be approximately 61,000 acre-feet per year greater than the sum of the export water target and the 2070 in-basin demand as reported in the current Region D plan. Table 17 uses a modified version of Scenario 2 that sets demands so that the total demand is very close to the yield of the reservoirs without any "excess" yield. This scenario describes a condition in which the combination project yield under alternative operations could be fully utilized. To do this, the Scenario 2 demands for irrigation and mining are set to zero and only 25% of the steam-electric demand is assumed to be met from Marvin Nichols. The full manufacturing and municipal demands would be met from the projects. This scenario uses the same Marvin Nichols release criteria as used for the run that created Table 16 (150 cfs when Patman is below 224.0 feet and Nichols has more than 150,000 ac-ft in storage).

Table 17: Comparison of Modified Scenario 2 Demands (Maximize In-Basin Use) to 2016 System Yield – Patman at 242.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	218,599	419,826	638,425	Yield with alternative operation
Modified Scenario 2	85,227	68,621	153,848	Scenario 2 modified so that system operates close to yield
Available for Other Uses	133,372	351,205	484,577	Remaining supplies after meeting modified Scenario 2 demands
Export Supplies			483,200	Established target
Surplus (+) or Deficit (-)			1,377	Unassigned supply

Table 18 compares the alternative operation yield with Patman reallocation to elevation 232.5 feet and Nichols at 328.0 feet. For this configuration, only the Scenario 1 demands are considered. In this scenario, all of the in-basin need can be met. Assuming that 80% of the firm yield is available for export (that is, the firm yield considering priority as reported in the section on 2016 Yields - 368,514 acre-feet per year), there is about 33,000 acre-feet of surplus yield that could be used for the benefit of the basin.

Table 18: Comparison of Scenario 1 Demands to 2016 System Yield – Patman at 232.5 and Nichols at 328
(values in acre-feet per year)

	Patman	Nichols	Total	Notes
New Yield	81,707	415,117	495,248	Yield with alternative operation
Sulphur Basin Only Demands (Scenario 1)	81,707	11,999	93,706	Region D in-basin demands as noted in July 2016 SBG memorandum
Available for Other Uses	0	403,118	401,542	Remaining supplies after meeting Scenario 1 demands
Export Supplies			368,514	Established target
Surplus (+) or Deficit (-)			33,028	Unassigned supply

Table 19 summarizes the results of the alternative operation scenarios for the combination of Lake Wright Patman reallocation and Marvin Nichols Reservoir at elevation 328 feet.

Table 19: Summary of Yield Benefit for Alternative Operation Scenarios

Patman Reallocation Elevation (feet)	Total New Yield (acre-feet per year)			% Change
	Priority Operation	Alternative Operation	Yield Increase	
232.5	460,643	496,824	36,181	8%
242.5	606,042	638,425	32,383	5%

All runs assume Marvin Nichols at elevation 328 feet. Yields do not include the 180,000 acre-feet per year already authorized for use from Lake Wright Patman.

4.2 Operation to Facilitate International Paper Discharge

International Paper (IP) has a large facility located downstream of Lake Wright Patman. The discharge of effluent from this plant is governed by a discharge permit that has seasonally varying discharge rates, expressed as a percentage of outflows from Lake Wright Patman. The highest percentages allowed by the permit occur in the winter months. Previous studies have demonstrated the potential for upstream development of water resources to decrease IP's ability to efficiently make discharges. The 2015 analyses of the potential impact of upstream development on IP evaluated strategies that could potentially mitigate those impacts. Most of the strategies evaluated in the 2015 analysis, would require modifications to IP's compliance permit, which IP has indicated is problematic and generally undesirable. However, more fully utilizing water currently available under their existing contract with the City of Texarkana to facilitate discharge under IP's existing permit, particularly when combined with environmental flow releases that would be associated with reallocation operations, may have the potential to minimize impacts on IP's operations without permit modification. The hydrologic efficacy of this concept is evaluated in this section of analysis.

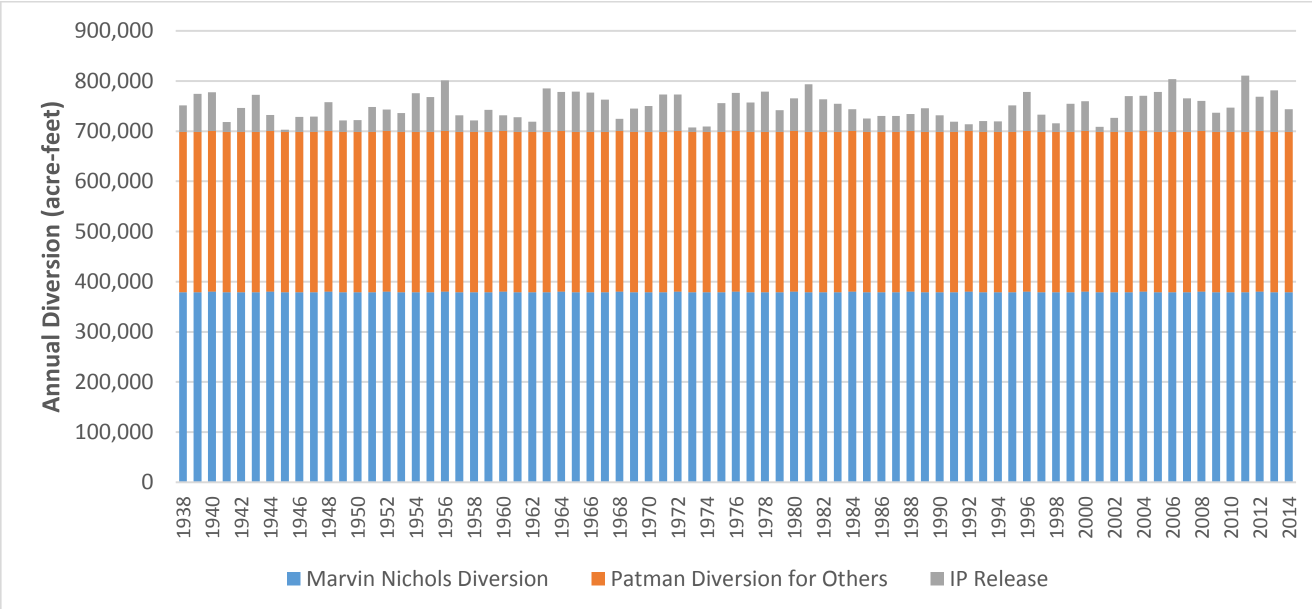
This strategy would call for making releases from Wright Patman whenever (a) IP needs to make discharges and (b) flows in the Sulphur River would be less than 250 cfs without said additional releases. (Note: there is a high degree of variability in estimation of the minimum flow required to allow IP to discharge. The minimum threshold in their discharge permit is 50 cfs; however practical considerations may result in a higher minimum flow requirement. In order to be conservative, this analysis uses a higher minimum threshold of 250 cfs.)

For this analysis, it was assumed that from September through April deliberate releases of at least 250 cfs would be made any time that outflows from Lake Wright Patman would otherwise be less than 250 cfs. From an accounting standpoint, these releases might be debited from the unused portion of the industrial authorizations in the existing water right (120,000 acre-feet per year), might be made to meet environmental flow requirements associated with the reallocation, or might be debited from the yield of the reallocation. Additional future modeling would be required to determine the likelihood of each "source."

Using this operational objective, the average release for IP over the 1938 to 2014 modeling period would be 50,800 acre-feet per year, with the largest annual release (112,550 acre-feet) called for in 2011, one of the driest years in the period of record. The average release during the critical period for Lake Wright Patman, as reflected in the model, which is 2003 to 2006, would be 82,000 acre-feet per year over that four-year period. The synthesis shows that there would be only four years (1956, 1981, 2006 and 2011) where the amount released would be greater than the unused portion of IP's current contract with Texarkana, estimated to be 84,000 acre-feet per year. (Note- the estimate of the currently-unused portion of the industrial component of the water right is based on information regarding Wright Patman withdrawals via the IP intake provided by IP in 2014.) In other words, assuming environmental flow requirements for the reallocation project similar to those described in this analysis, a minimum flow of 250 cfs downstream of the Wright Patman dam for the September through April could be sustained in all but the very driest of years without exceeding the parameters of IP's existing water contract with Texarkana.

It is hydrologically possible to ensure that the minimum 250 cfs criterion is met in all years, although this approach would affect the yield available for new water supply. Figure 2 shows the annual diversions from the reservoir, with the variable IP release shaded in gray. Note that the Wright Patman diversions include those under the existing water right for Texarkana.

Figure 2: Synthesized Annual Diversions from Marvin Nichols and Lake Wright Patman with IP Releases



This analysis shows that it would be possible to make deliberate releases from Lake Wright Patman to benefit IP operations and still generate a significant new supply from the reservoir. Compared to the firm yield, this very conservative analysis shows a reduction in reliable supply of about 36,500 acre-feet per year, or about five percent. The reliable supply reduction is the result of using more than the firm yield of the reservoir during drought conditions. Chances are that an operational policy could be developed that has less impact on reliable supplies.

4.3 Patman Reallocation Senior to Nichols

Prior yield estimates have typically been developed using the assumption that Marvin Nichols Reservoir (or any other upstream reservoir) would be senior to, or have the same priority as, reallocation of Lake Wright Patman. (If two projects have the same priority date, it is usually assumed that the upstream project is essentially senior to the downstream project when doing a water availability analysis). In other words, Marvin Nichols would only be obligated to pass inflows for Patman's existing water rights, not to any future reallocation. The analysis described in this section reverses that assumptions and demonstrates the impact of assuming that Wright Patman reallocation would be senior to Marvin Nichols, as shown in Table 20. For reallocation to elevation 232.5 feet, the yield of Lake Wright Patman reallocation would increase by 70,273 acre-feet per year. However, the yield of Marvin Nichols would decrease by 92,949 acre-feet per year, resulting in a net loss of 22,676 acre-feet per year, about 5 percent. With reallocation to elevation 242.5 feet, the increase in yield of Patman reallocation would be 77,010 acre-feet per year, and the loss of yield at Nichols would be 118,160 acre-feet per year, for a net loss in yield of 41,150 acre-feet per year (about 7 percent). The reason for this difference is that the critical period for Lake Wright Patman reallocation is shorter than the critical period for Marvin Nichols by almost a year and a half. If Patman reallocation is senior, there is a period of about six months at the beginning of Nichols' critical period where Nichols is passing water to Patman that subsequently spills out of the reservoir when Lake Patman fills.

These analyses show that it would be preferable to permit these two projects so that either they had the same priority date, Marvin Nichols was senior, or that Lake Wright Patman reallocation would be subordinate to Marvin Nichols.

Table 20: Impact of Seniority on the Yield of Patman and Nichols Combinations

Conservation Elevation		Priority Assumption	Wright Patman Yield			Nichols Yield		Total New Yield (ac-ft/yr)
Wright Patman (feet)	Marvin Nichols (feet)		Total Yield (cfs)	Total Yield (ac-ft)	New Yield (ac-ft/yr)	Yield (cfs)	Yield (ac-ft/yr)	
232.5	328.0	Reallocation junior to Nichols	360.0	260,807	80,807	524.3	379,836	460,643
232.5	328.0	Reallocation senior to Nichols	457.0	331,080	151,080	396.0	286,887	437,967
242.5	328.0	Reallocation junior to Nichols	561.5	406,786	226,786	523.5	379,256	606,042
242.5	328.0	Reallocation senior to Nichols	667.8	483,796	303,796	360.4	261,096	564,892

5 Summary and Conclusions

The 2016 Yields are an update of previous studies and reflect minor changes to the RiverWare model and its hydrology, and updates to the estimated environmental flow requirements. Table 21 shows the firm yields determined in this study. These yields assume:

- Priority operation of the basin, with Lakes Chapman, Ralph Hall and Nichols passing water for Lake Wright Patman's senior water right
- A minimum release of 10 cfs from Lake Wright Patman
- Application of 2016 environmental flow releases as determined by RPS Espey

The only project in the 2016 Yields that meets the supply goal of 604,000 acre-feet per year is the combination of reallocation of Lake Wright Patman to 242.5 feet and Marvin Nichols Reservoir at 328.0 feet.

The most significant difference between these yields and the 2015 Yield update is the application of new environmental flow releases provided by RPS Espey in August of 2016. In general, the 2016 estimates of environmental flow requirements for a stand-alone Patman reallocation are lower than the Lyons-method estimates while the 2016 estimates for a stand alone Marvin Nichols project and for combination projects are higher than the Lyons-method estimates. As a result, when compared to the work done in 2015, the stand-alone 2016 Yields are higher for Lake Wright Patman reallocation and lower for Marvin Nichols. The yield of combination projects of Patman and Nichols are lower as well.

Table 22 and Figures 3 and 4 compare alternative operation scenarios for the Nichols/Patman combination. These alternative operation scenarios make different assumptions about the priority operation of the basin. Previous studies have shown that additional supplies can be made available by operating the reservoirs as a system rather than making releases based on water right priority. In the 2016 study, SBG examined an alternative scenario where the four main water supply projects, Lakes Chapman, Ralph Hall, Marvin Nichols and Patman reallocation, are operated as a system. Instead of making priority releases, the proposed system operation makes releases from Marvin Nichols to “firm up” supplies from Wright Patman. Using this type of operation, supplies can be increased by five to eight percent, depending on project configuration. Operating in this manner would require an agreement among the various users of these water supply projects. It would also be desirable if the water rights for these reservoirs, when granted, recognized the ability to operate in this manner.

All previous yield studies conducted for the Sulphur Basin Feasibility Study assumed that Marvin Nichols was senior to Patman reallocation. For the 2016 Yields, an alternative was examined where Patman reallocation was senior to Marvin Nichols. This type of operation reduces overall yield of the combination projects between five to seven percent, depending on project configuration.

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Table 21: Summary of 2016 Yields

Run	Reservoir Elevation (feet)		Priority Assumption	Environmental Flow Releases	Wright Patman Yield			Marvin Nichols Yield		Total New Yield (ac-ft/yr)
	Wright Patman	Marvin Nichols			Total (cfs)	Total (ac-ft/yr)	New (ac-ft/yr)	(cfs)	(ac-ft/yr)	
1	232.5	n/a	Standard	Patman only	460.0	333,253	153,253	n/a	n/a	153,253
2	242.5	n/a	Standard	Patman only	669.3	484,883	304,883	n/a	n/a	304,883
3	252.5	n/a	Standard	Patman only	954.4	691,427	511,427	n/a	n/a	511,427
4	n/a	328.0	Standard	Nichols only	n/a	n/a	n/a	541.5	392,297	392,297
5	232.5	328.0	Reallocation junior to Nichols	Patman & Nichols	360.0	260,807	80,807	524.3	379,836	460,643
6	232.5	328.0	Reallocation senior to Nichols	Patman & Nichols	457.0	331,080	151,080	396.0	286,887	437,967
7	235.0	328.0	Reallocation junior to Nichols	Patman & Nichols	402.75	291,777	111,777	527	381,792	493,569
8	238.0	328.0	Reallocation junior to Nichols	Patman & Nichols	459.75	333,072	153,072	527	381,792	534,864
9	242.5	328.0	Reallocation junior to Nichols	Patman & Nichols	561.5	406,786	226,786	523.5	379,256	606,042
10	242.5	328.0	Reallocation senior to Nichols	Patman & Nichols	667.8	483,796	303,796	360.4	261,096	564,892

Table 22: Yield of Patman/Nichols Combinations with Different Modeling Assumptions
(Values in acre-feet per year)

Modeling Assumption	Patman Reallocation to 242.5 feet and Nichols at 328.0 feet			Patman Reallocation to 232.5 feet and Nichols at 328.0 feet		
	New Patman	Nichols	Total	New Patman	Nichols	Total
Patman Reallocation Junior	226,786	379,256	606,042	80,807	379,836	460,643
Patman Reallocation Senior	303,796	261,096	564,892	151,080	286,887	437,967
Alternative Operation	218,599	419,826	638,425	81,707	415,117	496,824

Figure 3: Comparison of Patman/Nichols Combinations with Different Modeling Assumptions – Patman reallocation at 242.5 feet and Nichols at 328 feet

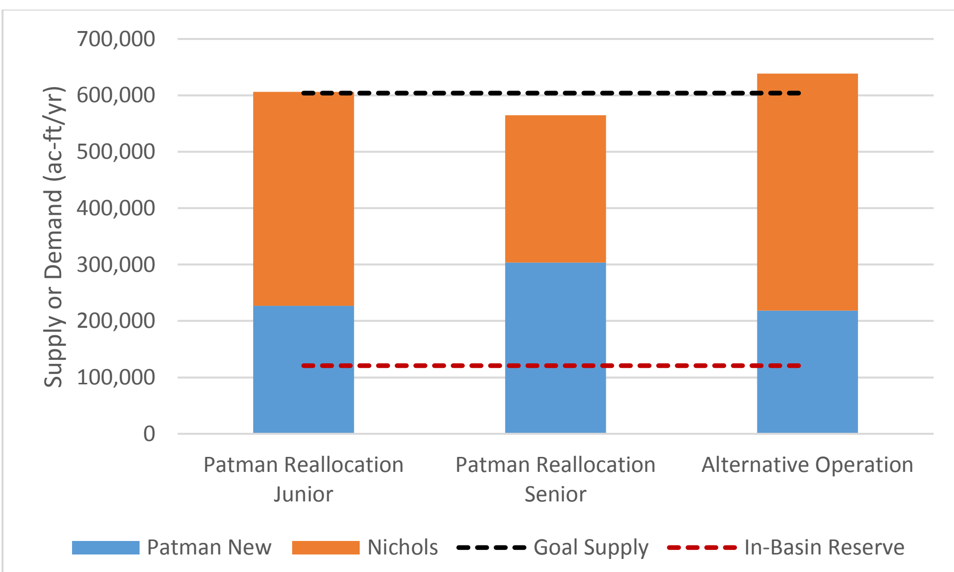
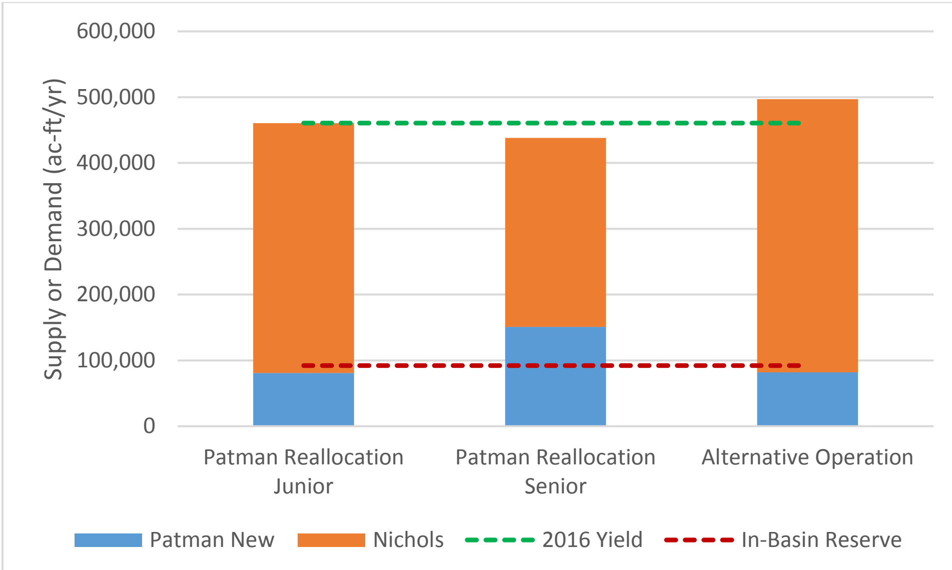


Figure 4: Comparison of Patman/Nichols Combinations with Different Modeling Assumptions – Patman reallocation at 232.5 feet and Nichols at 328 feet



Previous studies have shown that additional storage development in the Sulphur Basin can impact International Paper's (IP) operations. This study examined a release policy from Lake Wright Patman where flows downstream are never less than 250 cfs during times when IP can make substantial releases from their storage ponds. Using this type of operation, the average total supply from the combination of Patman reallocation to elevation 242.5 and Nichols at 328 feet is 749,499 acre-feet per year. Subtracting out the existing authorization at Lake Patman results in an average diversion of 569,506 acre-feet per year. If operated on a firm yield basis, the equivalent total firm yield from the same project configuration is 786,042 acre-feet per year (606,042 acre-feet per year new yield). Since this analysis is very conservative, it is possible that an operation scheme could be developed that would have less impact on firm yield. This could be examined in future studies.

Attachment A

Recommended 2016 Yield Modeling Assumptions for RiverWare Modeling

MEMORANDUM

TO: File

FROM: Jon Albright

SUBJECT: Recommended 2016 Yield Modeling Assumptions for RiverWare Modeling

DATE: April 22, 2016

PROJECT: Sulphur River Basin Feasibility Study
SBG15591

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1 Introduction

This memorandum describes the tools, parameters and assumptions that are proposed for use in the 2016 yield modeling for the Sulphur Basin Study and provides a set of recommendations to standardized yield modeling for the Wright Patman reallocation study. Included is a description of how these factors may have changed over the course of the study. These factors should be used for all yield modeling done in the 2016 studies. There may be cases where these factors need to be changed. In those cases, the changes should be part of the description of the modeling.

Table 1 summarizes the tools, parameters and assumptions proposed for the Baseline Scenario in the 2016 modeling. Other scenarios will be compared to the baseline. Major elements of the Baseline Scenario include:

- Lake Wright Patman operation using:
    - The Ultimate Rule Curve.
    - Diversions equal to the full 180,000 acre-feet per year authorized in the lake's water right when the reservoir is above 220 feet. Diversions will be shut off when the lake is below 220 feet.
    - A constant 10 cfs release at all times. (Consistent with USACE description of URC operations)
- Lake Ralph Hall operating at its proposed conservation storage at its full permitted diversion of 45,000 acre-feet per year.
- Lake Chapman operating at its full permitted diversion of 146,520 acre-feet per year when the reservoir is above 415.5 feet, even if the reservoir is in the flood pool. Diversions will be shut off only when the lake is below 415.5 feet.

The Baseline scenario does not reflect current conditions. However, it does reflect "without project" conditions for Patman reallocation above the Ultimate Rule Curve and for construction of Marvin Nichols. It is assumed that conversion to the Ultimate Rule Curve will go forward regardless of whether additional reallocation at Lake Patman or the construction of Marvin Nichols occur. Table 2 has the same information found in Table 1, but for the "with project" yield runs for Wright Patman reallocation scenarios and/or scenarios including the proposed Marvin Nichols Reservoir. The factors in these tables are discussed in more detail below in the section on Tools, Parameters and Assumptions. That section also includes a discussion of how these factors may have changed over the course of the Sulphur Basin Study.

Table 1: Recommended Tools, Assumptions and Parameters for 2016 Baseline Modeling

Tool, Assumption or Parameter	Description	
Model	SBG modified RiverWare Model	
Hydrology	USACE 3-29-16 hydrology 1938-2014	
Reservoir volumetric relationships[1]	Patman	TWDB 2010 Survey with extension above 226.3 feet using USACE data
	Chapman	TWDB 2007 survey. Extension above 440 feet from USACE RiverWare model
	Ralph Hall	As received from TCEQ
Wright Patman low-flow releases	10 cfs at all times	
Environmental flow releases[2]	Does not apply	
Priority releases[2]	From Chapman and Ralph Hall, as determined by appropriate miniWAM for Patman's existing senior right	
Ultimate Rule Curve implementation	Monthly stair step using appropriate operating level table[1]	
Diversions[1]	Chapman	146,520 ac-ft/yr (permitted diversions)
	Ralph Hall	45,000 ac-ft/yr (permitted diversion)
	Wright Patman	180,000 ac-ft/yr (permitted diversion)
	Lake O' the Pines	16,258 acre-feet per year
	Caddo	None
	Pirkey	15,214 ac-ft/yr
Diversion pattern[1]	Seasonal pattern at all reservoirs (including Patman)	

Notes:
1 Reservoir volumetric relationships, operating level tables and seasonal diversions may be found in Attachment A-1.
2 Environmental flow and priority releases will be determined in the 2016 study.

Table 2: Recommended Tools, Assumptions and Parameters for 2016 Yield Modeling of Wright Patman Reallocation and Marvin Nichols Reservoir

Tool, Assumption or Parameter	Description	
Model	SBG modified RiverWare Model with Patman reallocation and/or Marvin Nichols	
Hydrology	USACE 3-29-16 hydrology 1938-2014	
Reservoir volumetric relationships[1]	Patman	TWDB 2010 Survey with extension above 234.6 feet using USACE data
	Chapman	TWDB 2007 survey. Extension above 440 feet from USACE RiverWare model
	Nichols	From 2013-2014 SBG work
	Ralph Hall	As received from TCEQ
Wright Patman low-flow releases	10 cfs at all times when below Ultimate Rule Curve[2] (environmental flows apply above the Ultimate Rule Curve)	
Environmental flow releases[3]	To be determined	
Priority releases[3]	From Chapman, Ralph Hall and Nichols, as determined by appropriate miniWAM for Patman's existing senior right. May also include releases from Nichols for Patman reallocation in scenarios where Patman reallocation is senior to Nichols.	
Ultimate Rule Curve implementation[2]	Monthly stair step as incorporated in operating level table	
Diversions from non-yield reservoirs[1]	Chapman	146,520 ac-ft/yr (permitted diversion)
	Ralph Hall	45,000 ac-ft/yr (permitted diversion)
	Lake O' the Pines	16,258 acre-feet per year
	Caddo	None
	Pirkey	15,214 ac-ft/yr
Diversion pattern[1]	Constant at Lake Patman and/or Nichols, seasonal pattern elsewhere	

Notes:

1 Reservoir volumetric relationships, operating level tables and seasonal diversions may be found in Attachment A-1.

2 The Ultimate Rule Curve is incorporated in the Patman operating level table and controls environmental releases. Operating level tables may be found in Attachment A-1.

3 Environmental flow and priority releases will be determined in the 2016 study.

For 2016, there are four main factors that will be different than previous studies:

- *Environmental flows*. The current study will determine a recommendation for environmental flows that will be used in the modeling. These flows will be different than previous studies, which either did not include environmental flows explicitly in the modeling, or used Lyons method flows.

Environmental flows will be applied to Marvin Nichols and to reallocated Wright Patman storage above the Ultimate Rule Curve.

- *Hydrology for Lake Ralph Hall*. The 2016 study will use slightly different hydrology for Lake Ralph Hall. The modified hydrology begins in June 1942 and ends in September 1949. Since this change is before the 1950s drought it should have little if any impact on yields. This change was adopted so that SBG's modeling will match the USACE's modeling.

- *Lake Patman low-flow releases.* Some previous runs have used a combination of 10 cfs and 96 cfs low-flow releases from Lake Patman. After consultation with the USACE and the project sponsors, it has been agreed that all future modeling will assume only the 10 cfs low-flow release. For reallocation scenarios, this release will be made when the reservoir is at or below the Ultimate Rule Curve. Above the Ultimate Rule Curve, the environmental flows will apply.

- *Senior priority for Lake Patman reallocation.* Previous studies have all assumed that the reallocation of Lake Patman will be junior to Marvin Nichols. The 2016 study will include some scenarios that have the reallocation senior to Marvin Nichols in order to evaluate the potential impact of that assumption on yields.

Other assumptions will be the same as in previous studies.

1.1 Reporting Yields

For Lake Wright Patman, SBG reports yields in terms of "new" water – the yield in excess of the currently permitted 180,000 acre-feet per year. So for example, if the yield of Wright Patman reallocation is 467,445 acre-feet per year (645.23 cfs[1]), the new yield is 287,445 acre-feet per year. When reporting the Patman yield, SBG recommends reporting both total yield and the new yield if possible. If there is no space in a report table, the SBG recommends reporting only the new yield with a note saying that the full yield is 180,000 acre-feet per year more than the reported new yield. If the yield is less than 180,000 acre-feet and there is only space for one yield number, we recommend reporting yield as a negative number. The total yield can be reported in both cfs and acre-feet per year, if desired.

1.2 Previous Studies

SBG has provided three modeling studies that are part of the overall Sulphur Basin Study:

- *The 2014 WAM Yield Studies.* These yields use the SBG WAM to determine project yields using a variety of assumptions and combinations of projects. The yields are summarized in the January 2014 *Sulphur River Basin Overview Final Report.*

- *The 2014 Hydrologic Yield Studies.* This study uses both the RiverWare Model and SBG WAM to determine hydrologic yields. (Hydrologic yields are yields determined without applying the Texas

[1] For converting cfs to acre-feet per year, SBG recommends using 1.98347 ac-ft per day/cfs) * 365.25 (days/year) = 724.6424.

priority water rights such that water is allocate in upstream to downstream order). The report also includes an investigation of the differences between the two models. The results of this study are summarized in the August 2014 *Technical Memorandum on Hydrologic Yields*.

- *The 2015 Yield Updates.* These yields use the RiverWare model to update and supplement the 2014 WAM Yields of Wright Patman and Marvin Nichols. This study included an analysis of the impacts of different assumptions on project yields. The results of this study are found in the October 2015 *Memorandum Revised Patman and Nichols Yield Modeling*.

There are other informal yield calculations that have been performed over the life of this project. SBG does not recommend using these yield calculations. The previous studies discussed in this memorandum are limited to these three published studies.

2 Tools, Parameters and Assumptions

2.1 Models

Currently SBG uses a RiverWare model of the Sulphur and Cypress Basins initially developed by the USACE[2]. The USACE provided the first version of this model to SBG in December 2013 for use in the 2014 Hydrologic Yield Studies. The USACE RiverWare model was modified by SBG to include proposed projects (Parkhouse I and II, Marvin Nichols, Talco and Wright Patman reallocation), priority pass-throughs and Lyons environmental flows. These features can be turned on and off for various modeling exercises. The basic structure of the RiverWare model has remained unchanged since it was first provided by the USACE. However, both SBG and the USACE have modified the inputs and modeled operation over the course of the study. The most important modifications to the inputs are updated hydrology from the USACE and modifications to the Lake Patman volumetric data. Operational changes include low-flow releases from Lake Wright Patman, priority releases from upstream reservoirs, and the incorporation of environmental flows. The operational changes were all made by SBG. Each modification is described in more detail below.

For 2016, there will be two variations of the RiverWare model. The first has Ralph Hall, Chapman, Patman, Lake O' the Pines and Caddo. The second adds Marvin Nichols. All models include Lake Ralph Hall. Other proposed projects have been screened from consideration at this time.

2.1.1 Model History

The first yield studies performed for the Sulphur Basin Study were the 2014 WAM Yields. For these yields, SBG used a modified version of the Texas Commission on Environmental Quality's (TCEQ) Sulphur Basin Water Availability Model (SBG WAM). These yields are reported in the January 2014 *Sulphur River Basin Overview Final Report.* Modifications to the original TCEQ model are discussed in Appendix C of that report. The 2014

[2] The RiverWare model includes Lake O' the Pines and Caddo Lake in the Cypress Basin so that flood operations can be modeled. Flood operations key on the Shreveport Gage on the Red River in Louisiana. Flood flows at the Shreveport gage are primarily controlled by the reservoirs in the Sulphur and Cypress Basins.

WAM Yield Studies have a variety of assumptions regarding reservoir sediment conditions, operation of Lake Wright Patman, and the scale of proposed new projects.

As a result of dialog with the USACE and direction from our client, SBG changed to the RiverWare platform following the 2014 Hydrologic Yield Studies. This study compared hydrologic yields (yields that do not incorporate priority water rights) of the proposed projects using both the SBG WAM and the RiverWare model. The Hydrologic Yields Study revealed two important factors that significantly impact yield modeling. The first was that the extended hydrology results in a new critical period for most of the basinwhich substantially reduces the yield of projects as estimated by the model. The new drought is in the 2006-2007 timeframe, which is not included in the SBG WAM hydrology.

The second factor is the method used by the USACE in developing reservoir inflows. Once a reservoir is in operation, the USACE considers rainfall on the reservoir surface as part of the reservoir's inflows. This assumption underestimates the yield generated by reallocation of Lake Wright Patman because the surface area of the reservoir increases significantly with reallocation, increasing the inflow due to precipitation on the reservoir surface. These two factors lead to the adoption of the RiverWare platform in order to take into account the new drought. However, in order to use the model, the hydrology used in the RiverWare model needed to be revised so that rainfall on the reservoir surface would be modeled instead of input with the inflows. The USACE updated the hydrology (inflows and evaporation) and delivered it to SBG in March 2015.

2.2 Hydrology

For the upcoming 2016 studies SBG will be using hydrology obtained from the USACE in March of 2016. This hydrology is almost identical to the hydrology obtained from the USACE in March 2015. (The March 2015 hydrology does not include historical precipitation on the reservoir surface in the inflows, as discussed in the previous section.) The March 2016 hydrology changes the estimated flows at Lake Ralph Hall prior to the historical period of the North Sulphur gage. Since these flows are before either the 1950s or 2006-2007 drought, the change should not impact yields. This will be verified as part of SBG's 2016 efforts.

In November 2015 the USACE provided SBG with a model that was giving higher yields than previously calculated. After investigating the reasons for the discrepancies and discussions with the USACE, SBG has elected not to use November 2015 version of the model and will instead be adopting the March 2016 version. It is our understanding that the USACE will be using the March 2016 hydrology for further studies as well.

As with all previous models, SBG will be using net evaporation for Lake Ralph Hall and Marvin Nichols from 1940 to 2013 calculated using Texas Water Development Board evaporation and precipitation data, calculated using the same technique employed in developing the evaporation data for the TCEQ Sulphur WAM. From 1938 to 1939 and for 2014 SBG will use the USACE Chapman evaporation for Ralph Hall and the Patman evaporation for Nichols.

2.3 Reservoir Volumetric Relationships

For the 2016 modeling, SBG recommends using the most recent volumetric survey data for existing reservoirs, extended as needed using data from the USACE. Marvin Nichols will use the volumetric data generated for the Sulphur Basin Study. Ralph Hall will use the data obtained from TCEQ.

The 2014 Hydrologic Yields and 2015 Yield Updates also used the most recent volumetric survey data available for existing reservoirs. Future reservoirs are based on the volumetric conditions expected when the reservoir will be built. Most of the volumetric information for the reservoirs in the RiverWare model has not changed over the course of the study. The exception is Lake Wright Patman. The 2010 survey of the reservoir only goes up to elevation 226.3 feet, well below any reallocation scenario or the Ultimate Rule Curve. Initially, SBG extended the survey using areas from the TWDB 1997 survey. According to the 1997 and 2010 survey reports, the data above elevation 223 feet was determined by digitizing contours from USGS topo maps. This version of the Patman volumetric data was used for the 2014 Yield Studies. However, for their own work the USACE had extended the curve using areas from the original 1948 survey of the reservoir. At the USACE's request, SGB used the 1948 areas to extend the curve in the 2014 Hydrologic Yields Study and subsequent studies. Table 3 compares the surface areas from the two sources. There is a fairly significant difference between the areas, which translates into a fairly substantial difference in volume.

SBG recently calculated the surface areas at the elevations in Table 3 using available USGS DEM data (10-foot contours). These values are also shown in Table 3. The DEM areas are the closest to the USACE 1948 survey data. Therefore SBG recommends continuing to use the USACE 1948 areas rather than the TWDB 1997 data.

Table 3: Comparison of TWDB and USACE Surface Areas for Patman 2010 Survey Extension

Elevation (feet)	USACE 1948 (acres)	TWDB 1997 (acres)	SBG 2016 (acres)
230.0	38,600	34,882	39,014
240.0	60,500	56,966	60,568
250.0	88,100	82,980	86,766
260.0	121,300	111,880	117,327

For the 2015 Yield Updates, the intention was to use the USACE areas for the Wright Patman modeling in order to be consistent with parallel efforts by the USACE. However, when reviewing the models for this round of studies I noticed that the Wright Patman stand-alone models used the extension with the 1997 survey, while the combination yields used the USACE data. This will slightly change the yields of the Patman stand-alone options. These will be updated in 2016.

One issue that has not been addressed in any of the RiverWare modeling is the effect of future sedimentation. The 2014 WAM Yields examined the impact of sediment accumulation in existing projects and determined that there is some impact on yields, but it is fairly minor for larger projects. We recommend revisiting the impact of sedimentation once the preferred alternatives have been established.

2.4 Current Low-Flow Release from Lake Wright Patman

Under current Lake Wright Patman operation (Interim Rule Curve), the USACE makes a 96 cfs low-flow release from the reservoir from May to October and a 10 cfs release the rest of the year. However, the contract with the City of Texarkana only mentions a 10 cfs release. The 2014 WAM Yield Studies have only a 10 cfs release, while the 2014 Hydrologic Yields assume the combination of 10 and 96 cfs releases. The 2015 Yield Update evaluates the impact of both assumptions.

For the 2016 studies, SBG recommends using a constant 10 cfs release when diversion and storage under the existing Lake Wright Patman water right, as specified in the contract between the USACE and the city of Texarkana. This is consistent with the Corps' stated description of the Ultimate Rule Curve and URC operations as depicted in the RiverWare model. Since this release is not required by Lake Wright Patman's existing water right, the release will be made on a non-priority basis. In other words, upstream junior water rights will not need to pass water downstream for the 10 cfs release or to fill Patman storage emptied by making the 10 cfs release.

2.5 Environmental Flows

Neither the 2014 WAM Yields nor the 2014 Hydrologic Yields included explicit modeling of environmental flows. The 2015 Yield Update included Lyons method environmental flows developed by others. For the 2016 study, the Lyons flows will be replaced by environmental flows being determined by others. In all cases, the environmental flows will only be applied to diversion and storage of water under new authorizations and will be limited to inflows into the reservoir. At Lake Wright Patman, inflows that are diverted or stored under the reservoir's existing right will not need to be passed downstream.

2.6 Priority Releases

The 2014 WAM Yields and some of the 2015 Yield Updates include priority releases for Lake Wright Patman's senior water right. In some cases, priority releases were turned off for Marvin Nichols. This is described as having Marvin Nichols and Wright Patman operating as a system. The 2014 Hydrologic Yields do not have priority releases for either SBG WAM model runs or RiverWare model runs. In all of these studies, it was assumed that Marvin Nichols will be senior to Wright Patman Reallocation.

SBG determined the priority releases used in the 2015 Yield Updates using a "Mini-WAM". The Mini-WAM is a WRAP model that uses the RiverWare hydrology to determine priority releases from Ralph Hall, Chapman and Marvin Nichols for Lake Wright Patman. Other water rights are not explicitly modeled (although the impact of the historical operation of other water rights is contained in the hydrology used in the model). These releases became input into the RiverWare model. The mini-WAM should not be confused with the SBG WAM, which is a modification of the adopted TCEQ WAM, uses the TCEQ hydrology, and contains all water rights in the Sulphur Basin. These differences are summarized in Table 4.

Table 4: Differences Between Mini-WAM and SBG WAM

	Mini - WAM	SBG WAM
Model Source	Developed specifically for this project	TCEQ WAM
Modeling Platform	Water Rights Analysis Package (WRAP)	Water Rights Analysis Package (WRAP)
Water Rights Included	Major Reservoirs only	All
Hydrology Source	USACE RiverWare	TCEQ WAM

For the 2016 modeling, the existing Patman water right will be considered senior to all new water, including Marvin Nichols and reallocation. In most cases, we will continue to assume that Marvin Nichols will be senior to Patman reallocation. However, the 2016 studies will also include some scenarios that evaluate the impact on yield of having the Wright Patman reallocation be senior to Marvin Nichols in order to quantify the potential impact on yield of that assumption.

2.7 Interpretation of the Ultimate Rule Curve

The Ultimate Rule Curve is the operating curve found in the contract between the USACE and the City of Texarkana. To date this rule curve has not been implemented. In the contract, the Ultimate Rule Curve is specified as monthly elevations varying between 224.89 feet in January to 228.64 feet in June. The values are in the contract as a “stair-step”, with a constant value in each month. The Ultimate Rule Curve is also used to define conservation storage in Lake Wright Patman’s Texas water right.

Based on conversations with the USACE, they would prefer not to operate the lake in the stair-step fashion shown in the contract. The USACE would prefer using a smoothly varying curve, but the actual implementation has not been determined at this time. In order to reflect this preference, in previous studies SBG assumed a smoothly varying curve fit through the end-of-month elevation in the Ultimate Rule Curve. This assumption was used for all yields that needed the Ultimate Rule Curve. Other possible interpretations include a curve fitted to the beginning of the month, or a curve fitted to somewhere in the middle of each month. Each of these alternatives can affect estimated yields to some degree.

For 2016, since the USACE has not yet adopted a smoothed curve, SBG recommends using the stair-step that is in the Texarkana contract rather than the smoothly varying curve. We have discussed this with the USACE and they have concurred. This change will have some impact on yields, but it is not expected to be significant. Operating level tables incorporating the Ultimate Rule Curve may be found in Attachment A-1.

2.8 Diversions at Other Reservoirs

For the 2014 WAM Yields and the 2015 Yield Updates, the diversions at Lake Ralph Hall and Lake Chapman were set to the authorized diversion from those reservoirs (45,000 acre-feet per year and 146,520 acre-feet per year, respectively). In the 2014 Hydrologic Yields, the diversion from Lake Chapman was set to recent use (110,000 acre-feet) and the diversion from Ralph Hall remained at the authorized diversion (45,000 acre-feet per year).

For 2016, the full authorized diversion amount for Ralph Hall and Chapman will continue to be used when evaluating yields of Patman and/or Nichols. This is a conservative assumption that prevents Nichols or Patman from using water that has been allocated to other water rights.

Other assumptions may be made for other runs. For example, runs that focus on flooding impacts may want to assume that diversions from Chapman do not occur when that reservoir is in the flood pool. The two main users of Lake Chapman, the City of Irving and the North Texas Municipal Water District, cannot pump water from Chapman when the receiving lakes in the Trinity Basin (Lakes Lewisville and Lavon, respectively) are in the flood pool. Assuming that diversions are not being made is a logical conservative assumption for flood operations. However, it is not a conservative assumption for yield modeling. For yield modeling it is more conservative to assume that diversions from Chapman occur at all times, even if in actual operation it is likely that the receiving lakes would also be full when Chapman is full.

The diversions for Lake O’ the Pines, Caddo Lake and the Pirkey Power Plant are from the original USACE model and have not been changed by SBG.

2.9 Seasonal Diversion Pattern for Yields

The 2014 WAM Yields used the seasonal diversion patterns from the original Sulphur River WAM. However, when using the RiverWare model, SBG has followed the USACE practice of using a constant demand throughout the year when calculating a yield. The constant pattern was used for the 2014 Hydrologic Yields and the 2015 Yield Updates.

SBG recommends continuing using the constant diversion when determining yields for the 2016 studies. As long as the primary function of our studies is to feed information to the USACE, we recommend following their standard practice. However, a seasonal pattern may be examined to determine the change for key yield runs. We may also want to use a seasonal pattern for environmental analyses.

Reservoirs where yield is not being determined (Ralph Hall, Chapman, and Lake O’ the Pines) will continue to use a seasonal pattern. More information on these patterns may be found in Attachment A-1.

3 Alternative Assumptions

There may be modeling scenarios where deviations from the standard assumptions is required. In these cases, the changes should be reported along with the results. Table 5 contains some guidelines for consideration when evaluating alternatives to the factors discussed above. This is by no means a definitive list and is provided for guidance only.

Table 5: Considerations for Alternatives to Standard Assumptions

Tool, Assumption or Parameter	Possible Alternative
Model	At this time the USACE RiverWare model is the only model that includes a new critical period. The WAM model may be run, but it will need to be modified to incorporate the assumptions used for the 2016 runs.
Hydrology	The 2016 modeling will use the 3-29-16 hydrology. At this time SBG does not recommend using alternative hydrology in the RiverWare model. However, the period of record may be shortened for comparison with the WAM.
Reservoir volumetric relationships	Future sediment conditions should be considered once the preferred alternatives have been identified. Also, for the state water right process, original volumetric survey data will need to be used for Patman and Chapman.
Wright Patman low-flow and/or environmental releases	Alternatives may be examined throughout any future permitting process
Priority releases	For 2016, the study will examine having Nichols junior and senior to Lake Patman reallocation. Other studies may examine alternative operating procedures that achieve the same goal (i.e. protecting Patman's senior water right).
Ultimate Rule Curve implementation	The monthly stair-step would probably not be implemented in actual operation under the Ultimate Rule Curve. A more likely scenario would be some kind of smooth curve. The smoothed rule curve has not been developed at this time. If Patman is going to be operated only at the Ultimate Rule Curve (i.e. no reallocation above the curve), then the change in yield should be evaluated once the implementation has been determined.
Diversions from reservoirs	In order to be conservative, in a yield analysis the diversions from non-yield reservoirs in the same basin should be set at the maximum permitted amount. Purposes such as flood operation or some environmental analyses, it may be desirable to assume historical or expected diversions rather than full permitted amounts.
Diversion pattern	The standard USACE practice of a constant diversion typically gives a conservative estimate of the yield of a reservoir. However, a seasonal pattern that mimics possible use from the project may give a more realistic yield, and may be useful for environmental analyses. In most cases this will not change the yield significantly. However, if a reservoir has a relatively small conservation storage in comparison with the flow through the reservoir (for example, Lake Wright Patman operating under the Ultimate Rule Curve), the diversion pattern can make a significant difference in the yield.

For the 2016 study, runs will be made for environmental analyses. In general, there may be situations where runs for environmental analyses have different assumptions than yield runs. In some cases, a yield run will make assumptions that may or may not reflect the day-to-day operation of a potential project. For example, priority releases for senior water rights may not actually occur at the frequency shown in the TCEQ WAMs, which model a perfect application of the priority system. It is probably better to base an environmental analysis on the actual operation of a project.

In 2016, SBG and possibly others will produce modeling runs in support of the environmental impact analyses. These runs will use the RiverWare model and the March 2016 hydrology. SBG recommends that we use these assumptions for the 2016 work:

- *Diversions from reservoirs.* For the environmental analyses, SBG recommends assuming the full yield of the reservoirs is diverted at all times. Using anything less would not fully reflect the potential impact a project could have on the environment. However, instead of using the constant diversion pattern assumed in the yield runs, it may be beneficial for these runs to use a seasonal pattern that may more clearly reflect use from the reservoir. SBG will investigate if using a seasonal pattern makes enough difference to warrant applying a seasonal pattern for the environmental runs.

- *Latest volumetric survey*. At this point the timeline for reallocation of Lake Wright Patman is unknown. However, it is reasonable to assume that sediment accumulation prior to reallocation will not significantly affect how the reallocation will impact the environment.

- *Lake Patman low-flow releases*. Corps models reflect that with implementation of the Ultimate Curve, Lake Patman will be making a constant 10 cfs release when in conservation storage. SBG recommends that this be the minimum outflow from reallocated storage as well, regardless of inflow into the reservoir so that future conditions will never be worse than the assumed baseline condition (i.e. Patman operating at the Ultimate Rule Curve).

- *Environmental flow releases from Patman*. At this time the environmental flow releases have not been developed for either Nichols or Patman. Patman environmental flow releases will reduce the yield of reallocation. (Under current practice, in most situations the State of Texas does not retroactively apply environmental flows to existing water rights. Therefore we are assuming that environmental flows will not apply to the existing water right authorizations for Lake Patman and will only apply to the reallocation.) For the environmental runs, SBG proposes using the full yield of the reservoir. Any increased drawdown due to the passage of environmental flows will be offset by reduced diversions associated with yield reduction. This assumption should not substantially change the behavior of the reservoir.

- *Priority and environmental flow releases from Nichols.* Environmental analyses of the upstream impacts of Lake Patman will assume that Nichols has been built. Since environmental flow recommendations are being developed in parallel with this work, the environmental flow releases will not be incorporated in the modeling until a later stage. However, priority releases will be included. These releases should be similar to environmental releases, particularly during critical low-flow periods, and can act as a surrogate for environmental releases until they have been developed. During critical low flow periods the priority releases assume that all inflow into Nichols will be passed downstream for Patman's senior right, so the difference may not be significant.

- *Lake Ralph Hall.* Inclusion of Lake Ralph Hall is part of the baseline assumptions for all analyses of Lake Patman reallocation.

4 Summary

The most significant change for the 2016 modeling will be the incorporation of new environmental flows currently being developed by others. Other changes include slight modification to the hydrology for Lake Ralph Hall, and inclusion of a constant 10 cfs low-flow release from Lake Patman as the preferred modeling configuration. Previous studies have always assumed that Marvin Nichols will be senior to Lake Patman reallocation. The 2016 modeling will quantify the impact on yield if it is assumed that Lake Patman reallocation is senior to Marvin Nichols.

The Baseline Scenario for the yield study includes:

- Lake Wright Patman operating using:
  - The Ultimate Rule Curve.
  - The full 180,000 acre-feet per year authorized in the lake's water right when the reservoir is above 220 feet. Diversions will be shut off when the lake is below 220 feet.
  - A constant 10 cfs release at all times.

- Lake Ralph Hall operating at its proposed conservation storage at its full permitted diversion of 45,000 acre-feet per year.

- Lake Chapman operating at its full permitted diversion of 146,520 acre-feet per year when the reservoir is above 415.5 feet, even if the reservoir is in the flood pool. Diversions will be shut off only when the lake is below 415.5 feet.

With the exception of the 10 cfs release, this baseline is identical to previous baseline modeling. Previous baseline modeling used the 96 cfs release in the summer months.

Runs with Lake Patman reallocation and or Marvin Nichols add the following elements to the Baseline Scenario:

- Reallocation of Lake Patman above the Ultimate Rule Curve and/or the proposed Marvin Nichols Reservoir.

- Environmental releases associated with reallocation and Marvin Nichols.

- Constant diversions at the yield reservoirs

With the possible exception of the diversion pattern, environmental modeling will use the same assumptions as the yield modeling.

Ralph Hall.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	460	0
2	462	0
3	464	1
4	466	10
5	468	29
6	470	57
7	472	98
8	474	152
9	476	220
10	478	302
11	480	397
12	482	501
13	484	615
14	486	740
15	488	877
16	490	1027
17	492	1195
18	494	1380
19	496	1633
20	498	1969
21	500	2357
22	502	2857
23	504	3543
24	506	4487
25	508	5808
26	510	7521
27	512	9574
28	514	11998
29	516	14843
30	518	18110
31	520	21849
32	522	26068
33	524	30749
34	526	35961
35	528	41695
36	530	47989
37	532	54987
38	534	62714
39	536	71102
40	538	80185
41	540	90104
42	542	100905
43	544	112550
44	546	125029
45	548	138378
46	550	152630
47	551	160235
48	552	167840
49	554	184009
50	556	201167
51	558	219400
52	560	238693
53	562	259064
54	564	280506

Ralph Hall.Elevation Area Table

	Pool Elevation	Surface Area
	ft	acre
1	460	0
2	462	0
3	464	1
4	466	8
5	468	11
6	470	18
7	472	23
8	474	31
9	476	37
10	478	45
11	480	50
12	482	54
13	484	60
14	486	65
15	488	72
16	490	79
17	492	88
18	494	98
19	496	156
20	498	180
21	500	208
22	502	292
23	504	395
24	506	549
25	508	772
26	510	941
27	512	1112
28	514	1312
29	516	1532
30	518	1736
31	520	2003
32	522	2215
33	524	2465
34	526	2747
35	528	2987
36	530	3307
37	532	3691
38	534	4036
39	536	4352
40	538	4730
41	540	5189
42	542	5611
43	544	6035
44	546	6443
45	548	6906
46	550	7345
47	551	7605
48	552	7866
49	554	8303
50	556	8855
51	558	9379
52	560	9914
53	562	10457
54	564	10985

Ralph Hall.Operating Level Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	462	464	464	538	551	551	551	551	551	551	551	551	551	551	558	564

**Ralph Hall_Users.Periodic
Diversion Request**

	Diversion Request
	cfs
Jan	53.43
Feb	52.2
Mar	43.18
Apr	64.28
May	50.5
Jun	66.55
Jul	90.02
Aug	107.58
Sep	85.46
Oct	63.67
Nov	39.33
Dec	28.54

Attachment A-1

Cooper.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	396	0
2	397	1
3	398	1
4	399	2
5	400	5
6	401	286
7	402	901
8	403	1771
9	404	2882
10	405	4241
11	406	5896
12	407	7877
13	408	10189
14	409	12818
15	410	15808
16	411	19199
17	412	22947
18	413	27032
19	414	31426
20	415	36130
21	416	41136
22	417	46445
23	418	52051
24	419	57962
25	420	64164
26	421	70668
27	422	77478
28	423	84643
29	424	92257
30	425	100366
31	426	109066
32	427	118434
33	428	128478
34	429	139225
35	430	150604
36	431	162495
37	432	175115
38	433	188342
39	434	202262
40	435	217285
41	436	232754
42	437	248617
43	438	264866
44	439	281565
45	440	298930
46	441	318508
47	442	338645
48	443	359348
49	444	380603
50	445	402405
51	446	424755
52	447	447655
53	448	471110
54	449	495130
55	450	519725
56	451	544905
57	452	570680
58	453	597060
59	454	624055
60	455	651675
61	456	679893
62	457	708693
63	458	738093
64	459	768093
65	460	798693
66	461	829893
67	462	861693
68	463	894093

Cooper.elevation Area Table

	Pool Elevation	Surface Area
	ft	acre
1	396	0
2	397	0
3	398	1
4	399	1
5	400	8
6	401	477
7	402	746
8	403	990
9	404	1232
10	405	1492
11	406	1814
12	407	2145
13	408	2471
14	409	2792
15	410	3190
16	411	3573
17	412	3921
18	413	4242
19	414	4549
20	415	4865
21	416	5154
22	417	5459
23	418	5760
24	419	6058
25	420	6349
26	421	6655
27	422	6973
28	423	7377
29	424	7851
30	425	8387
31	426	8996
32	427	9714
33	428	10412
34	429	11087
35	430	11626
36	431	12331
37	432	12908
38	433	13597
39	434	14275
40	435	15274
41	436	15668
42	437	16051
43	438	16457
44	439	16976
45	440	17958
46	441	19850
47	442	20425
48	443	20980
49	444	21530
50	445	22075
51	446	22625
52	447	23175
53	448	23735
54	449	24305
55	450	24885
56	451	25475
57	452	26075
58	453	26685
59	454	27305
60	455	27935
61	456	28500
62	457	29100
63	458	29700
64	459	30300

Cooper.Operating Level Table

	1	2	3	3.25	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	396	415.5	415.5	420	431.46	440	440	440	440	440.64	441.92	443.2	444.44	445.61	446.2	452.8	459

Cooper Outflow.Level vs Low Flow Requirement

	1	3	3	16
	NONE	NONE	NONE	NONE
	----	----	----	----
	cfs	cfs	cfs	cfs
0:00 Jan 1	0	0	5	5
0:00 Feb 1	0	0	5	5
0:00 Mar 1	0	0	5	5
0:00 Apr 1	0	0	5	5
0:00 May 1	0	0	5	5
0:00 Jun 1	0	0	5	5
0:00 Jul 1	0	0	5	5
0:00 Aug 1	0	0	5	5
0:00 Sep 1	0	0	5	5
0:00 Oct 1	0	0	5	5
0:00 Nov 1	0	0	5	5
0:00 Dec 1	0	0	5	5

Cooper Outflow.Level Regulation Table

	500	500	1,000	1,000	3,000	3,000
	cfs	cfs	cfs	cfs	cfs	cfs
	---	---	---	---	---	---
	NONE	NONE	NONE	NONE	NONE	NONE
0:00 Jan 1	5	8.625	8.625	9.359	9.359	16

Cooper Currrent
Usage.Periodic Diversion

	Diversion Request
	cfs
0:00 Jan 1	173.6
0:00 Feb 1	171.28
0:00 Mar 1	159.81
0:00 Apr 1	190.62
0:00 May 1	178.29
0:00 Jun 1	220.01
0:00 Jul 1	271.71
0:00 Aug 1	294.32
0:00 Sep 1	253.3
0:00 Oct 1	210.85
0:00 Nov 1	160.97
0:00 Dec 1	135.83

Wright Patman.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	180	0
2	195	1
3	196	2
4	197	3
5	198	6
6	199	13
7	200	27
8	201	56
9	202	107
10	203	189
11	204	305
12	205	462
13	206	659
14	207	906
15	208	1296
16	209	2192
17	210	3705
18	211	5804
19	212	8775
20	213	12996
21	214	18531
22	215	25522
23	216	34079
24	217	44368
25	218	56551
26	219	70925
27	220	87300
28	221	105403
29	222	125611
30	223	147682
31	224	171069
32	225	195398
33	226	220465
34	226.3	228140
35	230	347178
36	231	386774
37	232	428370
38	233	472016
39	234	517812
40	235	565857
41	236	616103
42	237	668500
43	238	723096
44	239	779992
45	240	839288
46	241	901033

Wright Patman Elevation Area Table

	Pool Elevation	Surface Area
	ft	acre
1	180	0
2	195	1
3	196	1
4	197	2
5	198	4
6	199	10
7	200	20
8	201	39
9	202	65
10	203	98
11	204	136
12	205	177
13	206	219
14	207	286
15	208	597
16	209	1210
17	210	1780
18	211	2462
19	212	3562
20	213	4886
21	214	6243
22	215	7681
23	216	9493
24	217	11185
25	218	13291
26	219	15397
27	220	17240
28	221	19142
29	222	21231
30	223	22793
31	224	23924
32	225	24705
33	226	25435
34	226.3	26148
35	230	38600
36	231	40600
37	232	42600
38	233	44700
39	234	46900
40	235	49200
41	236	51300
42	237	53500
43	238	55700
44	239	58100
45	240	60500
46	241	63000

	Pool Elevation	Storage
	ft	acre-ft
47	242	965329
48	243	1032225
49	244	1101770
50	245	1174016
51	246	1249012
52	247	1326857
53	248	1407603
54	249	1491249
55	250	1577844
56	251	1667540
57	252	1760435
58	253	1856531
59	254	1955926
60	255	2058721
61	256	2164966
62	257	2274612
63	258	2387608
64	259	2503954
65	260	2623600
66	261	2746746
67	262	2873591
68	263	3004187
69	264	3138682
70	265	3277227
71	266	3419872
72	267	3566617
73	268	3717512
74	269	3872607
75	270	4031853
76	271	4195298
77	272	4363093
78	273	4535189
79	274	4711584
80	275	4892330
81	276	5077476
82	277	5267121
83	278	5461317
84	279	5660112
85	280	5863558
86	281	6071604
87	282	6284249
88	283	6501695
89	284	6723891
90	285	6950936
91	286	7182782

	Pool Elevation	Surface Area
	ft	acre
47	242	65600
48	243	68200
49	244	70900
50	245	73600
51	246	76400
52	247	79300
53	248	82200
54	249	85100
55	250	88100
56	251	91300
57	252	94500
58	253	97700
59	254	101100
60	255	104500
61	256	108000
62	257	111300
63	258	114700
64	259	118000
65	260	121300
66	261	125000
67	262	128700
68	263	132500
69	264	136500
70	265	140600
71	266	144700
72	267	148800
73	268	153000
74	269	157200
75	270	161300
76	271	165600
77	272	170000
78	273	174200
79	274	178600
80	275	182900
81	276	187400
82	277	191900
83	278	196500
84	279	201100
85	280	205800
86	281	210300
87	282	215000
88	283	219900
89	284	224500
90	285	229600
91	286	234100

Wright Patman.Operating Level Table
Ultimate Rule Curve

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	180	220	220	222.45	224.89	226.62	228.35	230.08	231.81	235.27	242.2	249.12	256.04	259.5	272.7	285.9
0:00 Apr 1	180	220	220	223.42	226.84	228.47	230.11	231.74	233.37	236.64	243.17	249.7	256.23	259.5	272.7	285.9
0:00 May 1	180	220	220	224.31	228.61	230.15	231.7	233.24	234.79	237.88	244.06	250.23	256.41	259.5	272.7	285.9
0:00 Jun 1	180	220	220	224.32	228.64	230.18	231.73	233.27	234.81	237.9	244.07	250.24	256.41	259.5	272.7	285.9
0:00 Jul 1	180	220	220	224.24	228.47	230.02	231.57	233.12	234.68	237.78	243.99	250.19	256.4	259.5	272.7	285.9
0:00 Aug 1	180	220	220	223.88	227.75	229.34	230.93	232.51	234.1	237.28	243.63	249.98	256.33	259.5	272.7	285.9
0:00 Sep 1	180	220	220	223.42	226.83	228.46	230.1	231.73	233.36	236.63	243.17	249.7	256.23	259.5	272.7	285.9
0:00 Oct 1	180	220	220	223.06	226.11	227.78	229.45	231.12	232.79	236.13	242.81	249.48	256.16	259.5	272.7	285.9
0:00 Nov 1	180	220	220	222.74	225.47	227.17	228.87	230.57	232.28	235.68	242.49	249.29	256.1	259.5	272.7	285.9
0:00 Dec 1	180	220	220	222.59	225.17	226.89	228.6	230.32	232.04	235.47	242.34	249.2	256.07	259.5	272.7	285.9

Configure as a lookup table

Wright Patman.Operating Level Table
Elevation 232.5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	180	220	220	224.9	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Apr 1	180	220	220	226.8	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 May 1	180	220	220	228.6	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Jun 1	180	220	220	228.6	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Jul 1	180	220	220	228.5	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Aug 1	180	220	220	227.8	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Sep 1	180	220	220	226.8	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Oct 1	180	220	220	226.1	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Nov 1	180	220	220	225.5	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9
0:00 Dec 1	180	220	220	225.2	232.5	234.1	235.7	237.3	238.9	242.1	246.45	250.8	255.15	259.5	272.7	285.9

Configure as a lookup table

Wright Patman.Operating Level Table
Elevation 242.5

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	180	220	220	224.9	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Apr 1	180	220	220	226.8	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 May 1	180	220	220	228.6	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Jun 1	180	220	220	228.6	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Jul 1	180	220	220	228.5	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Aug 1	180	220	220	227.8	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Sep 1	180	220	220	226.8	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Oct 1	180	220	220	226.1	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Nov 1	180	220	220	225.5	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9
0:00 Dec 1	180	220	220	225.2	242.5	244.1	245.7	247.3	248.9	250.5	252.1	254.1	255.7	259.5	272.7	285.9

Configure as a lookup table

Patman_User.Periodic
Diversion Request
180,000 ac-ft/yr

	Diversion Request
	cfs
Jan	233.63
Feb	238.24
Mar	248.78
Apr	243.23
May	243.72
Jun	262.06
Jul	255.8
Aug	267.88
Sep	256.46
Oct	251.19
Nov	243
Dec	231.21

Wright Patman Outflow.Level vs Low Flow Requirement

	1	3	3	16
	NONE	NONE	NONE	NONE
	----	----	----	----
	cfs	cfs	cfs	cfs
0:00 Jan 1	10	10	10	10
0:00 Feb 1	10	10	10	10
0:00 Mar 1	10	10	10	10
0:00 Apr 1	10	10	10	10
0:00 May 1	10	10	10	10
0:00 Jun 1	10	10	10	10
0:00 Jul 1	10	10	10	10
0:00 Aug 1	10	10	10	10
0:00 Sep 1	10	10	10	10
0:00 Oct 1	10	10	10	10
0:00 Nov 1	10	10	10	10
0:00 Dec 1	10	10	10	10

Wright Patman Outflow.Level Regulation Table

	10	96	200	1,000	1,600	2,600	3,700	6,000	10,000	10,000
	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs
	---	---	---	---	---	---	---	---	---	---
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
0:00 Jan 1	5	5.01	5.02	5.21	5.52	6	7.07	7.36	8	16

Lake O the Pines.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	182	0
2	183	1
3	184	2
4	185	3
5	186	6
6	187	10
7	188	16
8	189	26
9	190	39
10	191	59
11	192	86
12	193	126
13	194	187
14	195	281
15	196	424
16	197	642
17	198	968
18	199	1447
19	200	2148
20	201	3126
21	202	4429
22	203	6099
23	204	8181
24	205	10766
25	206	13930
26	207	17668
27	208	21976
28	209	26856
29	210	32324
30	211	38381
31	212	45021
32	213	52226
33	214	59972
34	215	68263
35	216	77153
36	217	86662
37	218	96803
38	219	107616
39	220	119091
40	221	131212
41	222	143996
42	223	157393
43	224	171392
44	225	185989
45	226	201205
46	227	216839
47	228	232892
48	229	250421

Lake O the Pines.Elevation Area Table

	Pool Elevation	Surface Area
	ft	acre
1	182	0
2	183	1
3	184	1
4	185	2
5	186	3
6	187	5
7	188	8
8	189	11
9	190	16
10	191	23
11	192	33
12	193	49
13	194	75
14	195	116
15	196	174
16	197	267
17	198	393
18	199	577
19	200	831
20	201	1137
21	202	1482
22	203	1862
23	204	2314
24	205	2875
25	206	3450
26	207	4024
27	208	4590
28	209	5169
29	210	5761
30	211	6353
31	212	6920
32	213	7483
33	214	8009
34	215	8581
35	216	9199
36	217	9821
37	218	10474
38	219	11146
39	220	11798
40	221	12449
41	222	13100
42	223	13696
43	224	14301
44	225	14909
45	226	15429
46	227	15840
47	228	16269
48	229	19030

	Pool Elevation	Storage
	ft	acre-ft
49	230	269826
50	231	289986
51	232	310916
52	233	332661
53	234	355276
54	235	378821
55	236	403281
56	237	428606
57	238	454826
58	239	481986
59	240	510131
60	241	539331
61	242	569586
62	243	600846
63	244	633136
64	245	666456
65	246	700736
66	247	735931
67	248	772061
68	249	809176
69	250	847336
70	251	886571
71	252	926871
72	253	968251
73	254	1010731
74	255	1054291
75	256	1099026
76	257	1145056
77	258	1192336
78	259	1240896
79	260	1290801
80	261	1341906
81	262	1394071
82	263	1447241
83	264	1501326
84	265	1556241
85	266	1611971
86	267	1668651
87	268	1726586
88	269	1786246
89	270	1848301
90	271	1912736
91	272	1978906
92	273	2046426
93	274	2115096
94	275	2184821
95	276	2255726
96	277	2328056

	Pool Elevation	Surface Area
	ft	acre
49	230	19780
50	231	20540
51	232	21320
52	233	22170
53	234	23060
54	235	24030
55	236	24890
56	237	25760
57	238	26680
58	239	27640
59	240	28650
60	241	29750
61	242	30760
62	243	31760
63	244	32820
64	245	33820
65	246	34740
66	247	35650
67	248	36610
68	249	37620
69	250	38700
70	251	39770
71	252	40830
72	253	41930
73	254	43030
74	255	44090
75	256	45380
76	257	46680
77	258	47880
78	259	49240
79	260	50570
80	261	51640
81	262	52690
82	263	53650
83	264	54520
84	265	55310
85	266	56150
86	267	57210
87	268	58660
88	269	60660
89	270	63450
90	271	65420
91	272	66920
92	273	68120
93	274	69220
94	275	70230
95	276	71580
96	277	73080

Lake O the Pines.Operating Level Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 May 19	182	200	223	225.5	228.5	230.04	231.48	232.85	234.15	236.56	240.85	244.57	247.93	249.5	269.9	277
0:00 May 20	182	200	223	226	230	231.38	232.68	233.93	235.12	237.34	241.32	244.83	248.01	249.5	269.9	277
0:00 Sep 15	182	200	223	226	230	231.38	232.68	233.93	235.12	237.12	241.32	244.83	248.01	249.5	269.9	277
0:00 Sep 30	182	200	223	225.5	228.5	230.04	231.48	232.85	234.15	236.56	240.85	244.57	247.93	249.5	269.9	277

Lake O the Pines Outflow.Level vs Low Flow Requirement

	1	3	3	16
	NONE	NONE	NONE	NONE
	----	----	----	----
	cfs	cfs	cfs	cfs
Jan	0	0	26	26
Feb	0	0	26	26
Mar	0	0	26	26
Apr	0	0	26	26
May	0	0	26	26
Jun	0	0	26	26
Jul	0	0	26	26
Aug	0	0	26	26
Sep	0	0	26	26
Oct	0	0	26	26
Nov	0	0	26	26
Dec	0	0	26	26

Lake O the Pines Outflow.Level Regulation Table

	26	26	550	1,000	3,000	3,000	3,000	3,000	3,000
	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs	cfs
	---	---	---	---	---	---	---	---	---
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
0:00 May 19	1	5	6	6.5	7	8	9	9.77	16
0:00 May 20	1	5	6	6.5	7	8	9	9.4	16
0:00 Sep 15	1	5	6	6.5	7	8	9	9.4	16
0:00 Oct 1	1	5	6	6.5	7	8	9	9.77	16

Lake O the Pines_User.Periodic Diversion Request

	Diversion Request
	cfs
0:00 Jan 1	15.92
0:00 Feb 1	15.19
0:00 Mar 1	14.54
0:00 Apr 1	18.94
0:00 May 1	22.12
0:00 Jun 1	26.64
0:00 Jul 1	29.65
0:00 Aug 1	31.62
0:00 Sep 1	28.22
0:00 Oct 1	27.3
0:00 Nov 1	20.33
0:00 Dec 1	18.44

Caddo.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	160	0
2	161	2500
3	162	9350
4	163	19700
5	164	33300
6	165	49900
7	166	69250
8	167	91200
9	168	115600
10	169	142300
11	170	171150
12	171	202150
13	172	235450
14	173	271050
15	174	308900
16	175	349050
17	176	391450
18	177	436100
19	178	483100
20	179	532450
21	180	584050
22	181	637900
23	182	694050
24	183	752450
25	184	813100
26	185	876000
27	186	937666.7

Caddo.Elevation Area Table

	Pool Elevation	Surface Area
	ft	acre
1	160	0
2	161	5000
3	162	8700
4	163	12000
5	164	15200
6	165	18000
7	166	20700
8	167	23200
9	168	25600
10	169	27800
11	170	29900
12	171	32100
13	172	34500
14	173	36700
15	174	39000
16	175	41300
17	176	43500
18	177	45800
19	178	48200
20	179	50500
21	180	52700
22	181	55000
23	182	57300
24	183	59500
25	184	61800
26	185	64000
27	186	66500

Caddo.Operating Level Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	160	166	166	167.3	168.5	170.49	170.49	170.49	170.49	170.49	170.5	170.5	170.5	170.5	173.5	186

MCN 1a.Elevation Volume Table

	Pool Elevation	Storage
	ft	acre-ft
1	270	0
2	271	185
3	272	999
4	273	2374
5	274	4306
6	275	6792
7	276	9833
8	277	13429
9	278	17578
10	279	22282
11	280	27540
12	281	33499
13	282	40312
14	283	47980
15	284	56502
16	285	65878
17	286	76108
18	287	87192
19	288	99131
20	289	111923
21	290	125570
22	291	140135
23	292	155683
24	293	172215
25	294	189730
26	295	208229
27	296	227711
28	297	248177
29	298	269627
30	299	292060
31	300	315476
32	301	339950
33	302	365556
34	303	392294
35	304	420163
36	305	449165
37	306	479298
38	307	510563
39	308	542960
40	309	576489
41	310	611150
42	311	647165
43	312	684756
44	313	723926
45	314	764673
46	315	806997
47	316	850899
48	317	896378
49	318	943435
50	319	992070
51	320	1042282
52	321	1094557
53	322	1149387
54	323	1206773
55	324	1266714
56	325	1329210
57	326	1394262
58	327	1461869
59	328	1532031
60	329	1604749
61	330	1680022
62	331	1757569
63	332	1837106
64	333	1918634
65	334	2002152
66	335	2087661
67	336	2175160
68	337	2264649
69	338	2356129
70	339	2449599
71	340	2545060

MCN 1a.Elevation Area Table

	Pool Elevation	Surface Area
	ft	**acre**
1	270	0
2	271	554
3	272	1107
4	273	1661
5	274	2215
6	275	2769
7	276	3322
8	277	3876
9	278	4430
10	279	4983
11	280	5537
12	281	6391
13	282	7245
14	283	8099
15	284	8952
16	285	9806
17	286	10660
18	287	11514
19	288	12368
20	289	13222
21	290	14076
22	291	15059
23	292	16043
24	293	17026
25	294	18009
26	295	18993
27	296	19976
28	297	20960
29	298	21943
30	299	22927
31	300	23910
32	301	25042
33	302	26174
34	303	27306
35	304	28437
36	305	29569
37	306	30701
38	307	31833
39	308	32965
40	309	34097
41	310	35228
42	311	36806
43	312	38383
44	313	39961
45	314	41538
46	315	43116
47	316	44693
48	317	46270
49	318	47848
50	319	49425
51	320	51003
52	321	53558
53	322	56113
54	323	58668
55	324	61223
56	325	63778
57	326	66333
58	327	68889
59	328	71444
60	329	73999
61	330	76554
62	331	78544
63	332	80535
64	333	82525
65	334	84515
66	335	86506
67	336	88496
68	337	90486
69	338	92477
70	339	94467
71	340	96457

MCN 1a.Operating Level Table

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft	ft
0:00 Jan 1	270	272	272	314	328	328	328	328	328	328	328	328	328	328	334	340

Attachment B

Description of SBG MiniWAM – 2016 Modeling

TECHNICAL MEMORANDUM

TO: File

FROM: Jon Albright

SUBJECT: Description of SBG MiniWAM – 2016 Modeling

DATE: October 31, 2016

PROJECT: Sulphur River Basin Feasibility Study
SBG15591

For the 2016 yields, a new version of the SBG MiniWAM was developed as part of the yield modeling. This version of the MiniWAM replaces the version used in the 2015 yield update[1]. The 2016 yields were determined using a modified version of the USACE RiverWare model of the Sulphur Basin. The SBG MiniWAM model was used to develop monthly time series of flows passed downstream for Lake Wright Patman's water right and for implementation of environmental flows. These flows were "hard wired" as reservoir releases in the RiverWare model. The SBG MiniWAM model was not used to directly calculate yields.

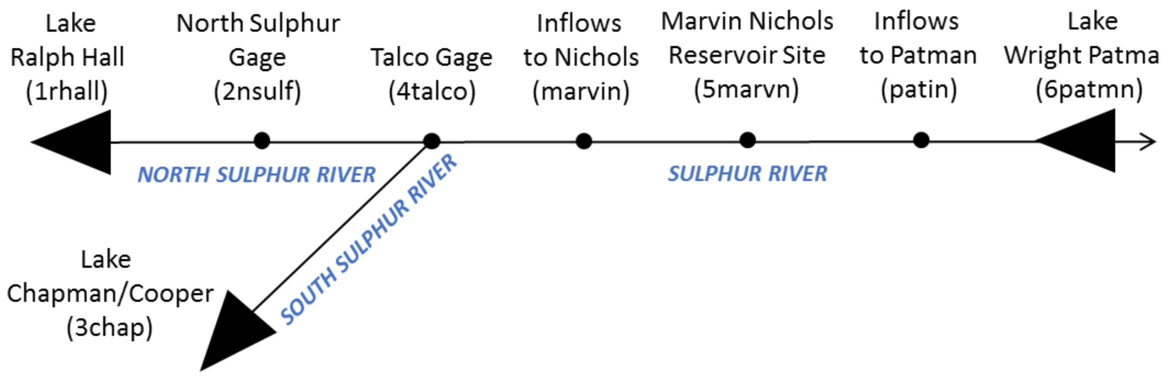
The SBG MiniWAM model models the basin twice using the sixteen control points and seven reservoirs shown in Figure 1. The reservoirs and control points labeled "Original Network" simulate existing water rights. (Existing water rights include Lake Ralph Hall, which has a Texas water right but at this time has not been constructed). The reservoirs and control points labeled "Parallel Network" simulates the basin with the proposed projects (Marvin Nichols and Patman reallocation) as well as environmental flows. These model features correspond to objects in the USACE RiverWare model. Not all objects in the RiverWare model are included – only those features that have direct bearing on priority releases to Patman and environmental flows are included in the SBG MiniWAM model. For example, the control point in the RiverWare model that corresponds to the White Oak Creek near Talco gage is not included in the MiniWAM because no projects upstream on White Oak Creek have water rights or potential environmental flow requirements that would affect the analysis However, the flows that originate in the White Oak Creek watershed are included in the model in the form of inflows to Lake Wright Patman. Flows for all other tributaries are included as well.

Table 1 shows the diversion, priority and storage used to model Lakes Chapman, Ralph Hall and Wright Patman in the SBG MiniWAM model. The diversions and priorities are directly from the water rights. The storage amounts for Patman and Chapman are based on the most recent volumetric surveys of the reservoirs (2010 and 2007, respectively). The 2010 survey for Patman was extended above elevation 226.3 feet using elevation and area data from the USACE. The storage amount for Lake Ralph Hall is the proposed storage in the reservoir. Storage and area records for Ralph Hall were obtained from TCEQ.

---

[1] In the 2015 work, the MiniWAM is also called the FNI SB WRAP model. The two terms refer to the same models.

Original Network



Parallel Network

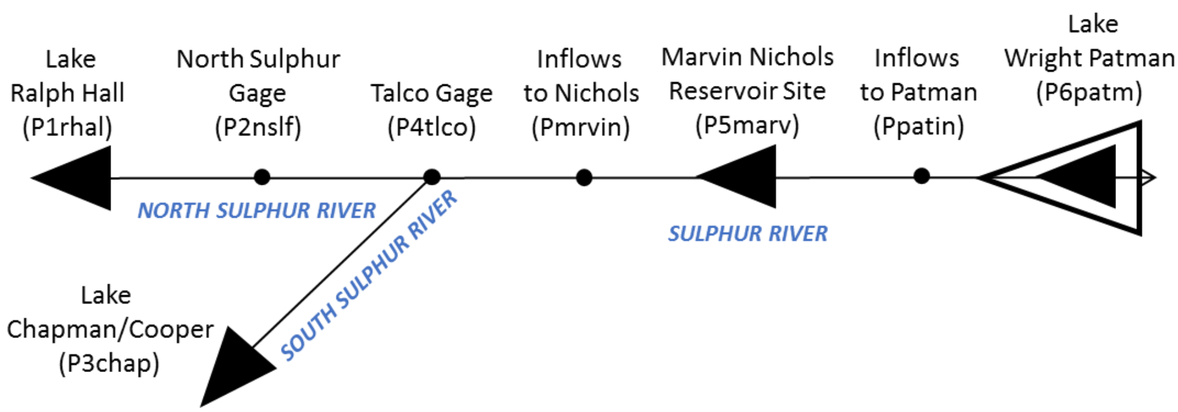


Figure 1: Control Points and Reservoirs in the SBG MiniWAM

Table 1: Reservoirs, Priorities, Diversions, and Storage Capacities as Represented in the SBG MiniWAM Model

Reservoir	Priority Date	Diversion (ac-ft/yr)	Storage Capacity (ac-ft)
Wright Patman	3/5/1951	14,572	302,137 (87,300 inactive)[1]
	2/17/1957	10,428	
	9/19/1967	20,000	
	2/17/1957	35,000	
	9/19/1967	100,000	
Total		*180,000*	
Jim Chapman	11/19/1965	16,106	298,930 (38,598 inactive)[2]
	11/19/1965	19,200	
	11/19/1965	3,214	
	11/19/1965	54,000	
	11/19/1965	54,000	
Total		*146,520*	
Ralph Hall	8/13/2004	45,000	160,235

1. For Lake Wright Patman, capacity is the maximum amount specified in the Ultimate Rule Curve (elevation 228.6 feet); storage capacities are based on the 2010 TWDB volumetric survey, modified to include storage above 226.3 feet.
2. For Lake Chapman, storage capacities are based on the 2007 TWDB volumetric survey

Unlike the MiniWAM used in the 2015 yield updates, the 2016 SBG MiniWAM model includes the 10 cfs low-flow releases from Lake Patman in the parallel network. The 10 cfs release is not part of the reservoir's Texas water right, but it is a requirement of the contract between the USACE and the City of Texarkana. This instream flow, which requires the release of stored water, is modeled with the most junior priority in the basin to minimize the impact on other water rights. Because the 10 cfs requires the release of stored water, it can have a small impact on other senior water rights when the storage emptied by release of stored water is filled in later timesteps. However, this volume of water is small and should have minimal impact on model results.

Hydrologic Input

The USACE model does not use naturalized flows. Inflows are input in some locations as local incremental flow (i.e. flow between points) or as cumulative flow (i.e. the sum of flow from all upstream points). The USACE model calculates flows at each location as the model executes and the upstream releases from reservoirs are known. The WRAP model uses cumulative flows that have been adjusted to remove the effects of upstream development, which are called naturalized flows. (The naturalized flows in the WAM are not appropriate in this case since they are different than the RiverWare hydrology and would give different results for the volume of water passed downstream.) In order to come up with the appropriate flows for the WRAP model, the USACE model must be executed first, the flow at each location extracted from the model, and the cumulative inflows for the WRAP model calculated from the output. The steps used in this calculation are as follows:

- Daily flows from the model are extracted at the eight locations in the Original Network portion of Figure 1. These flows are summed up to monthly totals. Control points *marvin* and *patin* are at the same geographic location as control points *5marvn* and *6patmn*, respectively, so these points have the same flow.

- For the two upstream reservoirs (Ralph Hall and Chapman), the WRAP model inputs (*1rhall* and *3chap*) are set to the respective monthly inflows into the reservoirs.

- The incremental flow between Ralph Hall and the North Sulphur Gage control point is calculated by subtracting the modeled Ralph Hall outflows from the modeled flows at the North Sulphur Gage control point. The incremental flows are added to the flows at *1rhall* to determine the WRAP model input at the *2nsulf* control point.

- Incremental flows between the North Sulphur Gage, Lake Chapman and the Talco Gage are calculated by subtracting the modeled flows at the North Sulphur Gage and the modeled outflow from Lake Chapman from the modeled flows at the Talco Gage control point. These incremental flows are added to the flows at *3chap* and *2nsulf* to determine the WRAP model input at *4talco*.

- Similarly, WRAP model input flows at *5marvin* and *6patmn* are calculated by determining the appropriate modeled incremental flow and then adding the incremental flow to the WRAP input flow at the upstream location.

- Flows at *marvin* are set equal to the flows at *5marvn* and flows at *patin* are set equal to the flows at *6patmn* since these points represent the same geographic locations.

- Flows at the control points in the Parallel Network are set equal to the equivalent control point in the Original Network.

This method results in negative incremental flows between control points during a few months. The negative incremental flows are set to zero before adding in the upstream flows.

Net evaporation rates in the WRAP model are the monthly sum of the daily rates from the USACE model.

Considerations Regarding Water Availability

The model first simulates existing water rights in the Original Network, then uses the depletions made by the original water rights to limit depletions in the Parallel Network. The Parallel Network includes new projects that do not currently have water rights (Marvin Nichols and Patman reallocation), as well as the proposed environmental flow requirements.

The Parallel Network is needed because the variable conservation storage of Lake Wright Patman (the Ultimate Rule Curve) complicates water availability for all water rights. Figure 1 shows the conservation volumes for the Ultimate Rule Curve. The conservation storage increases by 109,172 acre-feet between the end of March and the beginning of May. Water must be appropriated from inflows to fill that storage, in addition to water that is appropriated for diversions, to fill storage emptied in previous timesteps, and to offset evaporative losses. Then, beginning at the end of June, the conservation storage slowly decreases by the same amount through the end of December. In many cases, the reduction in storage is more than the other factors that empty storage (diversions and evaporative losses), resulting in previously stored water being added back into the stream.

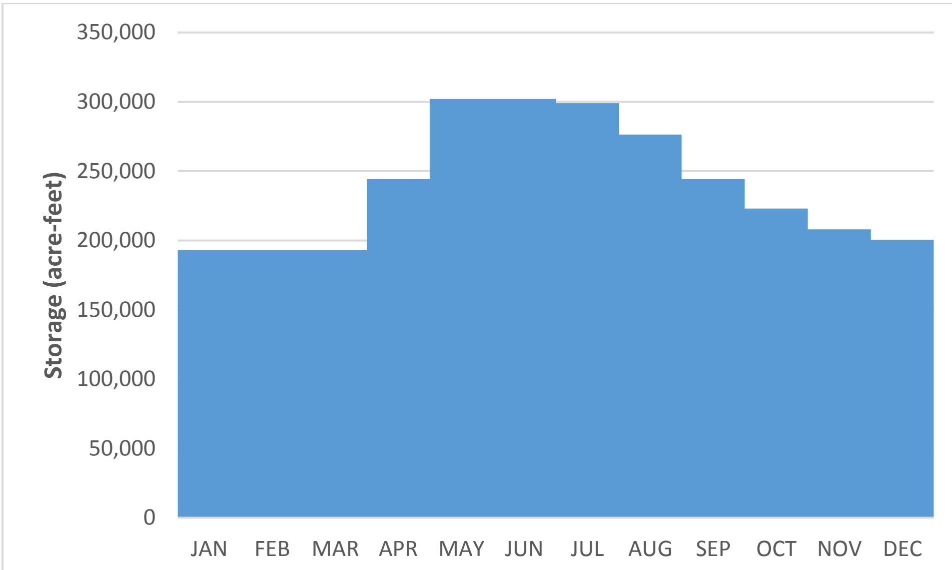


Figure 2: Monthly Conservation Volumes for Lake Wright Patman (Ultimate Rule Curve)

For this project we have assumed that Wright Patman will be reallocated to a flat conservation pool at a specific elevation, and that there will no longer be a requirement to "dump" stored water on the descending limb of the Ultimate Rule Curve.

For diversions, the default operation of the WRAP model is to first deplete available water from streamflow, only using stored water when streamflow is not available. If the default procedure was followed in months where the Ultimate Rule Curve is descending, with reallocation it would impact other water rights because the dumped water is no longer in the stream. In order to prevent this impact, a modeling approach was developed so that Patman's existing water right would use the amount that it would have dumped from conservation storage first before depleting streamflow.

Another modeling consideration is that there will be times in April and May when the full amount of water depleted by the existing rights cannot be used with a flat conservation storage. This is because the increase in conservation storage with the Ultimate Rule Curve is so large that there are occasions when there is simply not enough empty storage space available to use all of the water with a flat conservation storage. In this case, it was assumed that water that was appropriated by Patman's existing rights in the Original Network that could not be used by Patman's senior rights in the Parallel Network became available for appropriate by junior rights, including (in order of priority) Chapman, Ralph Hall, environmental flows, Marvin Nichols and Patman reallocation. This assumption is different than the one used in 2015, where it was assumed that the volume of water appropriated by Patman's senior right would be passed downstream even if it could not all be used at Patman's senior priority dates.

This change in the modeling logic requires that each reallocation level of Wright Patman have its own MiniWAM with the same configuration. In order to come up with the proper pass-throughs, the two models (MiniWAM and USACE) need to be iterated until both are operating at the same yield. Previous modeling had used one MiniWAM for each level of Patman reallocation, changing the model only if assumptions about priority changed.

Monthly Model Logic

The following describes operation with the standard assumptions about priority:

- Existing rights go first in priority order
- Environmental flows are senior to Marvin Nichols and Patman reallocation
- Marvin Nichols is senior to Patman reallocation
- The 10 cfs release from Patman executes at the most junior priority date.

In each month, the Original Network simulates as follows:

1. Prior to the execution of any water rights, on the descending limb of the rule curve, water is dumped from storage if needed to bring Patman down to conservation storage. This is hard-wired into the WRAP model and cannot be changed by the user.

2. Water right *1flow_added* records the volume of water "dumped" from Patman storage and stores that number in dummy control point *floadd*. The volume dumped is calculated as the difference between regulated and natural flow. This water right is given a priority date of 1 so it executes before all other water rights.

```
CPbigflo     OUT                      2     NONE    NONE      -3        0   1            9999999


WRbigflo                     1              1.0   floadd            1flow_added  PATMAN    4836
TO     2            ADD                  6patmn                             CONT
TO     1            SUB                  6patmn
```

3. Patman's 1951 and 1957 authorizations are executed (water rights *2_51_57mun* and *3_57ind*). Depletions for these priority dates are recorded in dummy control point *5157p*.

```
**  Combine by priority.  1951 and 1957 are senior to others in this model
WR6patmn   25000   4836M19510305                                    2_51_57mun  PATMAN    4836
WSPATMAN  302137                          87300  200411
**
WR6patmn   35000   4836I19570217                                       3_57ind  PATMAN    4836
WSPATMAN  302137                          87300  200411
**
**  Put 51 & 57 depletions in dummy CP 5157p
WRbigflo              19570217            1.0   5157p               4_51_57dep  PATMAN    4836
TO     6            SET                                     2_51_57mun    CONT
TO     6            ADD                                        3_57ind
```

4. The 5 cfs release from Lake Chapman is executed using instream flow *IF_Chapman*. Stored water is released from Chapman storage if necessary.

```
IF 3chap    3622   month19651119       3              IF_Chapman
WSRCHAP1  298930                           38598
OR 3chap                              -1
**
```

5. Chapman's 1965 authorizations are executed (water rights *4797M_UTRWD, 4797M_SSPRS, 4797_NTMWD, 4798_1*, and *4799M_1*). Depletions by these water rights are stored in control point *chapp*.

```
** Upper Trinity Regional Water District
WR 3chap   16106   4797M19651119   1                               4797M_UTRWD Chapman    4797
WSRCHAP1  298930                           38598
**
** Local demand (Sulphur Spr and Cooper)
WR 3chap   19200   4797M19651119   1                               4797M_SSPRS Chapman    4797
WSRCHAP1  298930                           38598
**
** North Texas Municipal Water District
WR 3chap    3214    479819651119                                    4797_NTMWD Chapman    4797
WSRCHAP1  298930                           38598
**
WR 3chap   54000    479819651119                                        4798_1 Chapman    4798
WSRCHAP1  298930                           38598
**
** City of Irving
WR 3chap   54000   4799M19651119                                       4799M_1 Chapman    4799
WSRCHAP1  298930                           38598
**
**  store depletions in dummy control point chapp
WRbigflo              19651119            1.0   chapp                  ChapDep Chapman
TO     6             SET                               4797M_UTRWD    CONT
TO     6             ADD                               4797M_SSPRS    CONT
TO     6             ADD                                4797_NTMWD    CONT
TO     6             ADD                                    4798_1    CONT
TO     6             ADD                                   4799M_1
**
```

6. Patman's 1967 priority authorizations are executed (water rights *5_67mun* and *6_67ind*). Depletions at this priority date are recorded in dummy control point *67p*.

```
WR6patmn   20000   4836M19670919                                       5_67mun  PATMAN    4836
WSPATMAN  302137                           87300  200411
**
WR6patmn  100000   4836I19670919                                       6_67ind  PATMAN    4836
WSPATMAN  302137                           87300  200411
**
**  Put 67 depletions in dummy CP 67p
WRbigflo              19670919            1.0     67p                  7_67dep  PATMAN    4836
TO     6             SET                                   5_67mun    CONT
TO     6             ADD                                   6_67ind
```

7. Lake Ralph Hall's 2004 priority rights are simulated by water right 15821F. Depletions by Ralph Hall are stored in dummy control point *hallp*.

```
WR1rhall   45000    HALL20040813       1                                15821F  rahall  15821F
WSRAHALL  160235
```

```
**  store depletions in dummy control point hallp
WRbigflo              20040813            1.0   hallp                 5821dep  rahall  15821F
TO     6             SET                                         15821F
```

At this point all existing water rights have executed in the Original Network. Next the Parallel Network executes. The Parallel Network adds the environmental flows, Marvin Nichols and the reallocated Wright Patman operating without the variable conservation storage. Patman is simulated with the full reallocated storage in each step. Limiting the Patman authorizations to the depletions in the Original Network prevents additional water being appropriated at the senior priority dates for the junior storage.

The Parallel Network operates in the following order:

1. The same volume of water dumped from original Patman storage in the Original Network (stored in dummy control point *floadd*) is dumped from the reallocated Patman storage in the Parallel Network by water right *8P_dump*.

```
WRP6patm              28000000   3   1     1.0  P6patm                8P_dump  PATMAN   p4836
TO     2             SET                  floadd
WS P_PAT  450193
```

2. Patman 1951 and 1957 authorizations are executed by water rights *9P_51_57mun* and *11P_57ind*. Depletions by these water rights are limited to the flow in dummy control point *5157p*. After each water right is executed, water rights *10P_51_57sub* and *11P_57ind_sub* subtract the depletions made by the 1951 and 1957 authorizations are subtracted from control point *5157p*. Negative depletions (which happen occasionally when there is a surplus of rainfall on the reservoir that cannot be stored) are retained so that this flow can be used later in the priority loop. This occasionally adds flow to control point *5157p*. *10P_51_57subadd* and *11P_57ind_subadd* also subtract the same depletions from the dumped flow volume contained in *floadd*. However, in this case negative depletions are not retained, so flows are only subtracted from *floadd*.

```
WRP6patm   25000   month29510305                                   9P_51_57mun  PATMAN   p4836
WS P_PAT  450193                         87300
LO     2             SET                 5157p
**
**  Subtract out the depletions made by municipal
**  Keeping negative depletions (excess precipitation) so they can be fully utilized by right
WR 5157p              29510305                                    10P_51_57sub  PATMAN acc4836
TO     6             SET      0                              9P_51_57mun
**  Also subtract out of flow added to the stream, but in this case don't retain negatives
WRfloadd      0.       29510305                                 10P_51_57subadd  PATMAN acc4836
TO     6             MAX      0                              9P_51_57mun
**
WRP6patm   35000   month29570217                                     11P_57ind  PATMAN   p4836
WS P_PAT  450193                         87300
LO     2             SET                 5157p
**
**  Subtract out the depletions made by industrial
**  Keeping negative depletions (excess precipitation) so they can be fully utilized by right
WR 5157p              29570217                                   11P_57ind_sub  PATMAN acc4836
TO     6             SET      0                                11P_57ind
**  Subtract depletions from flows added, not retaining negatives
WRfloadd      0.       29570217                                11P_57ind_subadd  PATMAN acc4836
TO     6             MAX      0                                11P_57ind
**
```

3. The parallel version of Chapman's 5 cfs release is executed (*P_IF_Chapman*).

```
IFP3chap    3622   month29651119       3            P_IF_Chapman
WSP_CHAP  298930                          38598
ORP3chap                               -1
**
```

4. Chapman's 1965 water rights are executed by water rights P_4797M_UTRWD, P_4797M_SSPRS, P_4797_NTMWD, and P_4798_1. Each diversion is limited by the flow in control point *chapp*. As each water right is executed, the Parallel network depletions are subtracted from *chapp* to prevent overuse of Chapman water.

```
** Upper Trinity Regional Water District
WRP3chap   16106   4797M29651119   1                              P_4797M_UTRWD Chapman   p4797
WSP_CHAP  298930                          38598
LO     2                                  chapp
**
WR chapp               29651119                                P_4797M_UTRWDsub Chapman acc4797
TO     6            SET                                   P_4797M_UTRWD
**
** Local demand (Sulphur Spr and Cooper)
WRP3chap   19200   4797M29651119   1                              P_4797M_SSPRS Chapman   p4797
WSP_CHAP  298930                          38598
LO     2                                  chapp
**
WR chapp               29651119                                P_4797M_SSPRSsub Chapman acc4797
TO     6            SET                                   P_4797M_SSPRS
**
** North Texas Municipal Water District
WRP3chap    3214    479829651119                                   P_4797_NTMWD Chapman   p4797
WSP_CHAP  298930                          38598
LO     2                                  chapp
**
WR chapp               29651119                                 P_4797_NTMWDsub Chapman acc4797
TO     6            SET                                    P_4797_NTMWD
**
WRP3chap   54000    479829651119                                       P_4798_1 Chapman   p4798
WSP_CHAP  298930                          38598
LO     2                                  chapp
**
WR chapp               29651119                                     P_4798_1sub Chapman acc4798
TO     6            SET                                        P_4798_1
**
** City of Irving
WRP3chap   54000   4799M29651119                                      P_4799M_1 Chapman   p4799
WSP_CHAP  298930                          38598
LO     2                                  chapp
**
WR chapp               29651119                                    P_4799M_1sub Chapman acc4799
TO     6            SET                                       P_4799M_1
**
```

5. Patman's 1967 authorizations are executed by water rights *12P_67mun* and *15P_67ind*, limited by the depletions from the Original Network stored in dummy control point *67p*. Depletions made by these two water rights are then subtracted from *67p* and *floadd* using the same criteria as in Step 2.

```
WRP6patm   20000   month29670919                                      12P_67mun  PATMAN   p4836
WS P_PAT  450193                          87300
LO     2                                    67p
**
```

```
**  Subtract out the depletions made by municipal
WR   67p             29670919                                       13P_67sub  PATMAN acc4836
TO     6            SET                                     12P_67mun
**  Added flow accounting
WRfloadd      0.       29670919                                   13P_67subadd  PATMAN acc4836
TO     6            MAX                                     12P_67mun
**
**  Allow access to unused 1967 priority depletions, if any
WRP6patm  100000   month29670919                                    15P_67ind  PATMAN   p4836
WS P_PAT  450193                        87300
LO     2                                 67p
**  Added flow accounting
WRfloadd      0.       29670919                                 15_P67indsubadd  PATMAN acc4836
TO     6            MAX                                     15P_67ind
```

6. Occasionally, there is some of Patman's 1951 and 1957 priority water that was not fully used for the 1951 and 1957 water rights. If there is empty storage at this point, the model allows Lake Patman to fill with these flows (water right *16P_67fillWithSr*). This assumption was made so that Patman could use its existing water rights to the fullest extent possible. Any depletions made by this step are subtracted from *floadd*.

```
WRP6patm               29670919                                 16P_67fillWithSr  PATMAN   p4836
WS P_PAT  450193                        87300
LO     2            SET                 5157p
**  Added flow accounting
WRfloadd      0.       29670919                                  16P_fillsubadd  PATMAN acc4836
TO     6            MAX                                 16P_67fillWithSr
```

7. The parallel version of Lake Ralph Hall is executed by water right *P_15821F*, limited by the depletions from the Original Network in control point *hallp*.

```
**  Parallel version limited to depletions in hallp
WRP1rhal   45000    HALL30040813       1                                P_15821F  rahall p15821F
WSP_HALL  160235
LO     2                                hallp
**
```

8. A last fill at Patman allows the reservoir to fill with any dumped water remaining after all existing water rights have executed (water right *17P_fillWithDump*). The remaining dumped flow is in control point *floadd*.

```
WRP6patm               30040814                                 17P_fillWithDump  PATMAN   p4836
WS P_PAT  450193                        87300
LO     2            SET                floadd
**
```

9. Environmental flows are applied using code provided by RPS Espey using standard TCEQ protocols for modeling environmental flows. The priority date of the eflows in the model is 30200000. This code is very lengthy and not included here.

10. Marvin Nichols is executed by water right *MARVIN_NICHOLS*.

```
WRP5marv  379836   month30200001   1   0       0                  MARVIN_NICHOLS nichols
WSMARVIN 1532031                                0
```

11. New diversions associated with Patman reallocation are executed by water right *P_4836new*. The diversion amount is set the same as the RiverWare model through an iterative process.

```
WRP6patm   80807   month30300001                                        P_4836new  PATMAN   p4836
WS P_PAT  450193                          87300
```

12. The 10 cfs instream flow, backed by reservoir storage, is executed last in the priority loop (identifier *IF_10cfs*).

```
IFP6patm    7245   month30300002       3                IF_10cfs
WS P_PAT  450193
ORP6patm                             -1
**
```

Incorporating Results in USACE Model

After running the SBG MiniWAM model, the output is used to determine the flows passed from Lake Ralph Hall, Lake Chapman and Marvin Nichols for Patman's existing water rights, combined with the flows passed at Marvin Nichols and Patman for environmental flows in the USACE model. In all cases, the flow passed downstream is calculated as the difference between the regulated and appropriated flows at the control point of interest. It is possible to identify the portion of the flow passed due solely to priority by looking at available flows right before the environmental flows are applied. Flows that are passed downstream for priority can also be used to meet environmental flows, and vice versa.

Flows passed downstream are not needed at the other points in the model (*2nsulf* or *4talco*) since we are not considering any projects at those locations.

The MiniWAM outputs monthly flow volumes which need to be translated to daily average flows for input into the USACE model. This is done using two different techniques. Inflows into Ralph Hall and Chapman are fixed and are independent of modeling assumptions. For these projects, the fraction of the monthly inflow volume passed downstream is determined and applied to the daily inflows. For example, in May 1938 all of the inflows into both Chapman and Ralph Hall are passed downstream. So the fraction of monthly flows passed is 1.0. This value is multiplied by the daily inflows into the reservoir to determine the bypass values. Occasionally this technique results in an unrealistically large flow being released from the project. In that case, the outflow is set to the maximum outflow capacity at that particular elevation, and flows over the next few days are increased (limited by the maximum outflow capacity) until the desired volume has been passed.

Other than the constant 5 cfs from Lake Chapman, flows passed out of Chapman and Ralph Hall are for Patman's senior water right only. The 2016 environmental flows are assumed to be junior to these projects.

The flows passed by Marvin Nichols and Patman reallocation are calculated in a slightly different manner. The flows at both projects are somewhat dependent on upstream conditions. When in flood operation, the volume of water retained in Chapman flood storage varies depending on flood storage in other projects in the model, primarily Patman and Lake O' the Pines. As a result, flow volumes may not be consistent from run to run in ways that are not present in the MiniWAM, which does not include flood operation. In order to keep flow volumes consistent, the distribution of monthly flows to daily uses a daily percentage of monthly flow value derived from a baseline RiverWare run without any new projects. The daily percentages are calculated by:

- Extracting the daily inflows to Marvin Nichols and Patman from the no new projects USACE model run,
- Summing up the daily inflows to monthly volumes, and
- Dividing each day's flow by the total volume for the month to obtain the fraction of monthly flows that occurred that day. This fraction is multiplied by the monthly pass requirement to obtain a daily pass requirement.

Once the time series of flows passed downstream has been determined, the daily values are then input into the USACE model as "hard-wired" releases at each timestep. On any given day, if the outflows from a reservoir are less than the releases, the outflows are set equal to the releases.

As with Chapman and Ralph Hall, there are times when the releases are unreasonably high and exceed the assumed maximum outflow capacity of the projects. In this case, the flows are set to the maximum outflow and additional water is released on subsequent days until the desired flow volume is reached.

The approach used in 2016 retains some of the daily flow variability that are incorporated into the 2016 environmental flows. Since it is possible that these runs will be used for environmental analyses, the daily flow variability would be valuable for that type of analysis.

This approach is different than the approach used in the 2015 modeling. In 2015, the MiniWAM was used only to calculate priority releases. The monthly releases were divided by the number of days in each month to determine daily flows, so they did not necessarily retain the variability of the inflows. The Lyons method environmental flows were programmed into the USACE model and were not incorporated in the MiniWAM.

Alternative Operation Models

Each alternative operation scenario has its own associated MiniWAM. There are two types of alternative operation – Patman reallocation senior to Nichols and the Alternative Demand scenarios. For modeling with Patman reallocation senior to Nichols, it is simply a matter of changing the priority date of Nichols and Patman reallocation so that the reallocation is senior. No other changes are needed. For the Alternative Demand scenarios, which assume non-priority system modeling, each water right is given a new priority date so that the model operates in upstream to downstream order. This includes environmental flows. Since we are assuming no priority operation, the environmental flows also operate in upstream to downstream order.

Attachment C

Explanation of Variation in Yields

Attachment C: Explanation of Variation in Yields

As shown in Table C-1, the yields for Marvin Nichols are slightly higher for the Patman reallocation elevations 235.0 and 238.0 feet compared to the reallocation at 232.5 and 242.5 feet. These yields differ because Lake Wright Patman fills early in the critical drought period for Marvin Nichols, causing the volume of water passed from Nichols to Patman to vary during one month of the critical drought period, May 2003. The critical drought period is the time between when the model shows the reservoir to be full and spilling and the minimum elevation in the reservoir. This is the period that determines the yield of the reservoir. For Marvin Nichols, the critical drought is from April 29, 2002 to March 31, 2007.

Table C-1: Combination Yields for Lake Wright Patman Reallocation and Marvin Nichols Reservoir

Run	Wright Patman Elevation (feet)	Marvin Nichols Elevation (feet)	Lake Wright Patman Yield [a]			Marvin Nichols Yield		Total New Yield [b] (ac-ft/yr)
			Total Yield (cfs)	Total Yield (ac-ft)	New Yield (ac-ft/yr)	Yield (cfs)	Yield (ac-ft/yr)	
5	232.5	328.0	360.0	260,807	80,807	524.3	**379,836**	460,643
7	235.0	328.0	402.75	291,777	111,777	527	**381,792**	493,569
8	238.0	328.0	459.75	333,072	153,072	527	**381,792**	534,864
9	242.5	328.0	561.5	406,786	226,786	523.5	**379,256**	606,042

a New Yield for Lake Wright Patman is the Total Yield of the reservoir less 180,000 ac-ft/yr already authorized for diversion from the reservoir.
b Total New Yield does not include the 180,000 ac-ft/yr already authorized from Lake Wright Patman.

The reason for the difference is as follows.

1. In the reallocation modeling, Lake Wright Patman fills several times in the Spring of 2003, about one year into Nichol's critical drought. In May 2003 under operation with the Ultimate Rule Curve (Patman current rights), Patman would not be full and spilling. However, with reallocation the reservoir would be full if only the 180,000 acre-feet per year of existing diversions were made from the reservoir. This is because under operation with the Ultimate Rule Curve, additional water would be needed to fill increasing conservation storage on the ascending limb of the curve. This is not the case in reallocation, where the maximum conservation storage is constant.

2. When Patman is full and spilling, the modeling assumes that no water is passed downstream from Marvin Nichols for Patman's senior right, even if under operation with the Ultimate Rule Curve water would need to be passed from Nichols to Patman. So in May 2003, some of the water that could be appropriated by Patman's senior water right is retained at Nichols, and some of the flow that originates between Nichols and Patman that would have gone into storage with the Ultimate Rule Curve is either (a) appropriated under Patman's reallocation right, or (b) is passed downstream because there is no place to store it with reallocation.

3. At each of these elevations, some of the water that could have been appropriated under Patman's existing senior right cannot be used at the senior right's priority date because there is no place to store it in the reservoir. In most cases, the volume of the unused senior water increases as the reallocated storage elevation decreases, with the least senior water unused at 242.5 feet and the most unused at elevation 232.5 feet. Table C-2 shows the Patman senior depletions and the volume of those depletions that remain unused after executing Patman's senior rights. In May 2003 the volume of unused senior water at 232.5 feet is enough that it qualifies as a high flow pulse, engaging the pulse criteria in the environmental flow requirements and increasing the flow reserved by the environmental flows. As a result, at 232.5 feet more water needs to be passed at Patman, and in order to meet Patman's environmental flow requirement some of that water needs to be passed from Nichols. This is the reason that the yield at Nichols is slightly lower when Patman is reallocated to 232.5 feet versus 235.0 or 238.0 feet.

Table C-2: Unused Patman Depletions at Various Reallocation Elevations – Year 2003
(Values in acre-feet)

Date	Patman Senior Depletion	Unused Senior Depletions			
		Reallocation at 242.5 ft	Reallocation to 238 ft	Reallocation to 235 ft	Reallocation to 232.5 ft
Jan-03	16,579	0	0	0	0
Feb-03	2,390	0	0	0	0
Mar-03	16,035	0	0	0	0
Apr-03	18,969	0	0	0	0
May-03	40,726	924	14,146	18,389	21,099
Jun-03	49,826	18,348	23,562	30,058	29,907
Jul-03	3,517	0	0	0	0
Aug-03	965	0	0	0	0
Sep-03	2,348	0	0	0	0
Oct-03	1,737	0	0	0	0
Nov-03	2,988	0	0	0	0
Dec-03	2,761	0	0	0	0

4. Also in May 2003, the length of time that the reallocated Patman is in the flood pool varies with the amount of reallocated storage, ranging from 4 days at elevation 242.5 feet to 6 days at elevation 232.5 feet. As a result, the critical drought for reallocation to 242.5 feet is slightly longer than at the three lower elevations (238.0, 235.0 and 232.5 feet). Evaporative losses are also higher for the larger storage volume because there is more surface area in the lake. These factors tend to make the Nichols yields a little higher at the lower Patman elevations.