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Draft Environmental Impact Statement

Lake Ralph Hall Regional Water Supply Reservoir Project

Volume II

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DiNatale
WATER CONSULTANTS

Matt Barkley
Michael Baker International
810 Hester's Crossing, Suite 163
Round Rock, TX 78681

June 3, 2016

Chandler Peter
US Army Corps of Engineers
Regulatory Division, Fort Worth District
819 Taylor St.
Fort Worth, TX 76102

Mr. Barkley and Mr. Peter,

Please find attached our draft-final report on our evaluation of the hydrologic modeling of the Sulphur River used for the Lake Ralph Hall EIS. This draft addresses your comments to our April 4, 2016 and May 24, 2016 drafts. Pursuant to the review process we have discussed, I submit this draft for your review. If you have no further questions, please forward this draft to the Upper Trinity Regional Water District.

Thank you,

Matt Bliss
Project Manager

STATE OF TEXAS
MATTHEW BLISS
107163
LICENSED
PROFESSIONAL ENGINEER

303 709 7044 dinatalewater.com
2919 VALMONT ROAD SUITE 204 BOULDER CO 80301

Evaluation of Hydrologic Modeling in Support of the Lake Ralph Hall Environmental Impact Statement

Prepared for the U.S. Army Corps of Engineers
Draft-final for Corps, Third Party Contractor and Upper Trinity Regional Water District Review
June 3, 2016

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1.0 Introduction

The United States Army Corps of Engineers (Corps) is developing an environmental impact statement (EIS) related to the proposed construction of Lake Ralph Hall near Ladonia, Texas. The applicant for the project is the Upper Trinity Reginal Water District (hereafter Applicant or Upper Trinity). During the course of the EIS, Upper Trinity has used hydrologic models to assess stream impacts to the Sulphur River. DiNatale Water was contracted as the Corps' third-party contractor to evaluate the adequacy of the hydrologic modeling for the purposes of the EIS, verify the modeling performed by Upper Trinity, and perform additional modeling as necessary.

The Corps' regulatory requirements associated with the EIS require an analysis of the impacts to aquatic resources caused by the proposed project. The Corps has identified the following aquatic resources that could potentially be impacted by the proposed project:

- Geomorphology and sediment transport
- In-channel pools and puddles that support benthic organisms and fish
- Floodplain resources
- Water quality and temperature
- Groundwater

Hydrologic modeling can be used to assist in quantitatively assessing the impacts to each of these resources by simulating a current conditions baseline scenario and a with-project scenario. The differences in hydrology between the baseline and with-project scenarios allow the resources to be evaluated under both conditions and any changes from the baseline are attributed to the project. The Corps' requirements also include an evaluation of cumulative impacts from other projects or reasonably foreseeable future actions. To assess cumulative impacts in locations where multiple projects are being considered or where land and water uses are projected to change significantly within the planning horizon timeframe, the Corps may simulate future hydrologic conditions to assess the likely future impacts attributable to the project. In this instance, the Corps determined that future hydrologic conditions were not necessary to adequately evaluate the aquatic impacts of Lake Ralph Hall, and therefore only current conditions hydrologic scenarios were used. A more in-depth discussion of this determination is included in Section 5.

Upper Trinity has used two different models to evaluate the flows below the proposed dam. The first is the State of Texas' Water Availability Model that uses the Water Rights Analysis Package modeling platform (WAM/WRAP) developed for the Sulphur River basin. The second is a RiverWare model developed by the Corps for a larger Red River Basin modeling effort (the Sulphur River is tributary to the Red River). The Corps also provided a HEC-RAS model that was developed by the Corps for the Sulphur River basin. The models have different characteristics and were built for different purposes. DiNatale Water evaluated the models in terms of the adequacy of assessing the impacts to the aquatic resources described above.

For the Lake Ralph Hall EIS, the Corps developed approaches to evaluation of each of the aquatic resources identified above. The hydrology for in-channel pools and puddles that support benthic organisms and fish was evaluated more in depth by the Applicant. This report evaluates the Applicant's analysis and provides recommendations on its use (Section 4.1). Detailed hydrology for floodplain resources was evaluated in this report using a Corps-developed HEC-RAS model for the Sulphur River Basin (Section 4.2). Geomorphology, water quality and temperature, and groundwater resources will be evaluated using a qualitative approach. These approaches do not require detailed hydrologic modeling for input, but we discuss the potential supporting role existing modeling can provide for these resources and identify modifications necessary if it is later determined that more refined evaluation is required for any of these resources (Sections 4.3, 4.4 and 4.5).

2.0 Site and Hydrology

The proposed Lake Ralph Hall is located in Fannin County, Texas near the town of Ladonia, northeast of the Dallas/Fort Worth metropolitan area. The proposed Lake Ralph Hall has a conservation pool capacity of approximately 160,000 AF and a maximum capacity of approximately 180,000 AF and a maximum surface area of 8,500 acres. The reservoir will be located on the existing channel of the North Sulphur River. Upper Trinity proposes to pump water directly from the reservoir through a new pipeline south and westward and will connect with an existing pipeline for delivery to the Upper Trinity service area. Upper Trinity anticipates pumping a maximum of 45,000 AF per year with a maximum diversion rate of 205 cubic feet per second (cfs) from Lake Ralph Hall. The WAM/WRAP hydrologic modeling used in support of the Lake Ralph Water right indicates the annual yield may drop to as low as 16,800 AF per year through the design drought of the 1950's.

At the location of the proposed dam for Lake Ralph Hall, the North Sulphur River resembles a deep canal (Figure 1). Prior to the 1930's, the bottomland of the North Sulphur River was a swamp and marsh area. In the late 1920's, local residents sponsored a channelization project and dug a straight canal through the bottomland to drain the area and open up large amounts of land for agriculture (TCEQ Proposed Order, undated). This canal is the current day course of the North Sulphur River. The channelized section of stream extends east to near Talco, some 40 miles from the Lake Ralph Hall site. The channelized section of the river is clearly visible from areal imagery to the confluence with the South Sulphur

River and to near the State Highway 37 bridge. Over the past 80 years, the North Sulphur River has eroded the canal and has cut down through layers of claystone and widened. The canal today is approximately 60 feet deep and 200 feet wide near the Lake Ralph Hall site.

The hydrology of the North Sulphur River is highly variable and flashy. The river will often have no flow, or very little flow. During a rain event, however, flows increase very rapidly and to flow rates of several thousand cfs. After a rain event, flows recede typically within a day or two to near zero flow again. After these large events, some small ponds and puddles form in the bottom of the river channel and may be able to sustain benthic organisms and fish between larger flow events. There is one stream gage on the North Sulphur River, located near the town of Cooper (USGS gage 07343000, N Sulphur Rv nr Cooper, TX, hereafter the "Cooper gage"). There are other downstream gages on the Sulphur River near Talco (USGS gage 07343200, Sulphur Rv nr Talco, TX, herafter the "Talco gage") and Sulphur River near Dalby Springs (USGS gage 07343450, Sulphur Rv at IH 30 nr Dalby Springs, TX, hereafter the "Dalby Springs gage"). Figure 2 shows a typical hydrograph storm events at the Cooper gage and follows these same storm events to the downstream Talco and Dalby Springs gages. The catchment basin above the Cooper gage is 311 square miles. The Lake Ralph Hall site is a subset of this basin with a catchment area of 101 square miles. Figure 3 shows the average annual rainfall totals in northeast Texas and the approximate locations of Lake Ralph Hall and the Cooper Gage. Although the Sulfur River and tributaries flow through two different types of land resource areas which are characterized by different soils, the Lake Ralph Hall site and the Cooper Gage lie within the same Blackland Prairie area with predominately clay and silty clay soils which help encourage agricultural land use above the confluence of the North and South Sulfur Rivers. Other than the trend of decreasing precipitation moving west in the basin, there are no distinguishing factors for the basin above the Lake Ralph Hall site that would indicate different runoff per unit area than at the Cooper Gage as a whole.

Figure 1. Photo of the North Sulphur River channel at the State Highway 34 bridge

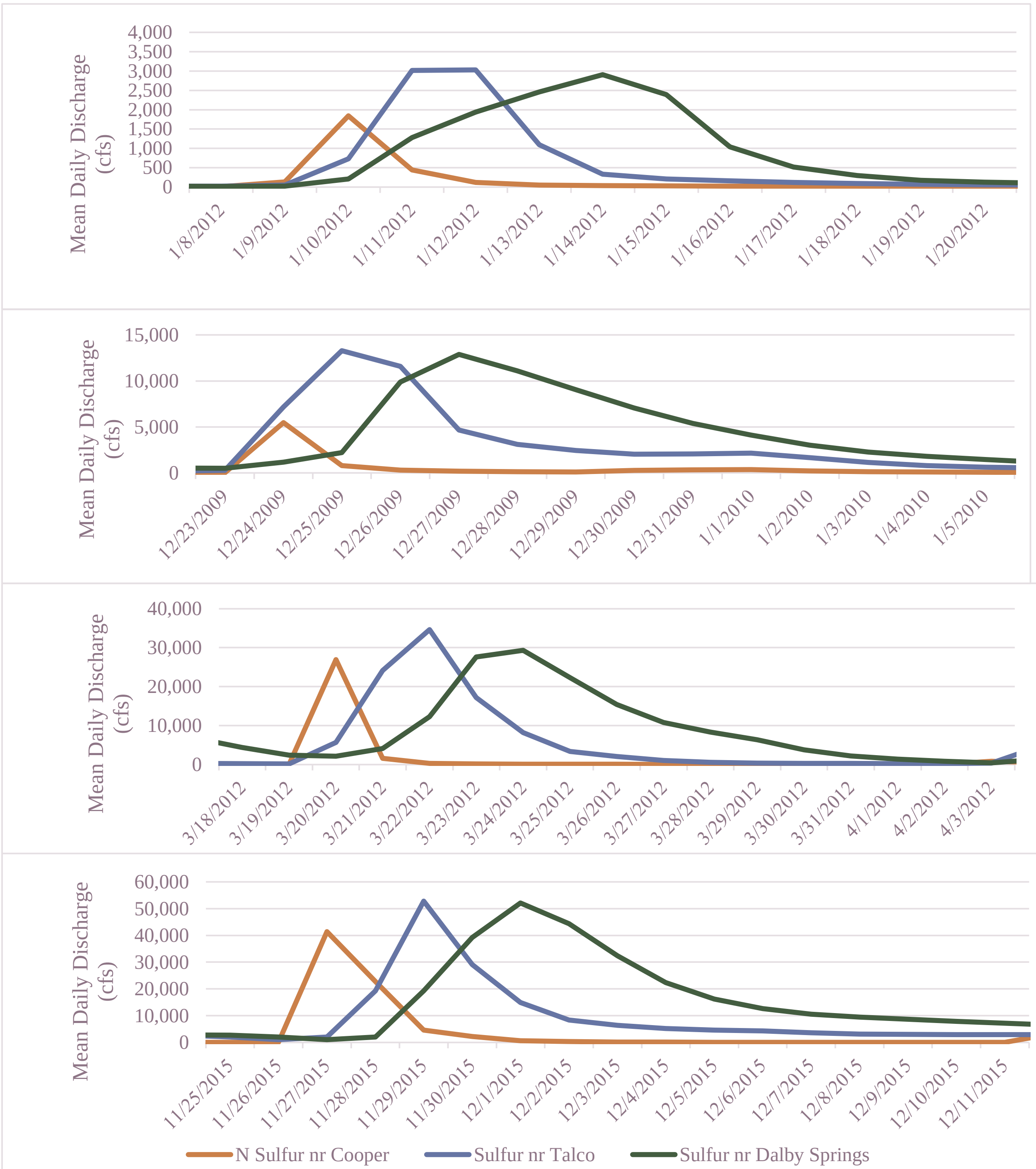

Figure 2. Hydrographs for each gage showing different levels of flow from different storm events.

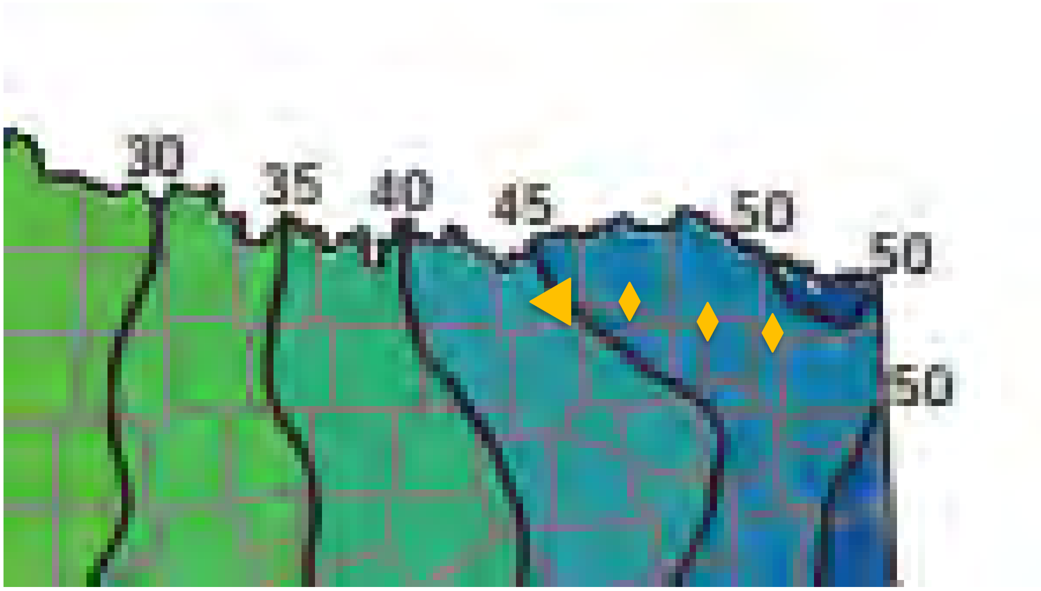

Figure 3. Average annual precipitation (1981 to 2010, values in inches) in northeast Texas. Lake Ralph Hall approximate location shown as a triangle, Cooper gage, Talco gage and the Dalby Springs gage approximate locations shown as a diamonds. Precipitation map source: 2012 Texas State Water Plan.

3.0 Hydrologic Models Utilized

Several hydrologic models have been used to-date for analysis of various aspects of the proposed project. Often models are constructed for one particular intended use, and the model results do not directly apply to evaluation of aquatic impacts. DiNatale Water evaluated the adequacy of the models for the purposes of evaluating the aquatic impacts for the EIS. For this project, we evaluated three model platforms 1) Sulphur River Water Rights Analysis Package and Water availability model (WRAP/WAM), 2) Corps RiverWare model of the Red River with Applicant modifications, and 3) a Corps HEC-RAS model.

3.1 Sulphur River WAM/WRAP

The Texas Commission on Environmental Quality (TCEQ) has developed several hydrologic water availability models for different river basins throughout Texas. The Water Rights Analysis Package (WRAP) is the computer program or modeling platform. Each river basin's model has its own set of input files that describe the hydrology, water rights, demands and other features of the basin. These inputs files are referred to as the Water Availability Model (WAM).

The water availability models are used by the TCEQ to evaluate whether water will be available to a proposed use under various assumptions. The Sulphur River WAM model simulates the North Sulphur River, South Sulphur River, Sulphur River mainstem, White

Oak Creek and the watershed above Wright Patman Lake. The simulation utilizes historical hydrology as flow inputs, but can be configured to include current demands (WAM Run Number 8), or can include full authorization of all water rights in the basin (WAM Run Number 3). The simulation allocates flow to the various water rights according to demand for water and priority of the water right. The TCEQ uses information from the full authorization model run to evaluate the reliability of a proposed water right under future conditions with other conservative assumptions about return flows and water reuse. This model run is useful in determining the future reliability of a water right, but is not necessarily representative of how streamflows will be affected under current water uses.

3.1.1 CORPS' EVALUATION OF WAM MODELS

The Corps recently completed an investigation into the utility of the publically available version of the Sulphur River WAM model developed by the TCEQ as compared to a model modified or developed for a specific project (Corps 2016). The report included a case-study evaluation of the Sulphur WAM model. One of the key conclusions in the report was that while WAM modeling is appropriate for its original intent – water rights administration and reliability analyses, the WAM modeling may not be appropriate for other resources that the Corps evaluates through the EIS process. The report pointed to several reasons why the WAM model may not accurately portray actual stream conditions to a level needed for the Corps analysis. The current conditions WAM model run (Run 8) is better suited to evaluate the impacts to streamflows that would be caused by a proposed project, but utilizes the highest demands from the past 10 years, sets agricultural return flows to zero and uses the lowest return flows in the past 10 years. These assumptions may over-predict diversions and under-predict streamflows under average current conditions.

The Corps 2016 report also compared several historical stream gage and historical reservoir storage levels against the WAM current conditions run. The quality of calibration varied between different locations in the basin. However, at the North Sulphur near Cooper gage (control point B10), the WAM flows matched gaged flows almost exactly. This is somewhat expected due to the minimal water resources development upstream of the Cooper gage. Therefore, use of the current conditions WAM flows on the North Sulphur River above the Cooper gage will avoid many of the potential shortcomings identified in the Corps 2016 report. Use of WAM flows at downstream locations, including the Sulphur River below the confluence with the South Sulphur River, is not recommended due to the relatively poor calibration depicted in the report near Lake Jim Chapman.

The Corps 2016 report also evaluated the WAM models from a temporal and spatial perspective. The WAM models use a monthly time step. This time step is appropriate for water rights reliability and yield analyses, but is inadequate for some of the resources being evaluated for the Lake Ralph Hall EIS. For example, floodplain resources are impacted by peak flow events when the river overtops its banks. This type of event would not be captured in monthly flow volumes due to the averaging of flows over the entire month. Water quality factors may not be accurately represented with a monthly time step, especially in the North Sulphur River. As depicted in Figure 2, the flashy nature of the flows is not captured in a monthly time step, and a small number of large flow events followed by no flow would likely have very different water quality effects than a monthly-averaged flow rate over the entire month. Additional information and recommendations are presented in Section 4 related to specific resources.

The Sulphur River WAM model uses hydrology from 1940 to 1996. This timeframe is reasonable because it captures periods with low, average and high flow events, including the 1950's drought which had been the drought of record throughout Texas. In some areas of Texas, the 2011 drought was more severe than the 1950's drought and established a new drought of record. During a project meeting, the Applicant stated that the 2011 drought was not as severe as the 1950's drought in the Sulphur Basin. Streamflow records at the North Sulphur near Cooper gage confirm this for the Lake Ralph Hall drainage basin, with the cumulative deficit (compared to average) from 1951 to 1957 larger than the cumulative deficit from 2010 to 2014. Although the more recent 2010 to 2014 drought appears to have been more intense than the 1950's drought, it was shorter in duration. Therefore, it is reasonable that the yield analysis performed using the WAM model and the 1940 to 1996 study period is valid in light of the more recent 2011 drought.

From a spatial perspective, the WAM model reasonably includes areas that could be affected by the proposed project in the Sulphur River Basin. To our knowledge, no analysis has been done about the potential impacts to the receiving basin, which is not included in the Sulphur WAM modeling. Water introduced to the Trinity River Basin from Lake Ralph Hall will be consumed by Upper Trinity customers through first use and reuse of the water. If additional analysis of the effects of this inflow water to the basin is needed, the Sulphur River WAM would not be the appropriate tool. The Trinity River WAM may provide some insight, but our assumption is that potential impacts to the Trinity River basin would involve water quality or reservoir operations in the receiving lakes that would be better addressed through reservoir and water quality analysis techniques better suited to evaluate those resources.

3.1.2 VERIFICATION OF WAM MODELS USED FOR LAKE RALPH HALL EIS

Upper Trinity provided DiNatale Water with the WAM model files that were used in the water right application for Lake Ralph Hall. The models provided by Upper Trinity include one version with Lake Ralph Hall operable, and one with Lake Ralph Hall disabled. DiNatale Water executed the models and was able to replicate the model results provided by Upper Trinity. We also compared the model inputs and model results to the publically available Sulphur River Basin WAM files available on the TCEQ website. The Upper Trinity version of the model had refined the area near Lake Ralph Hall considerably to include the details of the basin above and below the project site. We compared the hydrologic inflows above Lake Ralph Hall to the TCEQ version and found them to be identical. We compared other model inputs and outputs, including inflows at other locations, demands, and simulated stream flows at gaged locations and concluded that the WAM models used by Upper Trinity in its evaluation were reasonable adaptations of the publically available version.

The WAM model operates on a monthly time-step. This time-step is useful for determining the yield of a project and reservoir operations and for water supply planning purposes. The WAM model also adheres to the Texas water rights system where upstream junior water rights must pass water to downstream senior water rights when the downstream senior rights are not fully satisfied. However, given the flashy nature of streamflows in the North Sulphur River (Figure 2), monthly flows will not adequately capture the peak flows and long periods of low or no flow that are common to this river basin. For example, the second flow event shown in Figure 2 is one of two high flow events of that month. The peak flow lasts for two or three days, peaking at 5,470 cfs before flows return to near zero. When summarized on a monthly basis, the daily average flow for the entire month is 375 cfs.

One of the primary advantages to the Sulphur WAM modeling over the Corps' Red River RiverWare model of the basin is WAM's simulation of water rights in the Sulphur Basin. In an Applicant report (Brandes 2015), a comparison of releases from Lake Ralph Hall in the WAM model and the RiverWare model indicate higher releases in the WAM modeling than in RiverWare due to the draw from downstream senior water rights. Simulation of senior water rights in the WAM model simulates times when water would be bypassed at Lake Ralph Hall to downstream senior water users. This is particularly important to understanding the impacts of Lake Ralph Hall during low flow times, as downstream seniors would only call water past Lake Ralph Hall during times of shortage. The WAM modeling will show water bypassed at Lake Ralph Hall during some low flow periods where the Corps' RiverWare model – as currently configured – will not.

Although the WAM model will show bypasses to downstream senior water right at Lake Ralph Hall during low flow periods, the WAM modeling may over-predict the amount of water bypassed. The WAM documentation for the Sulphur River (Brandes 1999) indicated that the modeling of Lake Wright Patman included a seasonal conservation pool target. In months where the target storage level increases, an immediate demand for upstream water to satisfy the senior Wright Patman water right is simulated and water may be bypassed from upstream junior water rights, such as Lake Ralph Hall. With regard to Senate Bill 1 water availability analyses, this is the correct interpretation of strict administration of the prior appropriation doctrine. However, Brandes (1999) states that this situation is "somewhat artificial and not likely to happen under current reservoir operating procedures and water rights administration policies."

Therefore, while the WAM model results correctly simulates bypassing water to downstream senior water rights, it may over-predict streamflows below Lake Ralph Hall at times when the water is being passed downstream to Wright Patman. The potential impacts of this operation on aquatic resource evaluations are discussed in more detail below in Section 4.

3.1.3 CONCLUSIONS ON USE OF WAM FOR THE LAKE RALPH HALL EIS

The Corps' regulatory framework requires evaluation of impacts to the aquatic habitat resources that often require understanding of daily flow rates. Use of a monthly-averaged flow rate to evaluate these types of aquatic resources will not provide a correct evaluation of such resources. The Applicant's analysis of aquatic impacts to benthic organisms and fish in the puddles and pools below the dam used monthly flow values by determining a monthly flow threshold so that WAM monthly modeling results could be used. The aquatic impacts to floodplain resources require daily flow rates, and therefore the WAM model results would not be appropriate to use to evaluate these impacts. For the Lake Ralph Hall EIS, stream morphology, water quality and temperature, and groundwater resources are being evaluated qualitatively so detailed hydrologic modeling is not required. However, more detailed refined and quantitative analyses of stream morphology and water quality and temperature resources would likely require a daily time step and WAM would not be appropriate to support evaluation of these resources quantitatively. Monthly modeling results from WAM would likely be appropriate for groundwater resource evaluation given the typically longer time-scales associated with groundwater flow.

The Corps evaluation of the publically available WAM models identified certain assumptions in the WAM modeling related to the seasonal conservation pool in Wright Patman and the underlying assumptions used in the current conditions WAM model run 8 can introduce inaccuracies to simulated streamflows for both the current conditions baseline and with-project model runs. These potential inaccuracies were considered when evaluating impacts to various resources, and is discussed further in Section 4.

The monthly WAM model is an appropriate model to evaluate the reliability and yield of Lake Ralph Hall. Several conservative assumptions related to use of water by other water rights holders in the Sulphur River Basin, return flows from such uses, and strict administration of senior water rights at Lake Ralph Patman are all used in the analysis of firm yield and in the project's ability to meet the overall project purpose and need.

Despite its shortcomings for evaluation of some aquatic impacts for Lake Ralph Hall related primarily to the monthly time step, the WAM model can be used to inform other modeling efforts that are better suited for evaluating those impacts. For example, WAM modeling can be used to evaluate issues related to the Texas water rights system. The model includes extensive data-collection and documentation associated with its development for the Sulphur River that could be relied upon for more detailed analysis or to support conclusions from the less sophisticated evaluations.

3.2 Red River Basin RiverWare

The Corps developed a river network model for the Red River Basin using the RiverWare modeling platform. RiverWare is a modeling platform developed at the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES), located at the University of Colorado, Boulder, and funded primarily by the United States Bureau of Reclamation, Tennessee Valley Authority and the Corps. RiverWare models are able to simulate complex river and reservoir networks. One of RiverWare's most useful features is its user-developed policy rules. These rules allow nearly unlimited flexibility to develop and simulate different operating policies and protocols.

The Corps' Red River Basin RiverWare model includes the Sulphur River and North Sulphur River because these rivers are tributary to Lake Wright Patman (a Corps reservoir), and ultimately, tributary to the Red River. The model was developed to evaluate different operations for the Corps, including flood control in the Red River Basin. The model is a daily model that includes Lake Ralph Hall, but does not include any simulated diversions to Upper Trinity from the reservoir and simply spills any water over an uncontrolled spillway when full. While RiverWare is capable of simulating water rights priority, the Corps model did not include this feature in its Red River model, and Lake Ralph Hall does not pass water to downstream senior water rights as currently configured in the RiverWare model.

This model was modified by the Applicant (Brandes 2015) to include the Upper Trinity diversions at Lake Ralph Hall in order to produce a with-project RiverWare model. The Applicant also developed a without-project model that disabled Lake Ralph Hall rather than keeping the uncontrolled spillway used in the Corps version. Using the modified RiverWare models, the Applicant evaluated the effects of the reservoir on the flows at the Cooper and Talco gages, and in-channel pools and puddles that support benthic organisms and fish. Additional information on the Brandes 2015 analysis is presented in Sections 4.1 and 4.2.

3.2.1 VERIFICATION OF RIVERWARE MODELING

DiNatale Water reviewed the original Corps RiverWare model and the modified version used by the Applicant. We found the modifications to include Lake Ralph Hall to be appropriate. The modeled diversions from the reservoir were based on the same logic as in the Applicants' WAM modeling, diverting up to 45,000 AFY at a maximum rate of 205 cfs from Lake Ralph Hall to Upper Trinity, and reducing annual diversions to 16,800 AFY whenever the reservoir storage level fell below 27,500 AF.

The hydrologic inputs above Lake Ralph Hall in the RiverWare models are set to 37% of the Cooper Gage amount during periods when the Cooper gage was operational (beginning October 1949). The drainage area above Lake Ralph Hall is approximately 32.5% of the drainage area above the Cooper gage, based on data provided by the Applicant. It is not clear why 37% was used in the Corps models, but was potentially an approximation made by the original RiverWare modelers who may not have had detailed information on the Lake Ralph Hall site. In contrast, the WAM modeling modified for Lake Ralph Hall sets inflows to 32.5% of the Cooper Gage flow. Based on this difference, the RiverWare models have approximately 9,000 AFY more flow entering Lake Ralph Hall than the WAM models. This difference would have little effect on the Corps' flood control analysis, but could have important implications for the EIS analysis. Section 4.1 discusses this aspect relative to the evaluation of the impacts to benthic organisms and fish. If a quantitative approach is used in the future for stream morphology or water quality and temperature, the RiverWare modeled inflows should be adjusted downward to 32.5% of the Cooper gage flow to more accurately simulate flows downstream of Lake Ralph Hall.

The RiverWare model run without Lake Ralph Hall matches the historical gage flow at the Cooper gage almost perfectly. As in the WAM modeling, this is not a surprising result given the limited water resources development on the North Sulphur River. Calibration at the Talco gage is also good, although simulated flows are lower than observed flows by about 10%. This difference is likely attributable to the RiverWare operations at Lake Jim Chapman. We did not evaluate this further because the evaluation of benthic organisms and fish is focused on the pools that form on the North Sulphur River and refinement of the Lake Jim Chapman operations does not impact flows on the North Sulphur River. The quantitative hydrologic evaluation relative to floodplain resources assessed historical high flow events on the Sulphur River, so discrepancies in the RiverWare results would not impact the results. If a quantitative evaluation of stream morphology or water quality and temperature is used in the future that extends to the Sulphur River below the confluence with the South Sulphur River, the RiverWare operations at Lake Jim Chapman should be refined.

The Corps' RiverWare model does not incorporate the Texas water rights system, although RiverWare has the ability to simulate water rights through its water rights package. The Corps model developers presumably determined that the impact of the water rights administration was not relevant to the flood control and reservoir operations it evaluated with the model. This is a common modeling practice, as model developers will make certain assumptions based on the objectives of the modeling project. It is entirely plausible that the impacts of the Sulphur River water rights are not relevant to the flood control and reservoir operations objectives of the study for which the Corps model was developed, and disregarding the water rights was a reasonable assumption for that purpose. However, for the Lake Ralph Hall EIS, the water rights administration must be evaluated more closely for evaluation of aquatic impacts due to the impacts of water rights administration during periods of low flow.

In comparison, the WAM modeling includes water rights. Upstream junior water rights (e.g. Lake Ralph Hall) must pass water to downstream senior water rights if the downstream rights are not satisfied. The WAM modeling results show some water passed through Lake Ralph Hall to the more senior Wright Patman Lake. However, as discussed in Section 3.1.1 and 3.1.2, this operation may be overstated due to assumptions about return flows and demands in the current conditions WAM model run and historical operation of Lake Wright Patman. Given this understanding of how each model operates, the models provide an upper and lower limit to the flows that would be passed through Lake Ralph Hall to downstream rights: WAM's strict administration of water rights represents the most bypasses to downstream rights, and the absence of water rights in the RiverWare model represents the least amount of bypasses.

3.2.2 CONCLUSIONS ON USE OF RIVERWARE MODELS

The current configuration of the Corps RiverWare model and the version modified by the Applicant are not appropriate to support a detailed quantification of the aquatic impacts from Lake Ralph Hall to the benthic organisms and fish or the floodplain resources. However, the current models can assist in the evaluation of the impacts to benthic organisms and fish by providing an upper limit on the amount of low flows that would be passed through Lake Ralph Hall to downstream senior water rights (see Section 4.1). The RiverWare model uses a daily time step and, if needed, could be used to evaluate aquatic impacts with more precision than the monthly WAM model.

There are several possible methods of using the RiverWare and WAM models in coordination to obtain data needed for the impacts analysis if needed. The most involved process would be to reconfigure the RiverWare model to simulate water rights and would also require calibration of other major operations in the basin (e.g. Lake Jim Chapman and Lake Wright Patman). Documentation and inputs from the WAM modeling can be used to guide these modifications and calibration efforts. Alternatively, the monthly WAM model results can be used to inform the daily RiverWare model by evaluating times when the two model results diverge. For example, the WAM model monthly flows will indicate times when flows should have been passed to downstream senior water rights when the RiverWare model will show water stored at Lake Ralph Hall. A closer investigation of such instances or minor adjustments to the RiverWare model could provide additional modeling data that could be used in specific resource evaluations that may be sufficient for the purposes of the EIS without the time or expense a full reconfiguration and recalibration of the RiverWare model.

3.3 Sulphur River HEC-RAS Model

A HEC-RAS model of the Sulfur River Basin developed by the Corps was provided to DiNatale Water that included unsteady flow simulations of calculated probable maximum floods. The model includes multiple geometries with various proposed reservoirs in the basin, but does not include the proposed Lake Ralph Hall. DiNatale Water reviewed the cross-sections in the HEC-RAS model to confirm the location of the channelized river from other reports and found the general region of channelization to match the cross-sections. To verify the model, DiNatale Water compared gage heights at the Cooper Gage on the North Sulphur to the model's water depth at the Cooper Gage at matching steady state flows. The flows and gage heights predicted in the HEC-RAS model using steady state conditions matched reasonably well with the historical gage data (Figure 4). The HEC-RAS model was used to evaluate the potential impacts to floodplain resources as described in Section 4.2.

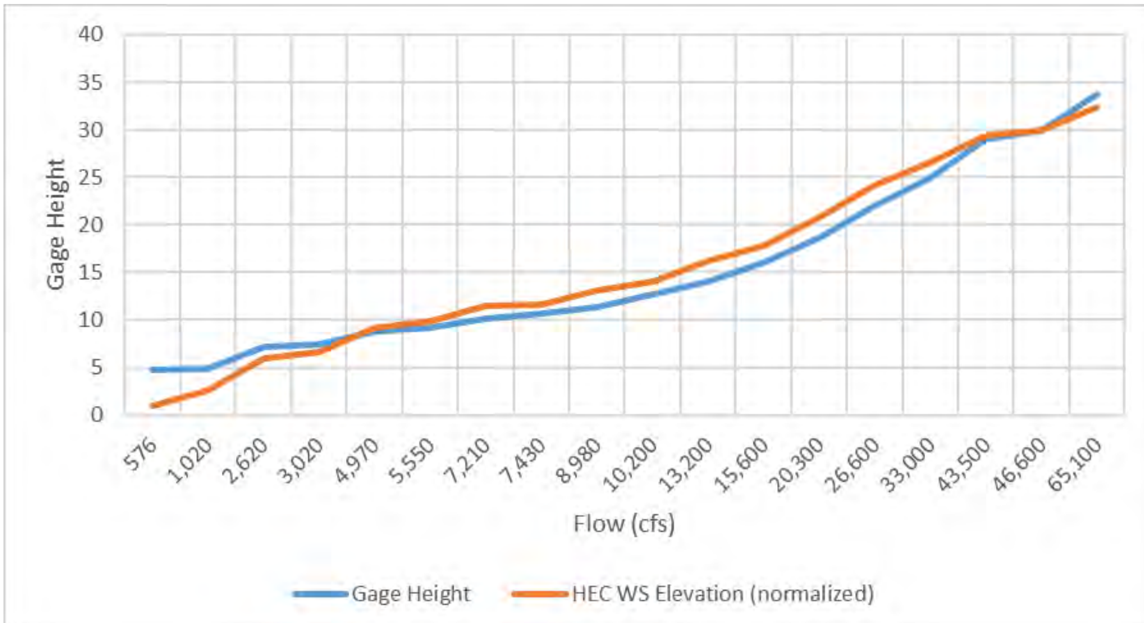

Figure 4. Comparison of USGS gage rating (Gage Height) compared to normalized HEC-RAS modeled water surface elevation at the Cooper gage. Gage height in feet.

4.0 Evaluation of Modeling for Aquatic Resources

Under NEPA and the 404(b)(1) Guidelines, the Corps is responsible for evaluating the impacts to various aquatic resources of a proposed project and its alternatives in order to determine the least environmentally damaging practicable alternative (LEDPA). For the Lake Ralph Hall project, the Corps identified the following aquatic resources for evaluation: benthic organisms and fish, floodplain resources, geomorphology and sediment transport, water quality and groundwater. Section 4.1 and 4.2 discuss the ability of the models to provide quantitative hydrologic data used to support assessment and conclusions of the impacts analysis for benthic organisms and fish, and floodplain resources. Sections 4.3, 4.4 and 4.5 identify modifications necessary if it is later determined that quantitative hydrologic data is required to support more a refined assessment of geomorphology and sediment transport, water quality and temperature, or groundwater resources.

4.1 In-channel pools and puddles that support benthic and fish communities

During the TCEQ water use permit process for Lake Ralph Hall, benthic communities were identified in the basin within in-channel pools and puddles in the North Sulphur riverbed. Cooperating agencies have also identified potential fisheries that may occur within these features. These pools and puddles form after flow events and can sustain the benthic organisms and potentially fish until the next flow event. Testimony from Dr. Norman Jones on behalf of the National Wildlife Federation during the water use permit process indicates that the total volume of such pools in the 20-mile reach between the proposed dam site and the Cooper Gage is 166 AF. Dr. Jones added a 5% channel loss factor to arrive at approximately 175 AF needed to fill the pools below the dam and above the Cooper Gage.

The Applicant analyzed impact of the reservoir on filling of the pools and puddles using the WAM model and the RiverWare model (Brandes 2015). This analysis was performed on a monthly time step with WAM results and the daily RiverWare results were aggregated to monthly flow volumes. The results were summarized with the percent of time the pools would be filled at various locations downstream from the dam. The results between the RiverWare model and the WAM model were very similar except for just downstream of the dam site, where the RiverWare model indicated up to a 13.5% decrease in the amount of time the pools would fill. The Brandes 2015 report attributed this difference to the lack of bypassed flows for downstream senior water rights in the RiverWare modeling.

As described in Section 3.2.1, the RiverWare and WAM results appear to provide the upper and lower ends of the range of flows expected below Lake Ralph Hall. The RiverWare model tends to have less flow because no water is passed for downstream water rights. The WAM modeling tends to have higher flows because of its strict adherence to downstream water rights and other conservative modeling assumptions. When both models are used on a monthly basis as in Brandes (2015), the actual impact based on the monthly flow analysis is between the impact predicted by WAM and by RiverWare. Table 1 is a replica of Attachment E of Brandes (2015) with additional annotation explaining the differences in the ‘Deviation From Without LRH Case’ column comparison between the models.

The analysis of filling the pools and puddles by Brandes (2015) is based on monthly flow volumes. A daily analysis would allow a more detailed analysis that would demonstrate how quickly the pools and puddles dry out due to evaporation, and if all the pools are filled or just a portion of the pools. For example, the monthly analysis shows a flow volume of at least 175 fills all the pools one time in a month. However, if the monthly flow is comprised

Table 1. Replica of Brandes (2015) Attachment E monthly analysis with additional explanation.

STATION NO.	WATER COURSE	LOCATION DESCRIPTION	DRAINAGE AREA sq. mi.	DISTANCE ABOVE N SULPHUR GAGE miles	VOLUME REQUIRED TO FILL ALL D/S POOLS ac-ft	POOL VOLUME IN EACH D/S REACH ac-ft	% OF TIME POOLS ARE FILLED		
							Without Lake Ralph Hall	With Lake Ralph Hall	Deviation From Without LRH Case
FROM RIVERWARE MODEL (06-26-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	--	--	--	--
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	92.7%	83.6%	-9.1%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	86.7%	73.2%	-13.5%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	85.8%	82.0%	-3.8%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	86.7%	86.3%	-0.4%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	85.8%	85.4%	-0.4%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	85.4%	83.6%	-1.8%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	89.8%	89.6%	-0.1%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	85.1%	82.7%	-2.3%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	--	--	--	--
FROM WAM (04-06-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	--	--	--	--
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	90.8%	90.2%	-0.6%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	84.8%	83.5%	-1.3%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	83.9%	83.8%	-0.1%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	85.4%	85.4%	0.0%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	83.9%	83.9%	0.0%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	83.3%	83.2%	-0.1%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	88.6%	88.6%	0.0%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	83.2%	83.0%	-0.1%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	--	--	--	--

Higher impacts below dam site shown with RiverWare model

Actual monthly impacts within the range between the two models

Lower impacts below dam site shown with WAM model

of two flow events of 87 AF each separated by a few weeks, it is possible that the first event would fill the uppermost pools, and then after evaporation reduces the amount of water in those pools, the second event would refill the upper pools. In that scenario, the lower pools would not be refilled unless enough inflow from contributing basins below Lake Ralph Hall were sufficient.

Use of a daily model will provide more detailed information on the impacts. However, based on the review of the pools analysis performed by Dr. Jones during the water permit process (TCEQ proposed order, undated), our inspection of the channel and other reports describing the condition of the channel, it appears that the monthly analysis will adequately represent stream impacts to the benthic communities in the ponds and puddles below the dam site for the purposes of the EIS. In the event that benthic resource specialists require more detailed data that can be provided by a daily model, modifications to the RiverWare model or a daily disaggregation of monthly WAM output would be appropriate. Such changes may not require a full reconfiguration of the RiverWare model, but could utilize WAM model outflows to guide a daily analysis for times when water should be bypassed at Lake Ralph Hall. In addition, Upper Trinity has proposed restoration of approximately three miles of original North Sulphur River stream channel below the dam site. The design is not yet complete on this mitigation system and could utilize a recirculating pump, but under some scenarios, water may be released out of the mitigation reach into the channelized portion of the existing river bed. These types of flows from the mitigation reach may assist in maintaining or filling of pools and puddles during dry times. More detailed analysis involving operational considerations may be needed to allow a determination of the value of such inputs associated with this proposed mitigation strategy. However, such conditions are not part of the impact assessment since USACE cannot use compensatory mitigation features, and their influence and benefits, in its impact analysis to determine the LEDPA.

Table 1 shows that the there is almost no difference between the with and without Lake Ralph Hall model runs for both the RiverWare and WAM models by the Cooper gage. It follows that downstream of the Cooper gage, there would be no impact of Lake Ralph Hall on filling puddles and pools below the gage because the increased drainage area below the Cooper gage is sufficient to fill the pools during rain events even if no flow passes the dam site.

4.2 Floodplain Resources

Downstream of the confluence with of the North and South Sulphur Rivers, the Sulphur River is not channelized as on the North Sulphur River, although some channelized portions are visible from aerial imagery. Riparian habitat is more established downstream of the confluence and the river meanders along its course rather than flowing through straight reaches of the channelized portions. High flows often provide benefits to the riparian habitat in the floodplain when flows go out of the banks of the river and infiltrate into the surrounding areas. Brandes (2015) notes that the flood stage flows in the North Sulphur River rarely if ever exceed the deep incised channel. However, no analysis was presented for more downstream locations where the channelized nature of the river changes to a more typical riverine system. We are not aware of other studies of floodplain impacts for the Lake Ralph Hall EIS that may include this more downstream reach, so we present a brief evaluation of floodplain impacts in this section.

The Corps' HEC-RAS model (Section 3.3) was utilized to assess the impacts to floodplain resources at more downstream locations. As received, the model included transient simulations for various flood control scenarios that were typically very high flow events only, meant for flood control and facility sizing events, and for a number of proposed reservoir sites. We took a simplified approach of using the HEC-RAS model to evaluate the river stage at several locations using historical gaged flows and evaluating river stage at steady state at that flow rate. We used the basin geometry (cross-sections) containing only existing reservoirs for the analysis.

This analysis requires daily flows, as monthly flow volumes averaged over a month will not represent the level of peak flow seen in the basin. In a more detailed analysis of the floodplain impacts, RiverWare model outputs could be used as inputs to the HEC-RAS model. However, since the RiverWare model is not currently configured to simulate Lake Ralph Hall operations, we took a simplified approach of using historical gage data for a baseline set, and we applied an adjustment to the gage flow to represent the maximum potential impact of Lake Ralph Hall (i.e. assume Lake Ralph Hall diverts and stores the entire inflow to the lake). This approach is a conservative approach because it assumes the maximum impact at Lake Ralph Hall. Therefore, the impacts computed under this approach will yield higher impacts than a more detailed approach using simulated outflows from Lake Ralph Hall.

Historical gaged flows from the Cooper Gage, Talco Gage, and Dalby Springs Gage were used in this analysis. Several flow events with varying levels of flow were selected and tracked through all three gages upstream to downstream. The historical flow rates at the three gages were simulated in the HEC-RAS model to determine river stage. The flow was then adjusted to assume Lake Ralph Hall stored the entire inflow to the lake during the flow event, and the adjusted flow was simulated in HEC-RAS to determine the river stage decline due to Lake Ralph Hall. Gaged flows at each location were adjusted by computing the total volume of the flow event and proportionally removing 33% of the volume of water observed at the Cooper Gage (33% was rounded from the 32.5% drainage area ratio of Lake Ralph Hall to the Cooper Gage). This approach maintained the flow routing and attenuation patterns from the upper reaches to the lower gages. The HEC-RAS model output provides a river stage, but also plots the inundated area of the cross section being evaluated. These visual depictions show the floodplain impacts laterally from the river, providing more information than the river stage only.

Four separate rainfall events were selected to evaluate Lake Ralph Hall's impacts to floodplain resources. The events were chosen based on frequency of the flow event, with the lowest flow expected to occur several times per year, the next highest flow expected to occur about once a year, the next highest expected once every few years, and the highest flow event expected to occur about once every 20 years. Table 2 shows the events, the gaged peak daily flow, the total flow volume of the event and the adjustments made for the without Lake Ralph Hall scenario.

Hydrographs for the January 8, 2012 event are shown in Figure 5**Error! Reference source not found.**. Cross-sections for the Talco and Dalby Springs gages for the without and with Lake Ralph Hall cases are shown in Figure 6 and Figure 7. Cross-Section and water surface of January 8, 2012 rain event at the Dalby Springs Gage for with and without Lake Ralph Hall scenarios., respectively. Figure 8, Figure 9, and Figure 10 are the corollary figures for the December 23, 2009 rain event. Figure 11, Figure 12, and Figure 13 are the corollary figures for the March 9, 2012 rain event. Figure 14, Figure 15, and Figure 16 are the corollary figures for the November 27, 2015 rain event.

The figures show how quickly the impact of Lake Ralph Hall is attenuated at downstream locations. Due to the large difference in contributing drainage area downstream of Cooper gage, a 33% decrease in flow at the Cooper gage due to Lake Ralph Hall has little effect on maximum river stage downstream following a rain event. During larger storms, while the magnitude of the flow decrease is significantly larger due to water going into storage at Lake Ralph Hall, there is still little effect on maximum river stage below the confluence of the North and South Sulphur Rivers. In all four rain events evaluated, the river stage changes at the Talco Gage are small, and become even smaller at downstream locations. The cross-section figures contain both the without Lake Ralph Hall baseline river stage and the with Lake Ralph Hall river stage. The decreases in river stage with Lake Ralph Hall are nearly imperceptible on the cross sections, and the lateral extent of the flow is nearly identical to the without Lake Ralph Hall scenarios. Table 3 shows the changes in river stage at the peak daily flow rates.

Based on the results of the HEC-RAS analysis and the estimates for streamflow reduction due to Lake Ralph Hall, there are no significant floodplain impacts due to the proposed Lake Ralph Hall because the river stage and lateral extent of flows changes very little downstream of the channelized section of the river. As with other resources, additional detail could be obtained by using daily modeling results rather than using the approach applied in this analysis. However, this analysis used conservative assumptions about the amount of water in storage at Lake Ralph Hall at the time of the flow event, so the additional precision gained through daily modeling will not yield differing hydrology results.

Table 2. Rain events used to evaluate flood plain resource impacts of Lake Ralph Hall.

		Without Lake Ralph Hall Observed Flow						With Lake Ralph Hall Adjusted Flow					
		Gaged Peak Daily Flow (cfs)			Gaged Total Event Flow Volume (AF)			Adjusted Peak Daily Flow (cfs)			Adjusted Total Event Flow Volume (AF)		
Beginning Date	**Frequency**	**Cooper**	**Talco**	**Dalby Springs**	**Cooper**	**Talco**	**Dalby Springs**	**Cooper**	**Talco**	**Dalby Springs**	**Cooper**	**Talco**	**Dalby Springs**
January 8, 2012	Several times per year	1,840	3,030	2,910	5,109	17,302	26,452	1,565	2,930	2,835	3,406	15,599	24,748
December 23, 2009	a few times per year	5,470	13,300	12,900	10,850	72,774	109,864	3,645	12,850	12,575	7,233	69,157	106,248
March 19, 2012	once every few years	26,900	34,600	29,300	56,450	186,684	242,162	18,975	33,200	28,435	37,633	167,868	223,345
November 27, 2015	once every 20 years	41,400	52,800	52,100	140,945	294,803	585,183	33,000	50,635	50,685	93,964	247,821	538,202

**Without Lake Ralph Hall adjusted flow computed by removing 33% of Cooper Gage flow volume from downstream gages, proportional to each day's flow volume during the flow event*

Table 3. Water surface elevation, in feet, with and without Lake Ralph Hall at key gages.

Beginning Date	**Frequency**	**Cooper without Lake Ralph Hall**	**Cooper without Lake Ralph Hall**	**Difference**	**Talco without Lake Ralph Hall**	**Talco without Lake Ralph Hall**	**Difference**	**Dalby Springs without Lake Ralph Hall**	**Dalby Springs without Lake Ralph Hall**	**Difference**
January 8, 2012	Several times per year	376.84	376.22	0.62	294.16	293.98	0.18	244.50	244.30	0.20
December 23, 2009	a few times per year	381.97	379.78	2.19	301.14	301.02	0.12	253.98	253.88	0.10
March 19, 2012	once every few years	396.56	392.26	4.30	303.76	303.64	0.12	257.00	256.89	0.11
November 27, 2015	once every 20 years	401.18	398.78	2.40	305.20	305.04	0.16	259.45	259.33	0.12

**Lake Ralph hall river stage computed using HEC-RAS model using maximum flow shown in Table 2*

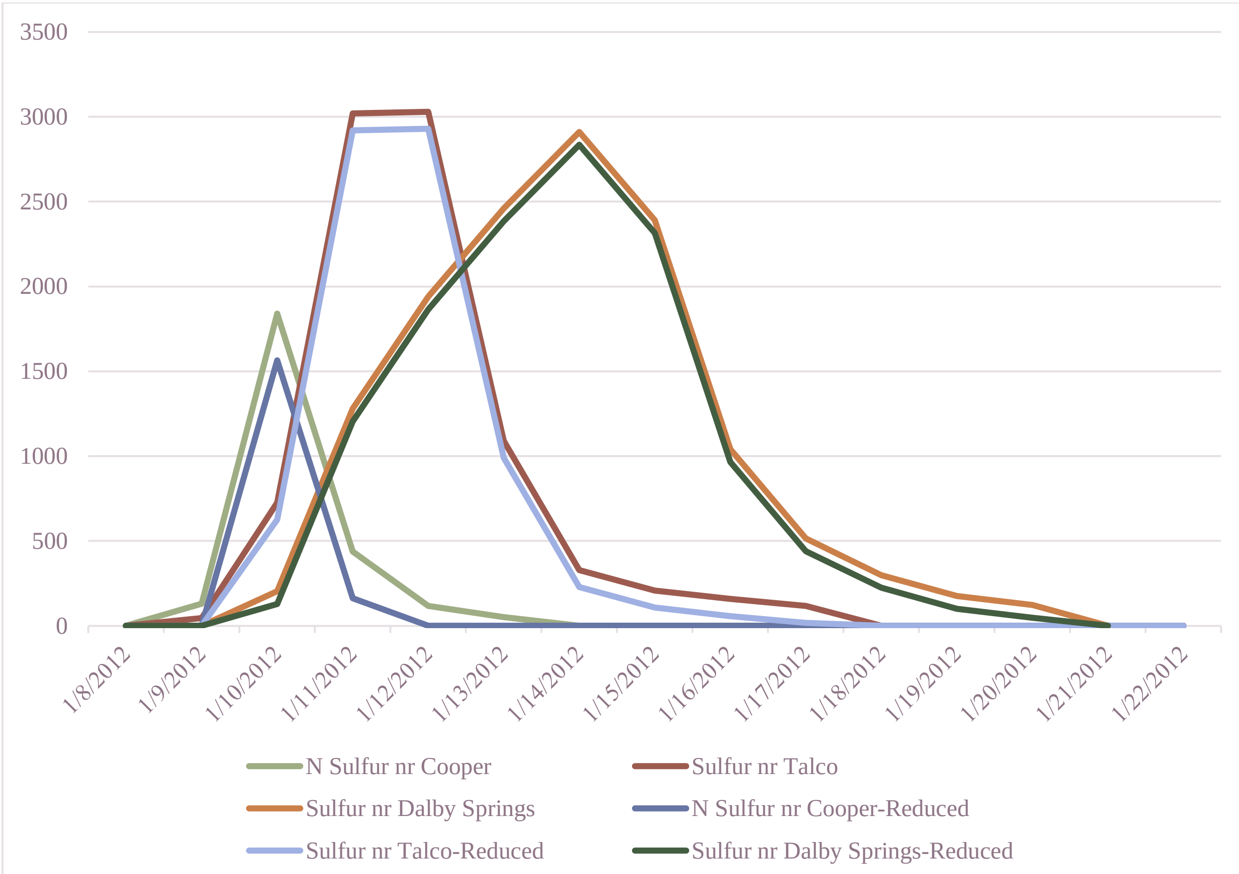

Figure 5. Hydrographs from gages for rain event beginning January 8, 2012 for with and without Lake Ralph Hall scenarios.

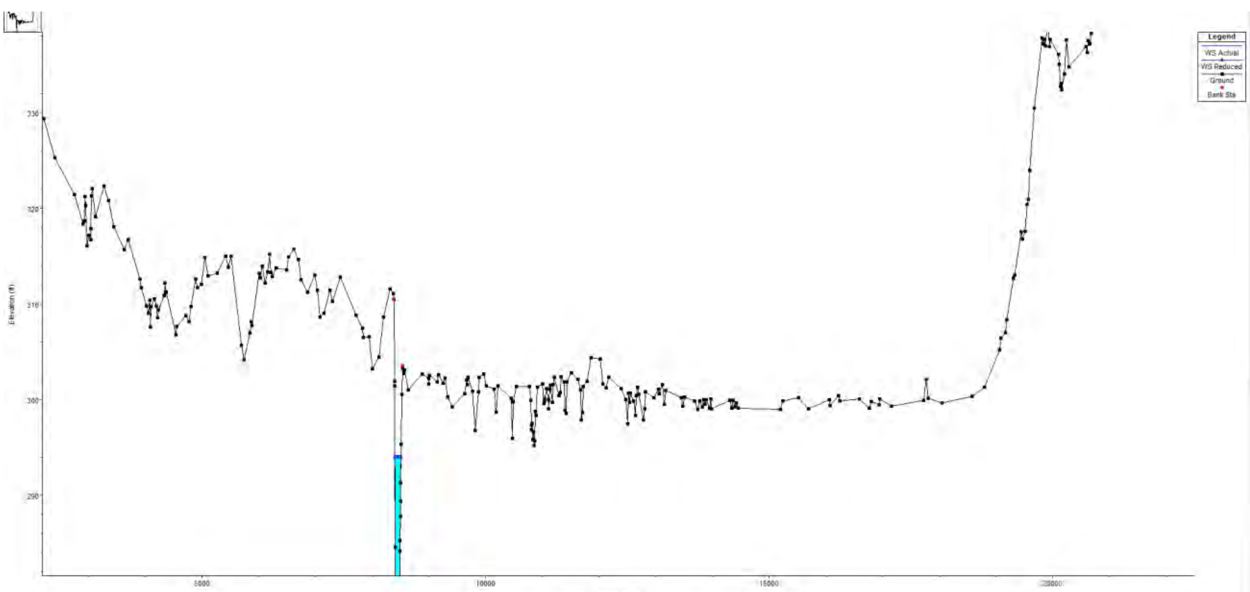

Figure 6. Cross-Section and water surface of January 8, 2012 rain event at the Talco Gage for with and without Lake Ralph Hall scenarios.

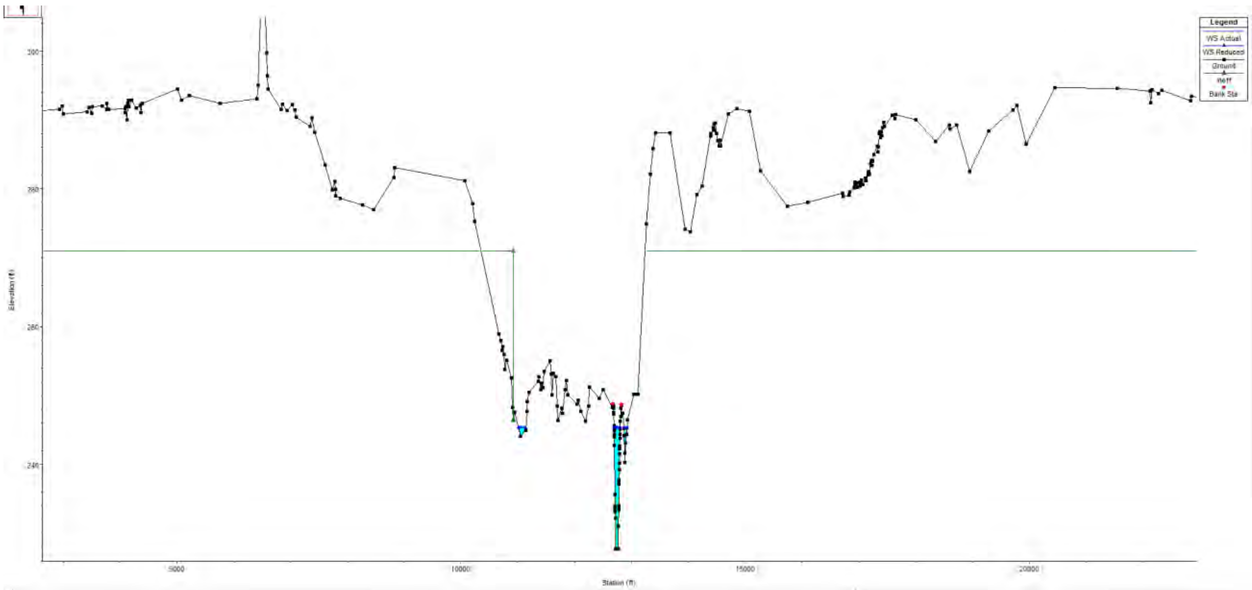

Figure 7. Cross-Section and water surface of January 8, 2012 rain event at the Dalby Springs Gage for with and without Lake Ralph Hall scenarios.

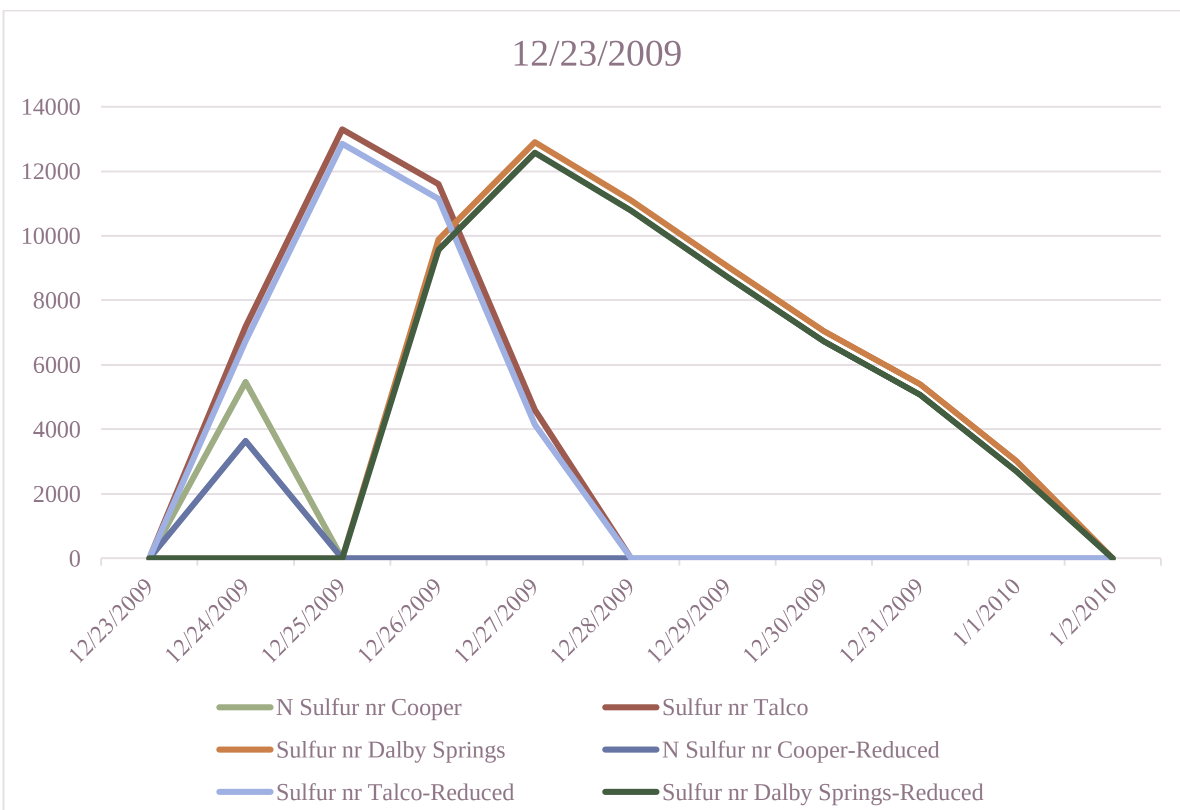

Figure 8. Hydrographs from gages for rain event beginning December 23, 2009 for with and without Lake Ralph Hall scenarios.

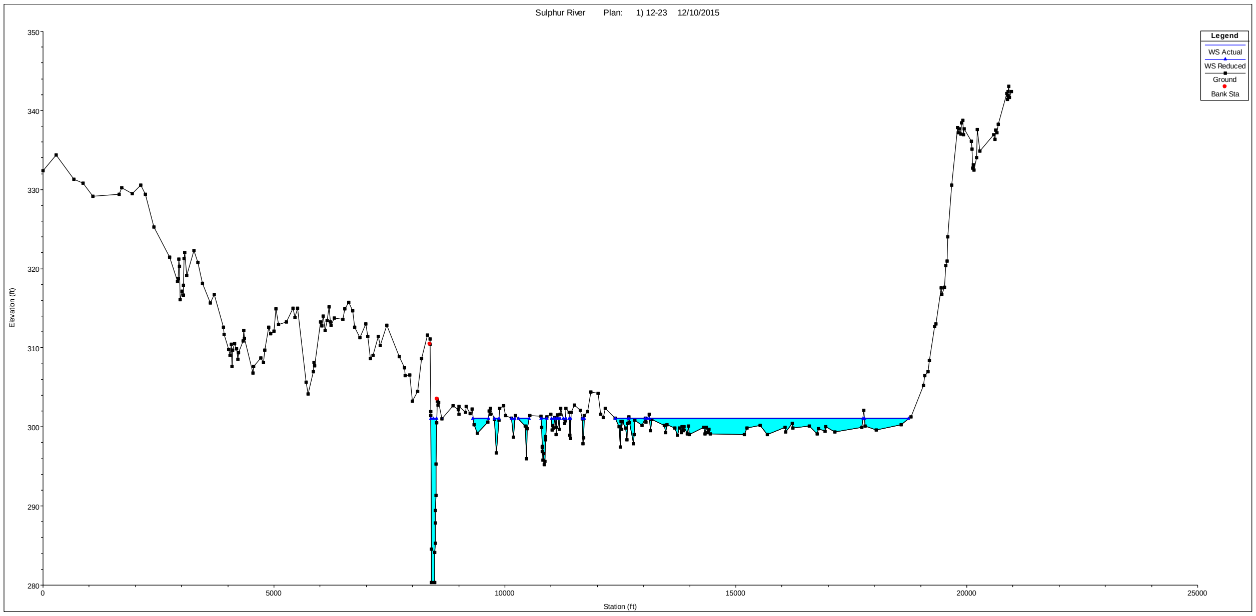

Figure 9. Cross-Section and water surface of December 23, 2009 rain event at the Talco Gage for with and without Lake Ralph Hall scenarios.

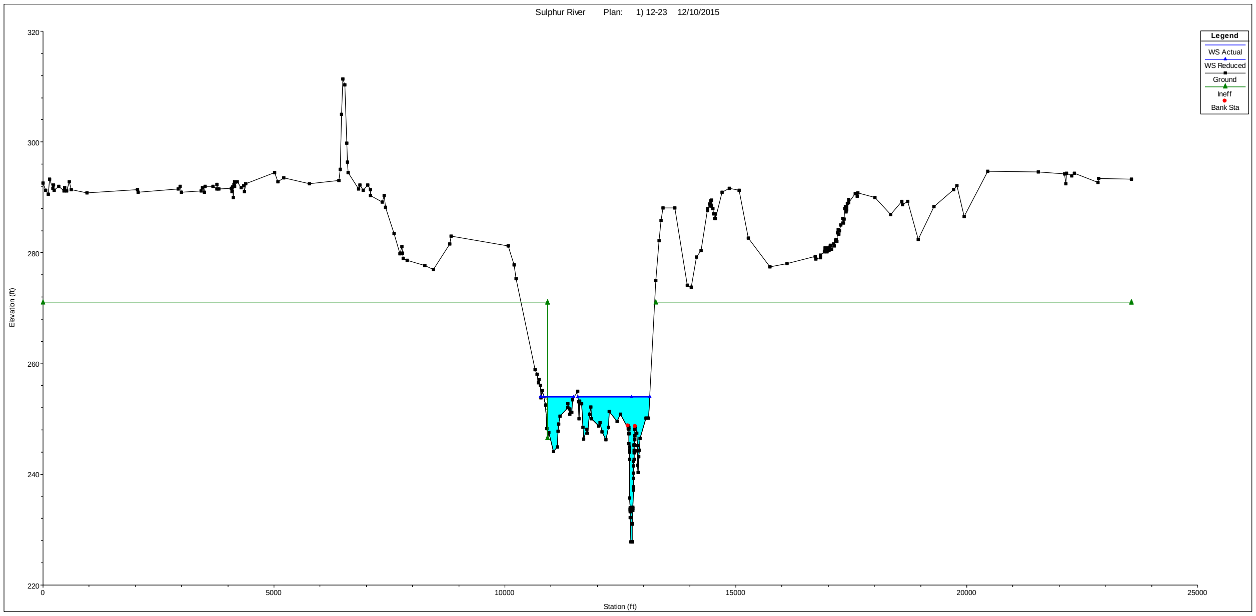

Figure 10. Cross-Section and water surface of December 23, 2009 rain event at the Dalby Springs Gage for with and without Lake Ralph Hall scenarios.

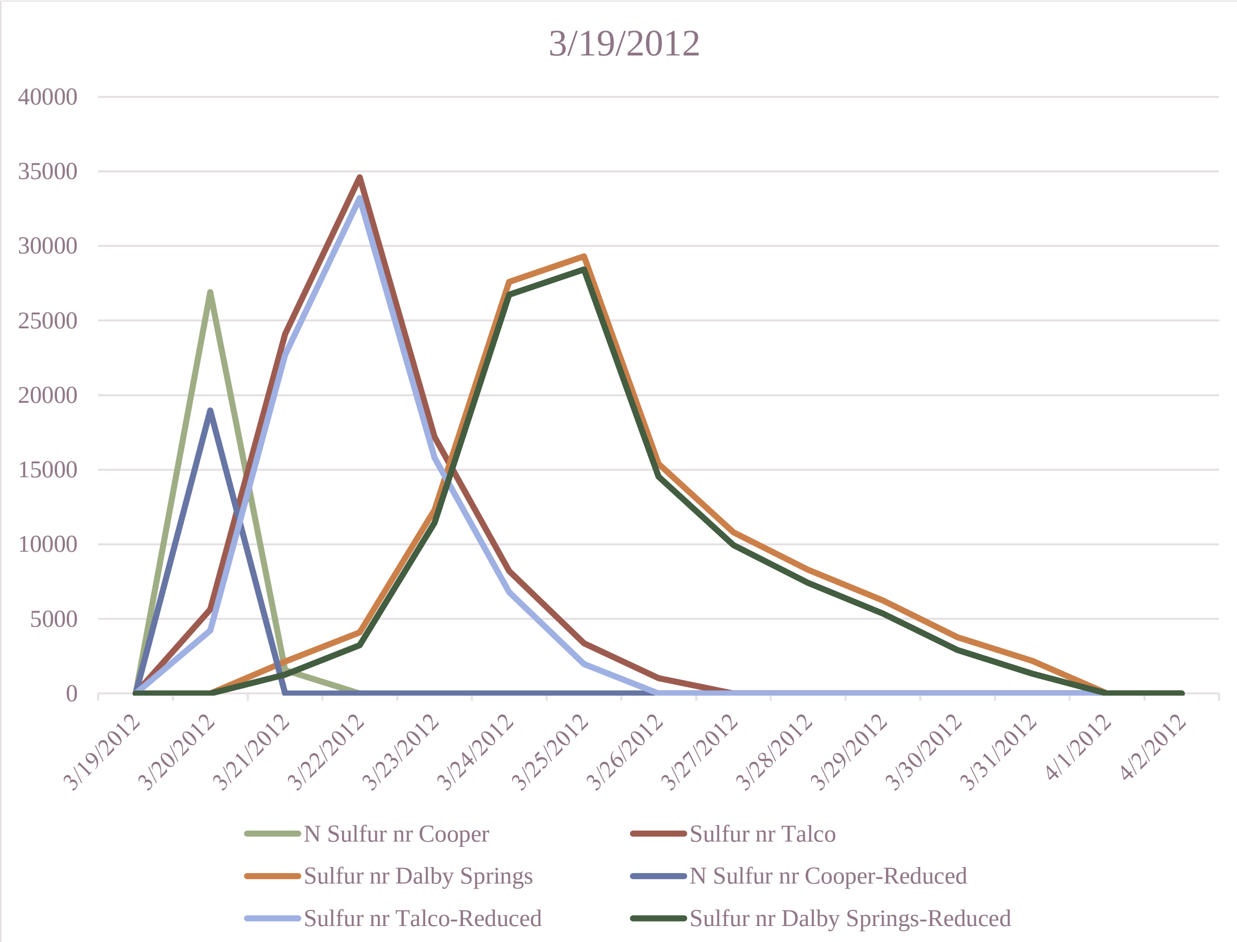

Figure 11. Hydrographs from gages for rain event beginning March 19, 2012 for with and without Lake Ralph Hall scenarios.

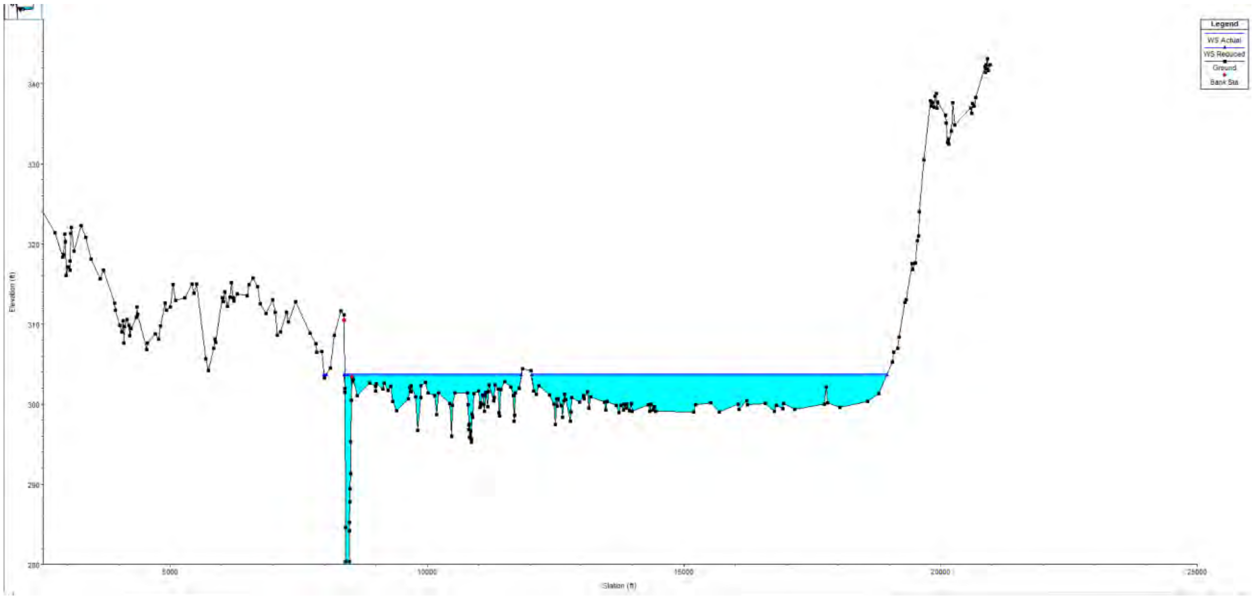

Figure 12. Cross-Section and water surface of March 19, 2012 rain event at the Talco Gage for with and without Lake Ralph Hall scenarios.

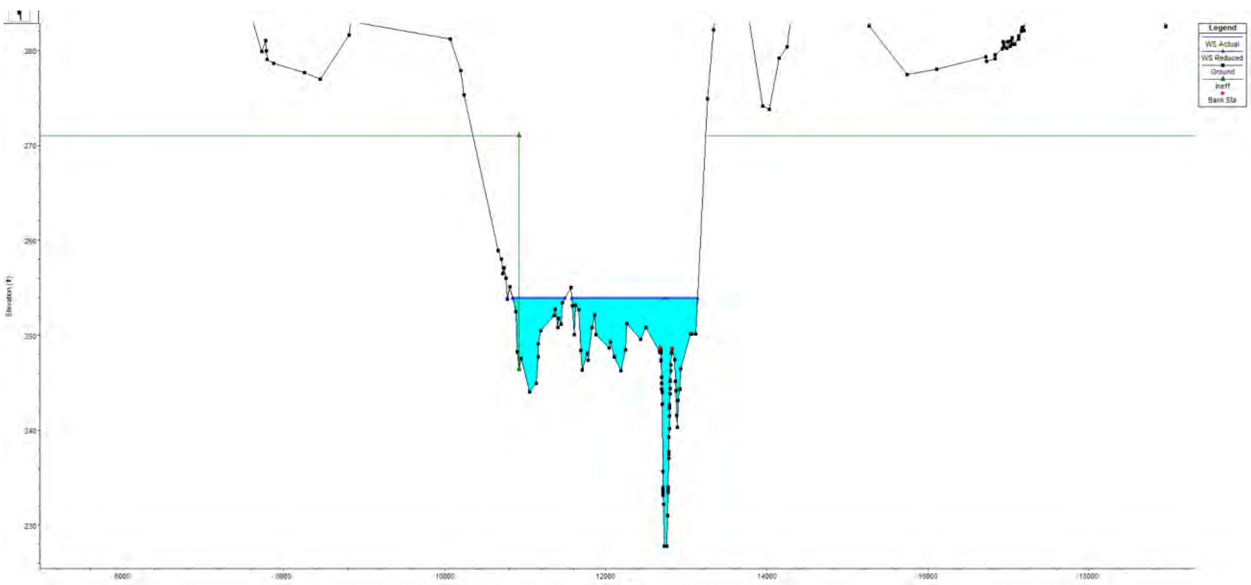

Figure 13. Cross-Section and water surface of March 19, 2012 rain event at the Dalby Springs Gage for with and without Lake Ralph Hall scenarios.

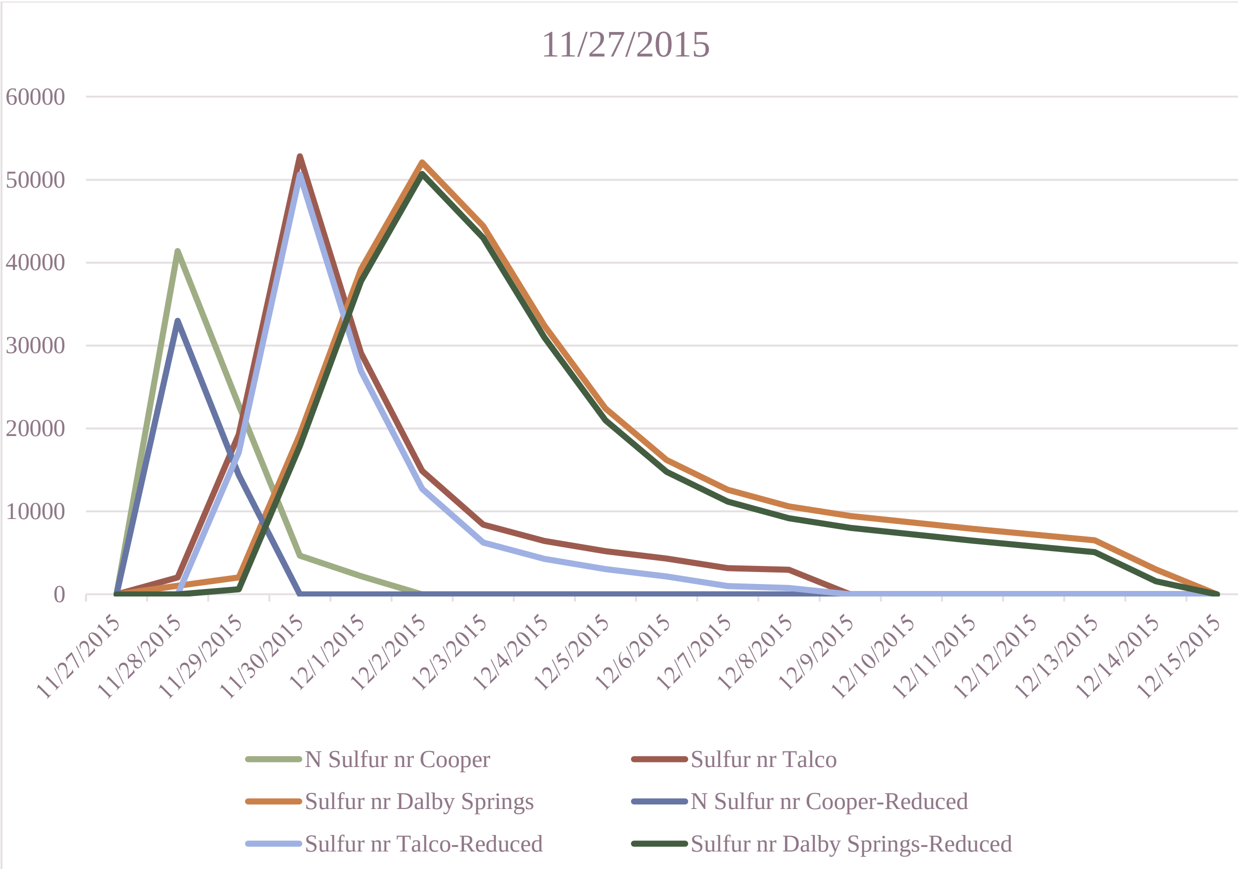

Figure 14. Hydrographs from gages for rain event beginning November 27, 2015 for with and without Lake Ralph Hall scenarios.

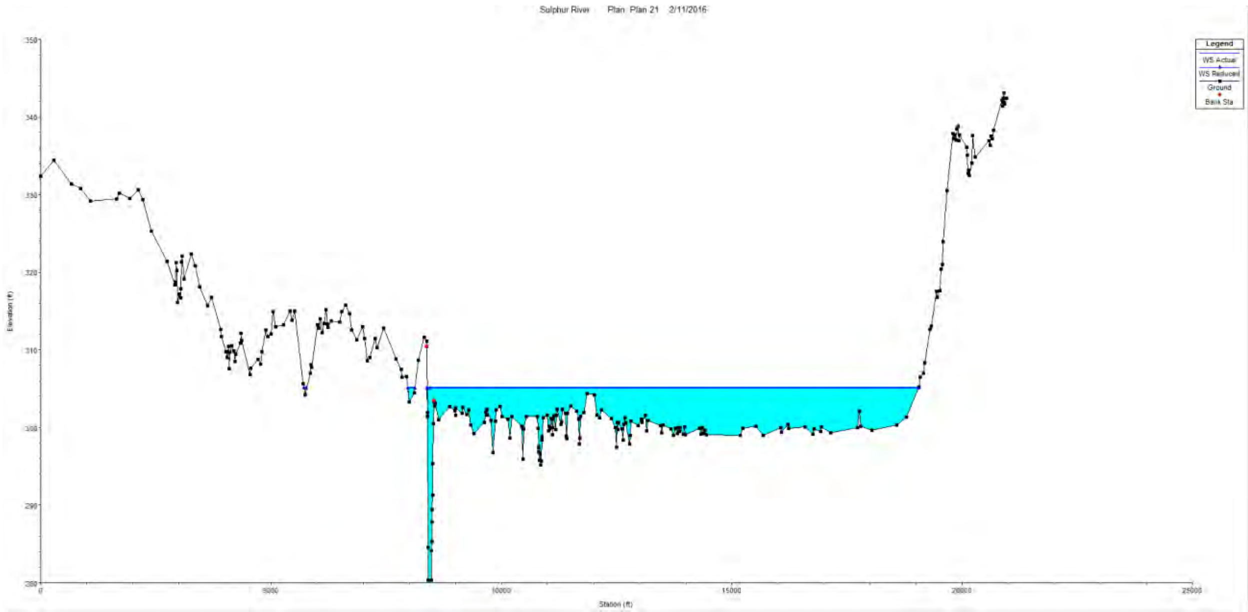

Figure 15. Cross-Section and water surface of November 27, 2015 rain event at the Talco Gage for with and without Lake Ralph Hall scenarios.

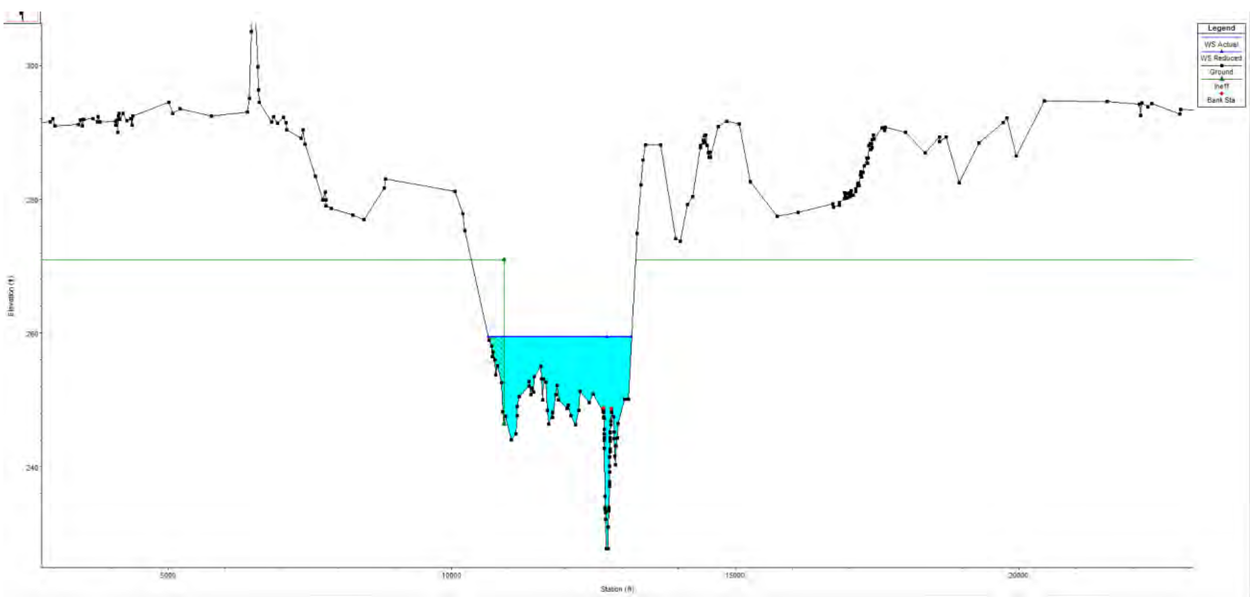

Figure 16. Cross-Section and water surface of November 27, 2015 rain event at the Dalby Springs Gage for with and without Lake Ralph Hall scenarios.

4.3 Geomorphology and Sediment Transport

The proposed approach to assess the potential impact of the Lake Ralph Hall project on stream morphology is to use the Texas Rapid Assessment Method (TXRAM) to assess the current morphological condition of the stream. TXRAM does not include an intensive, quantitative functional assessment nor does it focus on specific ecological functions. TXRAM was chosen because it is an accepted method for assessment of stream integrity and health in Texas and can be used to assess stream impacts, including the comparison of stream alternatives (Corps 2010). TXRAM requires an analysis dependent on field observations, photos, and aerial assessments and the assessment would be based on existing field data. Two components within the TXRAM analysis consider flow, specifically flow regime or a ranking of the stream flow conditions, and channel flow status, which accounts for the movement of water through a reach. The primary method used to obtain information to complete the TXRAM analysis for all of the required components is through field assessments. The method is a general conditional assessment which allows for the inference of resource function and condition but does not require quantitative hydrologic data. The Corps has stated that the degraded condition of the channel as well as the unique properties associated with the channel's substrate do not warrant a more intensive review and detailed hydrologic analysis.

The TXRAM approach being pursued by the Corps does not require detailed quantitative information for a with-project scenario. Current modeling using the WAM model results or the RiverWare results are not adequate to support an intensive quantitative functional assessment of the geomorphology and sediment transport impacts assessment. The WAM modeling uses a monthly time step which does not represent peak flows and rapid recession of flows common to this basin. These types of peak flows are important to geomorphology and sediment transport evaluation. The RiverWare modeling provides daily flow values, but the model inputs would need to be adjusted as recommended in Section 3.2.2 and water rights should be added to the model if detailed quantitative hydrologic data is desired for a more detailed approach to geomorphology and sediment transport.

However, both the WAM and RiverWare models may be able to support qualitative conclusions in the TXRAM approach. For example, the WAM model as configured by the Applicant has multiple sub-basins below Lake Ralph Hall and may contain useful information on soil composition and drainage areas that contribute to the North Sulphur reach at several locations below the dam site. Basic mass balance analysis of the inflows into Lake Ralph Hall, diversions and evaporation rates from the WAM and RiverWare models may also help provide a qualitative picture of with-project streamflows.

We also reviewed existing reports prepared for Upper Trinity on hydraulics and hydrology and fluvial geomorphology (Upper Trinity 2004, Upper Trinity 2006). Both reports included analyses of the area upstream of the Lake Ralph Hall dam site and downstream on the North Sulphur River for 100 feet below the dam, which does not cover the extent of the potential impacts on the North Sulphur River and Sulphur River downstream of the dam site.

4.4 Water quality and Temperature

The water quality and temperature assessment is using a qualitative approach and will include analysis of water quality stored in Lake Ralph Hall as well as impacts to stream reaches below the dam. By nature, a qualitative approach does not require an intensive quantitative model, therefore there is no need to perform additional hydrologic modeling to support the qualitative water quality assessment. This seems to be an appropriate approach based on the degraded condition of the existing river channel downstream of the dam site. Existing monthly model results may provide sufficient information to support the in-lake water quality and temperature analysis.

If the Corps subsequently determines that a more detailed quantitative analysis of water quality impacts is required, the most rigorous method would be reconfiguration and calibration of the RiverWare model as described in 3.2.2. However, as described for the other resources, some daily data can be more readily determined from existing modeling in order to reduce the time and expense of a full RiverWare model update. Daily information for Lake Ralph Hall inflows can be estimated as 32.5% of the Cooper gage flows. Diversions from the lake to Upper Trinity can be estimated as a constant daily rate as simulated in the WAM modeling (or based on some other pattern based on Upper Trinity's demand for water). Daily outflows would require somewhat more analysis that would be determined based on the specific needs for a quantitative water quality analysis.

4.5 Groundwater

Groundwater aquifers in the region are much deeper than the river channel. The river channel at the Lake Ralph Hall site is comprised primarily of clay that impedes vertical flow to lower aquifers. The lack of connection even to local shallow aquifers is apparent by the lack of stream baseflow in the North Sulphur River during the periods of low precipitation. Therefore, there is limited potential for hydrologic interrelationships between the river and the groundwater system.

Downstream locations closer to Lake Wright Patman may have increased groundwater interaction where the river overlies the Carrizo-Wilcox aquifer, downstream of the channelized portion of the North Sulphur River. However, at these downstream locations, the differences in flow due to Lake Ralph Hall are minimal in terms changes in river stage (see Section 4.3) and therefore changes to the surface water-groundwater interaction would be small or negligible.

If the Corps determines that more detailed quantitative evaluation of the groundwater impacts are necessary, the monthly WAM model results would be suitable for simulating the surface water component of the evaluation. Groundwater time-scales are typically much longer than surface water systems, so a monthly time step would be appropriate. Due to the minimal interaction between the surface water and groundwater system near the dam site, the WAM model's conservative assumptions that tend to overstate the amount of water bypassed to downstream water rights would provide a scenario where the upper limit of impacts to groundwater resources could be determined.

5.0 Cumulative Impacts

As part of its responsibilities to disclose impacts of a proposed projects to the public, the Corps must consider the cumulative impacts of other known and reasonably foreseeable future actions that may also impact the project area. In project areas where land and water uses are rapidly changing, or where other projects are proposed, the Corps may require a future conditions baseline scenario for evaluating impacts. A future condition baseline helps determine which impacts to a project area are attributable to the proposed project, and which are attributable to the reasonably foreseeable future actions.

For the Sulphur River Basin, the Corps determined that a future conditions baseline modeling scenario is not required at this time. This decision was based on minimal expected changes to the Sulphur River basin in terms of development and land and water use which would modify hydrology in the foreseeable future that are in addition to the proposed Lake Ralph Hall project. Several other reservoir sites have been proposed in the Sulphur River Basin, including Marvin Nichols. An organization called the Sulphur Basin Group, which is a consortium of parties interested in water development in the Sulphur River basin, evaluated the Marvin Nichols and other dam sites for yield and reliability using the WAM model (SBG 2015). Recently the Marvin Nichols reservoir was removed from state planning documents and would not be constructed prior to 2070. Due to more than 50 years between the current evaluation for Lake Ralph Hall and potential future construction, Marvin Nichols was not considered a reasonably foreseeable future action. Construction of Marvin Nichols would require a Corps permit, and the impacts of Lake Ralph Hall (if permitted and constructed), would be considered in the impact analysis of Marvin Nichols.

Regional water providers are also evaluating re-allocation of storage in lake Wright Patman. This proposed project would not affect the Lake Ralph Hall evaluation because changes to storage levels in Lake Wright Patman due to the reallocation will impact the inundation area and flows downstream of Lake Wright Patman. In Section 4.2, we demonstrated that changes to the flow due to Lake Ralph Hall do not have a significant impact on river stage or floodplain resources at downstream locations, such as Lake Wright Patman. Therefore, the outcome of the Wright Patman reallocation are irrelevant to the impacts analysis of Lake Ralph Hall.

In summary, the projected consistent land and water use in the Sulphur River Basin and lack of other reasonably foreseeable future actions in the region support the use of an impacts analysis that relies on a current conditions baseline and comparing to a with-project future scenario.

6.0 Conclusions

The purpose of this report was to determine the adequacy of existing hydrologic modeling to support the evaluation of the impacts to the aquatic resources caused by the proposed Lake Ralph Hall in the Sulphur River Basin. Existing modeling tools include Texas' WAM models, as modified by Upper Trinity to simulate with and without Lake Ralph Hall conditions, the Corps' RiverWare model of the Red River basin that includes the Sulphur and North Sulphur Rivers as tributaries to the Red River, and the Corps' HEC-RAS model of the project area. The Corps took a more robust approach to evaluate impacts to benthic organisms and fish, and this report included a quantitative analysis of hydrologic impacts to floodplain resources. The Corps has taken a more qualitative approach to evaluating other resources including geomorphology and sediment transport, water quality and temperature and groundwater impacts. This report identified potential supporting uses of the models for these approaches and recommended approaches to modifying the existing modeling in the event additional detailed analysis is used in the future.

6.1 Conclusions Related to Available Models (Section 3)

The WAM models of the Sulphur River utilize a monthly time step that is appropriate for water rights administration purposes and yield and reliability analyses, but is not appropriate for evaluating impacts that require daily resolution of flow. In the North Sulphur River, this point is important due to the flashy nature of the river system, where flows can fluctuate between no flow and several thousand cfs within a few days. The WAM model current conditions run uses some conservative assumptions on demands and return flows that may not accurately represent streamflow during average years.

The current configuration of the RiverWare model is not appropriate for supporting determinations of aquatic impacts of Lake Ralph Hall because of the lack of detailed operations at Lake Ralph Hall, including bypasses to downstream junior water rights. The

RiverWare model uses a daily time step and, if needed, could be used to evaluate aquatic impacts with more precision than the monthly WAM model with appropriate modifications.

Although neither the WAM nor the RiverWare model were configured for the purposes of the EIS evaluations, there are several possible methods of using the models as-is or with minor modifications to better support resource analyses. The WAM and RiverWare models simulate opposite tendencies with respect to the amount of water passed downstream at Lake Ralph Hall. The WAM model passes flows downstream to meet the demands of senior water rights. This is an important feature to include in resource analysis, however, the conservative demand and reuse assumptions in WAM, and the manner in which Lake Wright Patman is simulated may overstate these bypassed flows. The RiverWare model, on the other hand, never passes water downstream to senior rights. Therefore, the streamflows and resource impacts can therefore be predicted to occur within the range of hydrologic impacts predicted by the two models in situations where monthly flows provide a sufficient level of detail.

For the evaluation of the impacts to benthic organisms and fish, the current configuration of the RiverWare model in combination with the monthly WAM results provides a sufficient level of detail that does not require model changes at this time. If additional detailed assessments, refinements or modifications are made in the future for any of the resources, the RiverWare model's naturalized flows at Lake Ralph Hall should be reduced to 32.5% of Cooper gage. If additional detail for impacts analysis at the Talco Gage or downstream are needed, additional calibration of Lake Jim Chapman should be part of the that RiverWare model refinement.

6.2 Conclusions Related to Use of Output for Evaluation of Resource Impacts (Section 4)

The Applicant evaluated the use of WAM and RiverWare to inform impact assessments to the benthic and fish communities in the pools and puddles in the North Sulphur River channel. Daily flows from the RiverWare model were summed to monthly values by the Applicant to compare the results from the two models. Use of the daily data could provide more detailed information relative to resource impacts than monthly flows. However, based on a comparison of the bias inherent in the WAM monthly model and the RiverWare daily model, the hydrologic impacts to the benthic organisms and fish are within the range of impacts simulated by the two models. Hydrologic impacts are shown on Table 1 for both models. Based on these results, the results of the existing WAM model and RiverWare model are adequate to represent hydrologic impacts to the benthic communities and fish in the North Sulphur River for the purposes of the EIS and a more detailed daily model is not required.

Floodplain resources downstream of the Lake Ralph Hall dam site had not been previously quantified. We utilized the Corps HEC-RAS model of the Sulphur River basin to analyze streamflow and lateral extent of flows at the Talco and Dalby Springs gages several miles downstream of the proposed Lake Ralph Hall where the Sulphur River is no longer channelized. The analysis was done for a variety of flow events, ranging from a frequency of a few times per year to a one-in-twenty year event. Flows were estimated for a scenario with Lake Ralph Hall and compared to the historical river stage and lateral extent of flow. The results showed very small differences between the scenarios with and without the Lake Ralph Hall project due to the increasing contributing drainage area and flow to the river further downstream of the site. The analysis showed the impacts to floodplain resources due to Lake Ralph Hall are negligible downstream of the channelized portion of the river.

Geomorphology and sediment transport are being generally assessed using the TXRAM method in light of additional data that will not require detailed quantitative hydrologic data. If more detailed quantitative analysis of this resource category is required in the future, the current modeling configuration of WAM would not be suitable due to the monthly time step. If refined as described above, the RiverWare model could be used to inform quantitative assessments for this resource category. Both the WAM and RiverWare in their current configurations could be used to support the qualitative conclusions by utilizing model inputs, documentation and mass balance to support the qualitative findings from TXRAM.

Water quality and temperature are being evaluated by the Corps using a qualitative approach in coordination with the Texas Commission on Environmental Quality 401 certification agency. Modeling results from the WAM model and the RiverWare model can provide bounds on a range of likely flow conditions that could impact water quality and can support the qualitative conclusions of the analysis, if needed. It is likely that any additional quantitative detail for water quality would require daily resolution of flows, making modifications to the RiverWare model the preferred approach if the Corps determines a more detailed quantitative approach is warranted at some point in the future.

Due to the limited connection between surface water and deeper groundwater aquifers, hydrologic data is not required for assessment to groundwater resources near the project site. The lower reaches of the Sulphur River overlay the Carrizo-Wilcox aquifer. Due to the small changes in river stage at downstream locations, the effects on the Carrizo-Wilcox aquifer are likely very small or negligible. If a more detailed quantitative analysis were used in the future, these effects could be quantified using a groundwater model and monthly WAM output due to the longer time scales associated with groundwater flow.

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D-2: Hydrologic and Hydraulic Studies for Lake Ralph Hall

ATTACHMENT 2
HYDROLOGIC AND HYDRAULIC STUDIES OF LAKE RALPH HALL REPORT

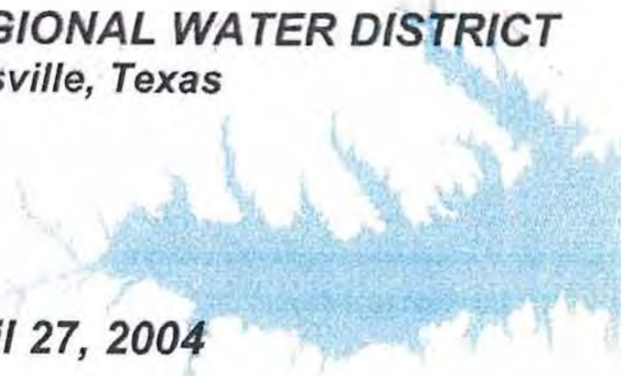
PREPARED BY
R.J. BRANDES COMPANY

UPPER TRINITY
REGIONAL WATER DISTRICT

HYDROLOGIC AND HYDRAULIC STUDIES OF LAKE RALPH HALL

prepared for

UPPER TRINITY REGIONAL WATER DISTRICT
Lewisville, Texas



April 27, 2004

prepared by

R. J. BRANDES COMPANY
Austin, Texas

HYDROLOGIC AND HYDRAULIC STUDIES OF LAKE RALPH HALL

prepared for

UPPER TRINITY REGIONAL WATER DISTRICT

UPPER TRINITY REGIONAL WATER DISTRICT
Lewisville, Texas

April 27, 2004

STATE OF TEXAS
ROBERT J. BRANDES
39120
REGISTERED PROFESSIONAL ENGINEER

04-30-04

prepared by

R. J. BRANDES COMPANY
Austin, Texas

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HYDROLOGIC AND HYDRAULIC STUDIES OF LAKE RALPH HALL

1.0 PROJECT DESCRIPTION

Lake Ralph Hall (the "Project") is being proposed on the North Sulphur River in the Sulphur River Basin in Fannin County, Texas by the Upper Trinity Regional Water District ("UTRWD") for the primary purpose of creating and developing a municipal water supply reservoir. Water from the Project is to be used to meet future water demands within that portion of Fannin County that lies in the Sulphur River Basin and within the service area of the UTRWD in the Trinity River Basin. The use of water from the proposed reservoir in the Trinity River Basin will involve an interbasin transfer across the boundary between the Sulphur and Trinity Basins.

As proposed, Lake Ralph Hall will have a maximum conservation storage capacity of 160,235 acre-feet (at an elevation of 551.0 feet above mean sea level), and at that capacity, the surface area of the reservoir will cover approximately 7,605 acres (or about 11.9 square miles). The maximum depth of the reservoir at the dam will be approximately 90 feet. The firm yield of the Project is estimated to be approximately 32,940 acre-feet/year; however, annual withdrawals from the reservoir may be as much as 45,000 acre-feet/year as the Project is operated in a systems mode with other UTRWD sources of water in order to maximize UTRWD's overall available water supply.

Ralph Hall Dam is to be located on the North Sulphur River approximately 22.5 miles southeast from the city of Bonham, the county seat of Fannin County. Figure 1-1 presents a map of Fannin County that shows the location of the dam and the associated reservoir. An enlarged map of the reservoir area and the boundary of the reservoir is presented in Figure 1-2. The closest city to the Project is Ladonia, which is located approximately 3.5 miles southwest of the dam. The basin boundary of the North Sulphur River upstream of Ralph Hall Dam is delineated on the map of the region in Figure 1-3, along with sub-basin boundaries used in the hydrologic analyses. The total area of this watershed above the dam site is approximately 64,600 acres, or about 100.9 square miles. As shown on the map, the area surrounding and upstream of Lake Ralph Hall is rural and generally undeveloped and used primarily for agriculture, both farming and ranching.

The reach of the North Sulphur River where the Project is to be located is unique because of the river's deep, incised and eroded channel that lies within a fairly broad, flat floodplain. While the depth and width of the river channel vary in the vicinity of the proposed Project, at the proposed dam site it is a steep-walled, deep gorge approximately 40 feet deep and 300 feet wide, with the capacity to fully contain and convey the 100-year flood. The existing river channel has been formed over the years by extensive erosion of a relatively small man-made drainage ditch that was constructed in the late 1920's and early 1930's along the valley of the North Sulphur River to protect and drain agricultural fields. With the impoundment of Lake Ralph Hall, the ongoing erosional processes in the river channel within the reservoir and for some distance downstream will be curtailed.

The proposed structure for Ralph Hall Dam will consist of an earth-filled embankment across the valley of the North Sulphur River with a concrete uncontrolled principal spillway located within the existing channel of the river and a concrete ogee-type emergency spillway located within the

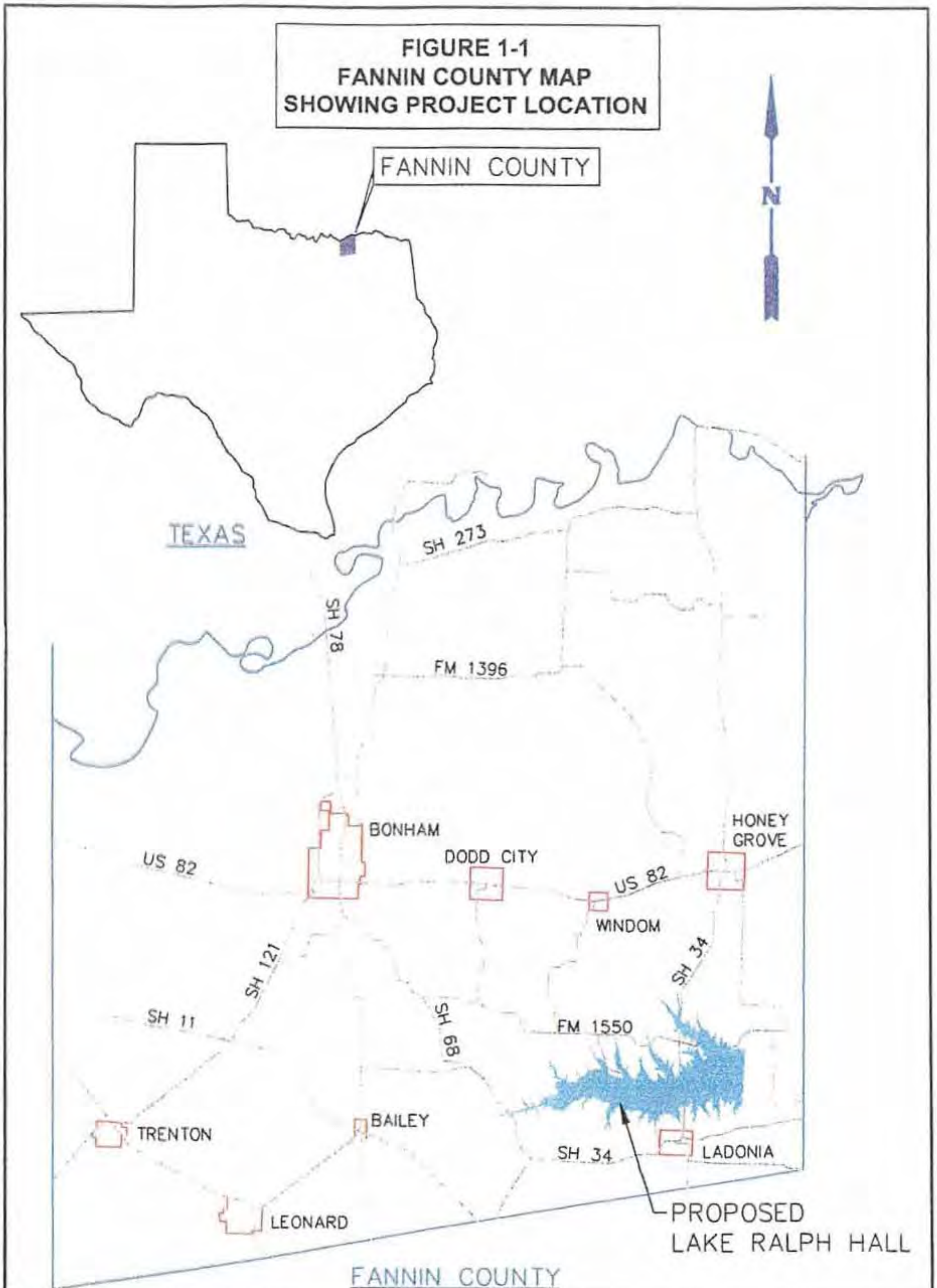


FIGURE 1-1
FANNIN COUNTY MAP
SHOWING PROJECT LOCATION
FANNIN COUNTY
N
TEXAS
SH 273
SH 78
FM 1396
BONHAM
HONEY GROVE
US 82
DODD CITY
US 82
WINDOM
SH 121
SH 34
SH 11
SH 68
FM 1550
TRENTON
BAILEY
SH 34
LADONIA
LEONARD
PROPOSED LAKE RALPH HALL
FANNIN COUNTY

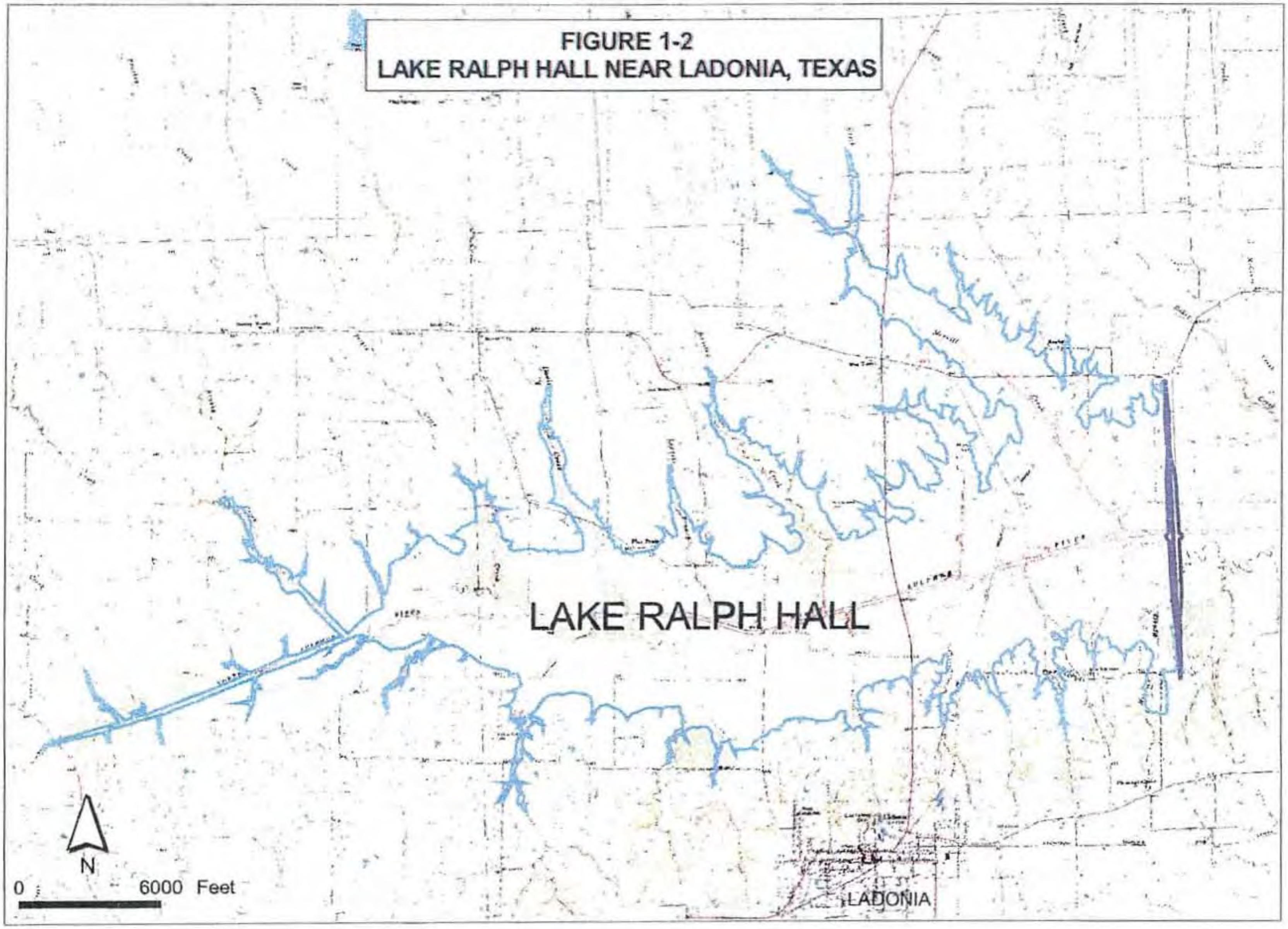
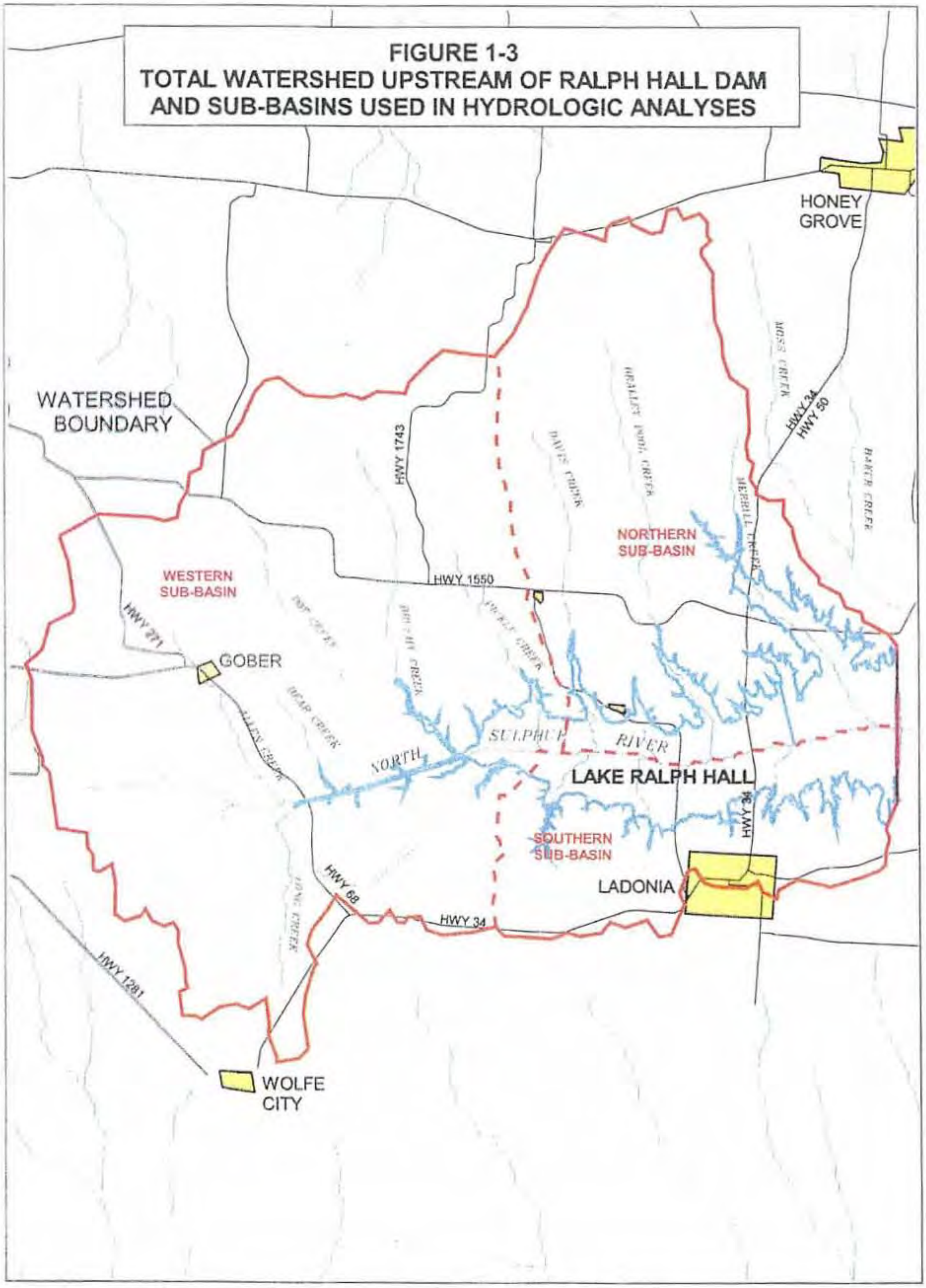


FIGURE 1-2
LAKE RALPH HALL NEAR LADONIA, TEXAS
LAKE RALPH HALL
LADONIA
N
0
6000 Feet

FIGURE 1-3
TOTAL WATERSHED UPSTREAM OF RALPH HALL DAM AND SUB-BASINS USED IN HYDROLOGIC ANALYSES



embankment on the northern floodplain of the river. The top of the dam (embankment) will be at an elevation of 562.0 feet above mean sea level ("msl") and will tie in to existing natural ground on both ends of the structure.

The principal spillway, which is configured as a five-cycle, 300-foot wide trapezoidal labyrinth weir with a total crest length of 827 feet and a crest elevation of 552.0 feet msl, is designed to pass the 100-year flood with only about 3.1 feet of rise in the level of the reservoir above the top of the conservation pool. The downstream end of the center cycle of the labyrinth weir will be lowered by 1.0 foot (to elevation 551.0 feet msl) to provide an 80-foot long service spillway for the dam with the capacity to pass small flood flows (up to approximately the two-year flood). With its crest at elevation 551.0 feet msl, this service spillway will control the maximum level of the conservation pool of the reservoir. An additional low-flow pipe outlet with a gate tower also is to be installed to provide a means for passing low river flows through the dam when the normal overflows through the service spillway are not sufficient to satisfy downstream flow requirements. The low-flow pipe outlet also may be used to provide flows into an abandoned segment of the old river channel downstream of the dam that is being considered for restoration as part of the Project for environmental mitigation purposes.

The crest of the emergency spillway is to be set at an elevation of 554.1 feet msl, i.e., the maximum level of the reservoir during passage of the 100-year flood, and this spillway, combined with the principal spillway, is designed to safely pass the probable maximum flood with approximately 2.0 feet of freeboard. Downstream of the dam, a set of training berms are to be constructed to direct overflows from the emergency spillway across the northern floodplain toward the existing channel of the river.

2.0 RIVER HYDROLOGY

Flows in the North Sulphur River primarily are runoff-driven, although spring discharges do occur for sustained periods following rainfall events. During prolonged dry periods of several months, conditions of no flow persist along substantial reaches of the channel of the North Sulphur River.

There is one streamflow gage located on the North Sulphur River that can be used to characterize and evaluate historical river flow conditions. This gage is operated by the U. S. Geological Survey ("USGS"), and it is referred to as the "North Sulphur River near Cooper, TX" gage (No. 07343000). Mean daily streamflow records from this gage are available since October, 1949. The gage is located approximately 20 river miles downstream of the Ralph Hall Dam site. The total drainage area upstream of this gage covers 276 square miles, which is approximately 175 square miles more than the drainage area above the dam site. The drainage area above the dam site represents 36.6 percent of the total drainage area above the gage.

The mean daily flow in the North Sulphur River at the gage for the period from October, 1950 through September, 2001 is reported by the USGS to have been 261 cubic feet per second ("cfs"), which is equivalent to a mean annual flow of approximately 188,900 acre-feet per year. The median flow of the river for this same period was only 11 cfs, which indicates that the flow in the river has been low much of the time and that significant flood events periodically have occurred and caused the historical mean flow of the river to be relatively high. Statistical analyses of the historical daily flows at this gage indicate that the flow has been zero at least ten percent of the time, and that it has exceeded only 306 cfs approximately ten percent of the time.

Historical monthly flows measured at the gage on the North Sulphur River are plotted on the graph in Figure 2-1. As shown, the monthly river flows have varied considerably obviously in response to rainfall conditions in the basin. Some months the flows have been almost zero, whereas in other months significant flood flows have occurred. These historical monthly flows have provided a substantial part of the hydrologic record that has been used to develop the inflows to Lake Ralph Hall for purposes of evaluating the yield of the reservoir.

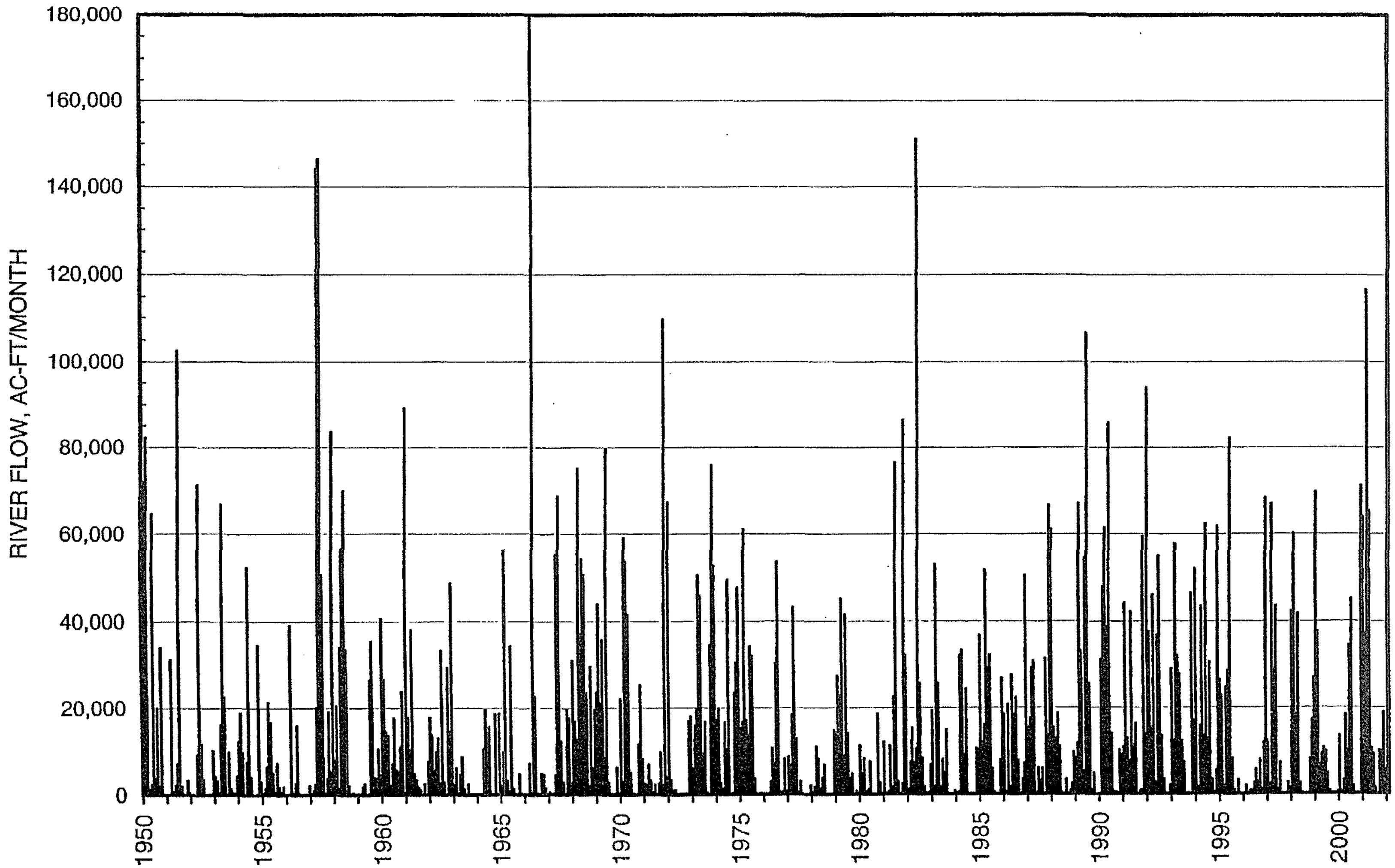
An important aspect of the hydrologic conditions that have occurred historically on the North Sulphur River relates to certain minimum flows that may be necessary to protect the existing aquatic ecosystem of the river. Even though the gage records indicate that river flows have been zero for extended periods of time suggesting that viable communities of aquatic organisms are not likely to have been sustained continuously over time along the river, the construction of Ralph Hall Dam and the operation of Lake Ralph Hall will likely require that certain quantities of river flow be passed through the reservoir, but not released from reservoir storage, in order to protect downstream aquatic resources.

The amounts of these required environmental flows for the Project will be finally determined based on results from in-depth field and analytical studies and future discussions with State regulatory agencies. However, in the mean time, it is considered prudent to include some level of environmental flow requirements in the analysis of the firm yield of Lake Ralph Hall. For this purpose, the default methodology of the Texas Commission on Environmental Quality ("TCEQ"), referred to as the Lyons Method, for establishing preliminary minimum environmental flows in Texas streams has been applied. This method basically assumes that 40 percent of the median daily flow for each of the months of October through February and 60 percent of the median daily flow for each of the months of March through September are adequate to protect existing riverine aquatic resources. Notwithstanding that historical flows in the North Sulphur River often have been less than these levels of flow and, in fact, some times have been zero for extended periods, the Lyons Method has been used to establish preliminary estimates of the required minimum environmental flows for the sole purpose of determining the yield of Lake Ralph Hall.

Results from applying the Lyons Method to the historical flows of the North Sulphur River are summarized in Table 2-1. In this table, the historical median daily flows in the river at the "North Sulphur River near Cooper, TX" gage are listed for each month of the year based on October, 1949 through September, 2002 daily flow records. The corresponding median monthly flows at the dam site are estimated by applying the drainage area ratio for the dam site relative to the gage (0.366). The Lyons monthly flow factors (40% or 60%) then are applied to the monthly median daily flows at the dam site to establish the corresponding preliminary estimates of the required monthly minimum environmental flows for the North Sulphur River at the dam site.

It is the practice of the TCEQ that the minimum environmental flows for a particular stream reach should not be less than the minimum flow that is necessary for application of the State's water quality standards in that particular reach. In this case, the minimum flow required for application of the State's water quality standards in this reach of the North Sulphur River as

FIGURE 2-1
HISTORICAL MONTHLY NORTH SULPHUR RIVER FLOWS AT GAGE NO. 07343000



established by the TCEQ is 0.1 cfs, or approximately 6.0 acre-feet/month. An adjustment for this minimum flow condition is required for the month of August (when the Lyons minimum environmental flow in Table 2-1 is indicated to be less than 0.1 cfs). With this adjustment, the preliminary minimum environmental flows at the dam site that have been used for purposes of the Project yield analyses have been determined and are listed in the far right column of Table 2-1. As shown, these flows range from 0.1 cfs (6 acre-feet/month) during August and September when zero or low river flows often occur up to 7.9 cfs (486 acre-feet/month) during March in the spring when storms typically produce higher flows in the river. The values of the preliminary monthly minimum environmental flows listed in Table 2-1 have been specified as environmental flow requirements in the yield analyses for Lake Ralph Hall, and these are the quantities of river flow that have been passed through the reservoir for environmental purposes, limited to the available inflows to the reservoir.

TABLE 2-1
ANALYSIS OF LYONS ENVIRONMENTAL FLOW REQUIREMENTS

Drainage Area at Ralph Hall Dam Site:	100.9	square miles
Drainage Area at Gage No. 07343000	276.0	square miles
Ratio of Dam-to-Gage Drainage Areas:	0.366	
TCEQ Minimum Flow for Water Quality:	0.1	cfs (7Q2 Flow)
TCEQ Minimum Flow for Water Quality:	6	ac-ft/month

MONTH	MEDIAN * FLOW AT GAGE	MEDIAN FLOW AT DAM SITE	LYONS % OF MEDIAN FLOW	LYONS MINIUMUM ENVIRON. FLOWS AT DAM SITE		PRELIMINARY MINIMUM ENVIRON. FLOWS AT DAM SITE	
	cfs	cfs		cfs	ac-ft	cfs	ac-ft
JAN	26.0	9.5	40%	3.8	211	3.8	211
FEB	40.0	14.6	40%	5.8	325	5.8	325
MAR	36.0	13.2	60%	7.9	486	7.9	486
APR	28.0	10.2	60%	6.1	365	6.1	365
MAY	24.0	8.8	60%	5.3	324	5.3	324
JUN	11.0	4.0	60%	2.4	144	2.4	144
JUL	1.6	0.6	60%	0.4	22	0.4	22
AUG	0.2	0.1	60%	<0.1	3	0.1	6
SEP	0.5	0.2	60%	0.1	7	0.1	7
OCT	1.6	0.6	40%	0.2	14	0.2	14
NOV	9.3	3.4	40%	1.4	81	1.4	81
DEC	20.0	7.3	40%	2.9	180	2.9	180
						Total =	2,164

* Based on 1949-2002 mean daily flow records.

3.0 PROJECT YIELD

The firm annual yield of Lake Ralph Hall has been evaluated using the TCEQ's current version of the Water Availability Model ("WAM") for the Sulphur River Basin. For these analyses, the Run 3 data set, which assumes full utilization of all water rights in the basin and no return flows from municipal and industrial wastewater treatment plants, has been applied. This is the data set that the TCEQ normally would use for evaluating water availability for applications for new or amended surface water appropriations. Lake Ralph Hall has been incorporated into the Sulphur Basin WAM by establishing a new control point on the North Sulphur River at the location of the proposed dam site and assigning appropriate watershed parameters to the control point for the upstream drainage area, i.e., drainage area equal to 100.9 square miles, curve number equal to 70 and mean annual rainfall equal to 43.0 inches. Elevation-area-capacity relationships and the corresponding conservation storage capacity for the proposed reservoir, as determined from a two-foot contour map of the reservoir site prepared specifically for the Project, also were specified in the WAM data file. The elevation-area-capacity relationships for the proposed reservoir are plotted on the graphs in Figure 3-1.

The modified WAM with Lake Ralph Hall included has been operated for a range of maximum conservation storage capacities to develop a relationship between reservoir storage and firm annual yield for Lake Ralph Hall. For these simulations, the maximum elevation of the conservation pool of the reservoir has been assumed to range between elevation 545 feet msl and elevation 552 feet msl, and the corresponding maximum conservation storage capacities have been used in the firm yield analyses. For each maximum conservation storage capacity, iterative simulations with assumed annual demands on the reservoir have been made with the WAM until the firm yield has been determined. For all of these simulations, a municipal-type monthly demand distribution has been used. The resulting yield-versus-conservation storage capacity relationship is plotted on the graph in Figure 3-2.

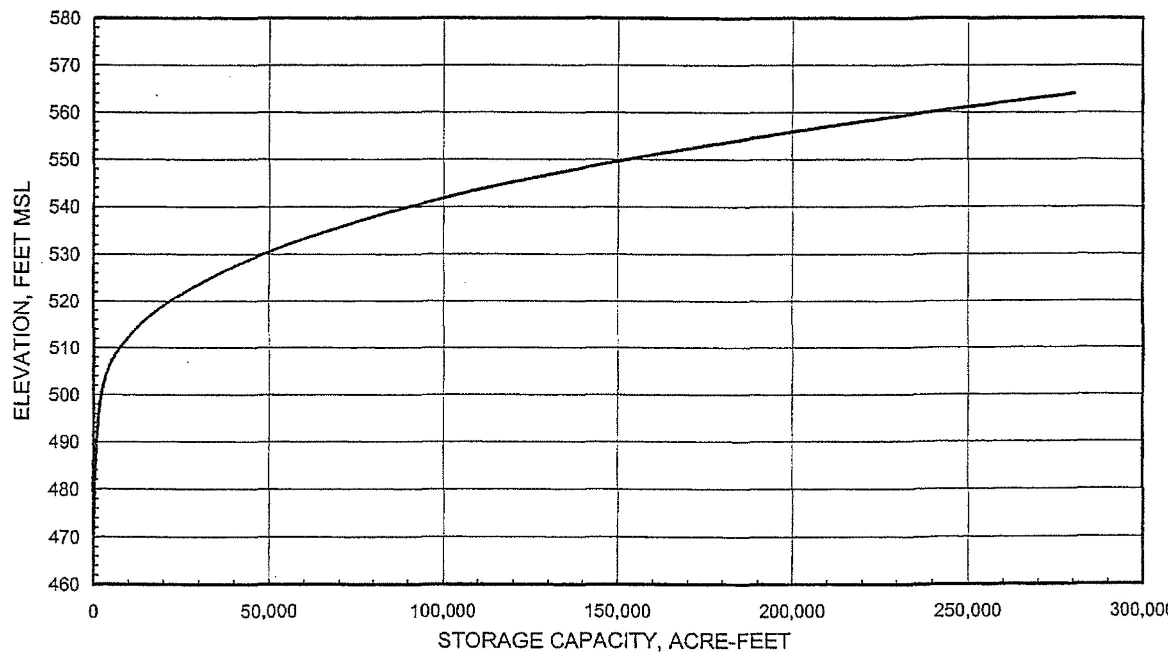
The determination of the final configuration and size of the proposed Lake Ralph Hall and Ralph Hall Dam has involved consideration of the firm yield results depicted in the above graph in conjunction with results from the analysis of the ability of the reservoir to safely pass various design floods as described later in this report. The adopted designs for the service, principal and emergency spillways for the dam correspond to a maximum conservation pool level of 551.0 feet msl and a maximum conservation storage capacity of 160,235 acre-feet. As shown on the graph in Figure 3-2, the resulting firm annual yield for this size reservoir based on the WAM simulations is 32,940 acre-feet/year, and this is the yield that has been used by the UTRWD for purposes of water supply planning relative to Lake Ralph Hall.

4.0 FLOOD MODELING

For analyzing the flood operation aspects of Lake Ralph Hall and Ralph Hall Dam, several different hydrologic and hydraulic models have been developed to represent conditions at the reservoir site. For simulating flood flow hydraulics along the existing channel and floodplain of the North Sulphur River in the vicinity of the reservoir, the Corps of Engineers' HEC-RAS River Analysis System program has been applied. For simulating stormwater runoff hydrographs for the drainage area upstream of the reservoir in response to specified rainfall events and for routing these flood flow hydrographs down the river in the vicinity of the reservoir under existing conditions and through the reservoir under conditions with the Project in place, the Corp of Engineers' HEC-1 Flood Hydrograph Package program has been used.

FIGURE 3-1
LAKE RALPH HALL ELEVATION-STORAGE-SURFACE AREA RELATIONSHIPS

STORAGE CAPACITY VERSUS ELEVATION



SURFACE AREA VERSUS ELEVATION

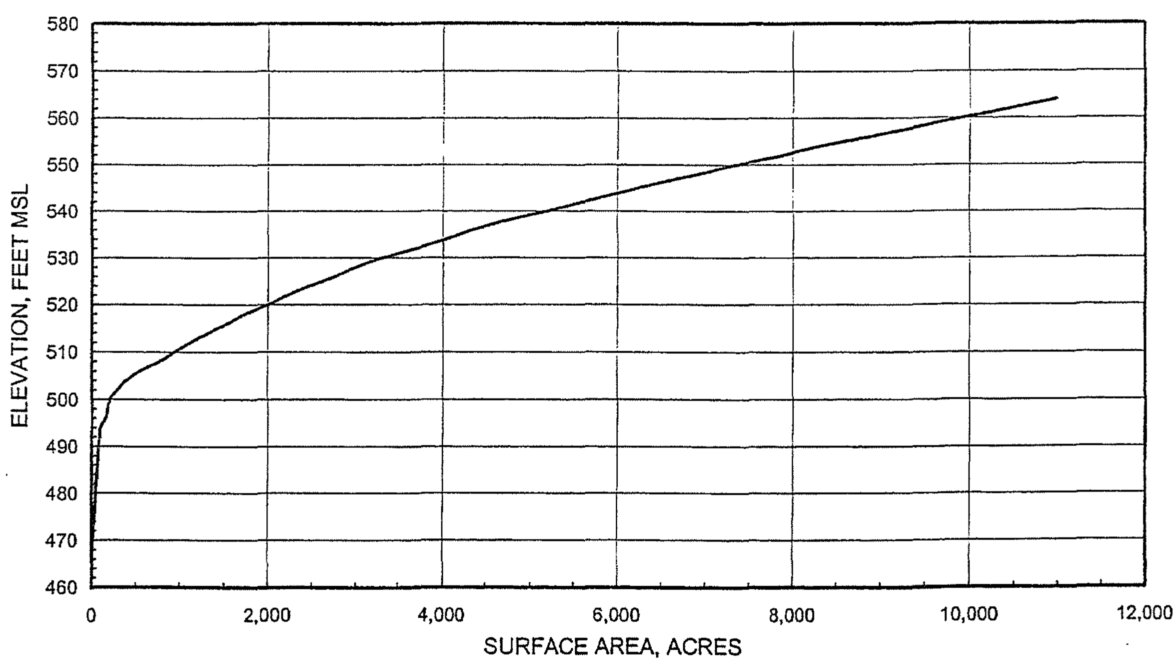
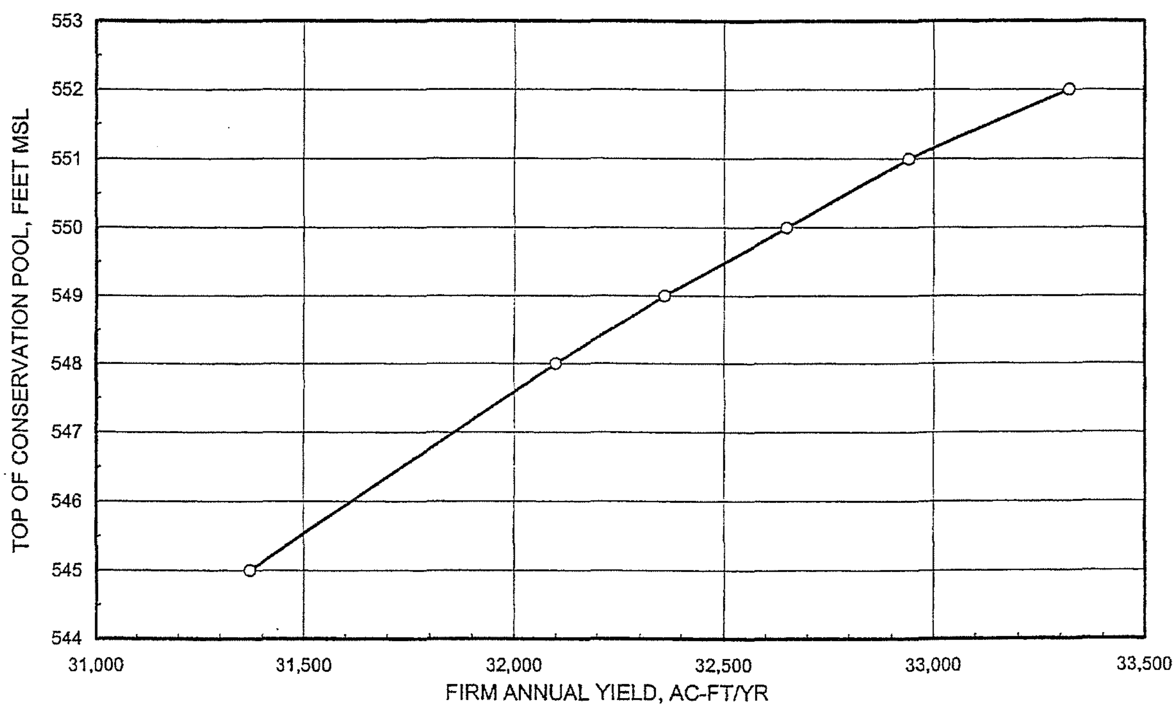


FIGURE 3-2
VARIATION OF PROJECT YIELD WITH CONSERVATION STORAGE CAPACITY



Together, these modeling tools provide the means for evaluating the behavior of the reservoir and the operation of the proposed spillways under different design flood conditions and for assessing the impacts of the Project with respect to flooding along the river both downstream and upstream of the dam.

4.1 HEC-RAS Model

The computational sections used to construct the HEC-RAS model of the reach of the North Sulphur River in the vicinity of the proposed reservoir are delineated on the map of the area in Figure 4-1. There are 32 sections included in the model to describe the geometric configuration and hydraulic roughness condition of the river channel and floodplain through this reach of the river. For each of these sections, geometric data describing the cross-sectional shape of the section have been developed from the two-foot contour map of the reservoir site that was prepared specifically for the Project. These data have been extended to include the higher floodplain areas using available USGS topographic maps of the area.

Manning's "n" roughness coefficients have been assigned to different segments of each of the HEC-RAS computational sections based on inspection of aerial photography of the reservoir area to identify general land use types and vegetation coverage and field observations of actual channel and overbank roughness conditions. Generally, the assigned values of the Manning's

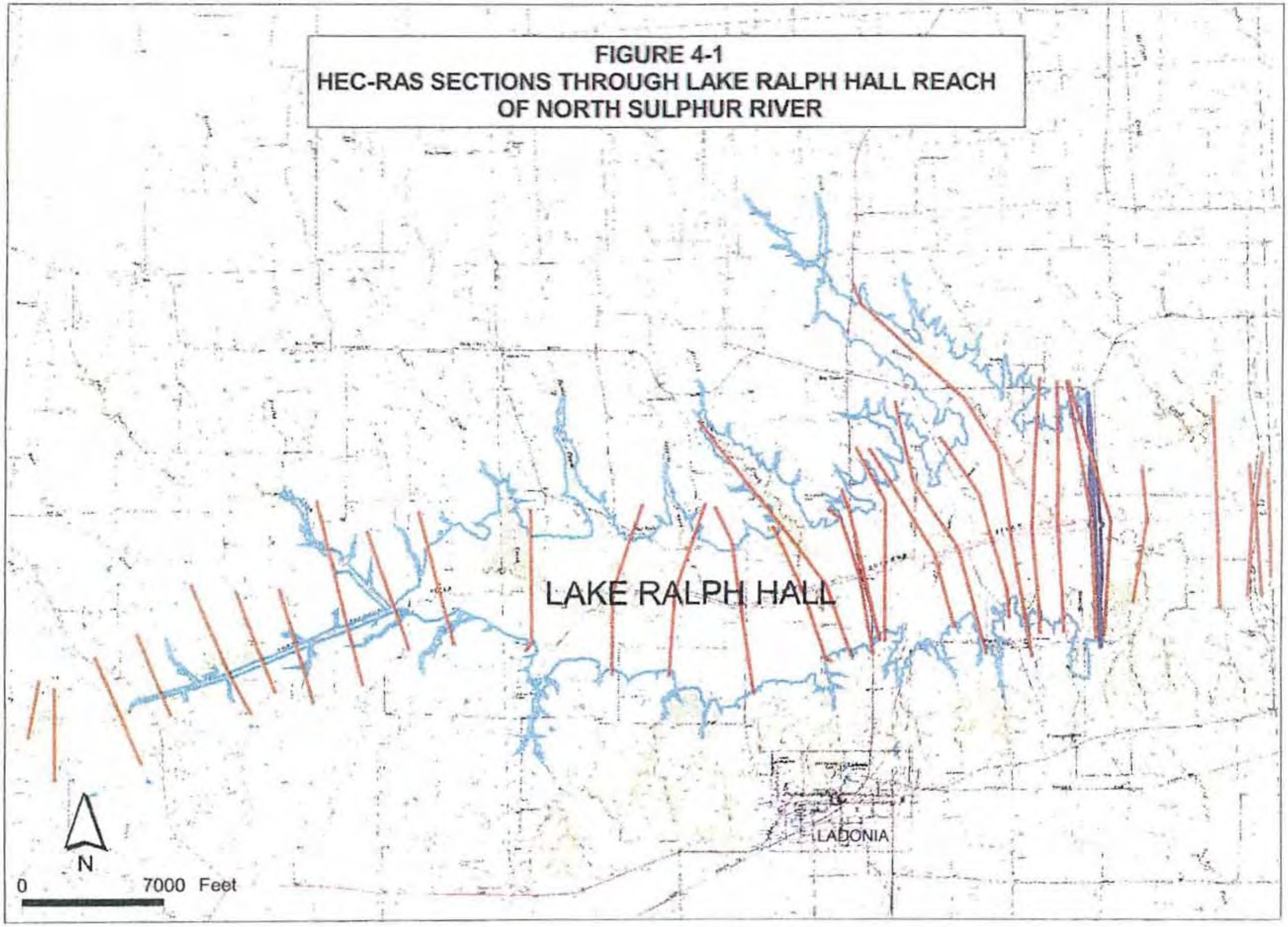
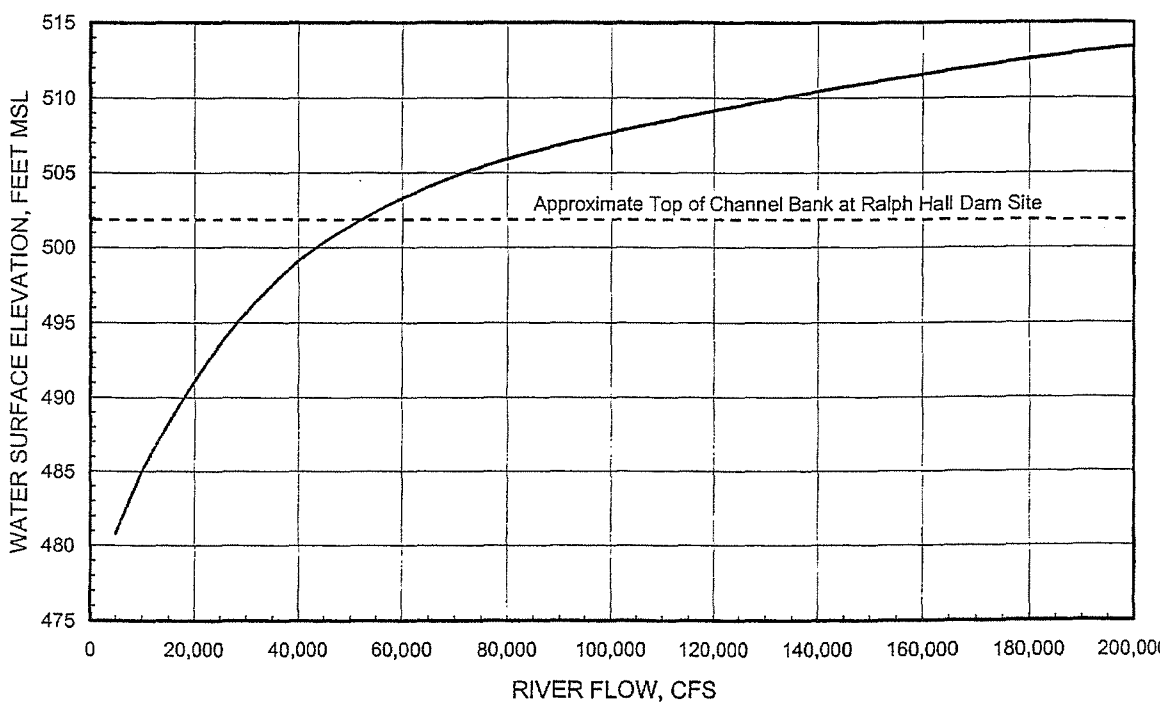


FIGURE 4-1
HEC-RAS SECTIONS THROUGH LAKE RALPH HALL REACH
OF NORTH SULPHUR RIVER
LAKE RALPH HALL
LADONIA
N
0
7000 Feet

"n" parameters used in the HEC-RAS model are on the order of 0.05 for the river channel and in the range of 0.07 for the overbank and floodplain areas.

The HEC-RAS model has been used primarily to investigate flood levels along the river in the vicinity of the reservoir under existing conditions for different levels of river flood flow to establish the flood-carrying capacity of the existing channel and to determine tailwater conditions at the dam site. The graph in Figure 4-2 shows the variation of the water level in the river at the proposed dam site with flow as simulated with the HEC-RAS model. As indicated, river flows on the order of 50,000 cfs begin to overtop of the existing channel banks and cause inundation of the floodplain. HEC-RAS simulations also have been made to establish the storage-versus-discharge relationships for the river that have been used for Modified Puls flood routing in the HEC-1 model.

FIGURE 4-2
WATER SURFACE ELEVATION VERSUS FLOW IN NORTH SULPHUR RIVER
AT PROPOSED RALPH HALL DAM SITE AS SIMULATED WITH HEC-RAS MODEL



4.2 HEC-1 Models

As noted above, two different HEC-1 flood routing models have been developed for the Project. One reflects existing channel and floodplain conditions along the river in the vicinity of Lake Ralph Hall (referred herein as the "existing conditions" HEC-1 model), and the other represents conditions with the proposed reservoir in place with its associated spillways in operation (referred herein as the "reservoir conditions" HEC-1 model).

Both HEC-1 models include the same representation of the upstream watershed that contributes runoff and flood flows to the reach of the river that is to be occupied by the reservoir (as in the case of the existing conditions model) or actually occupied by the reservoir (as in the case of the reservoir conditions model). The existing conditions HEC-1 model routes flood flows from the upstream watershed through this river reach using the Modified Puls method with appropriate storage-versus-discharge relationships derived from the HEC-RAS hydraulic model. The reservoir conditions HEC-1 model routes flood flows from the upstream watershed and rainfall that falls directly on the reservoir surface through the reservoir itself using the level-pool routing procedure in the HEC-1 program. Both models produce a flood flow hydrograph immediately downstream of the proposed dam site. These are the hydrographs that have been compared to evaluate the impacts of the proposed Project on downstream flooding conditions.

For structuring the runoff component of the HEC-1 models, the total Lake Ralph Hall watershed has been divided into three sub-basins to facilitate the description of actual rainfall-runoff processes and the overall hydrologic behavior of the watershed. These sub-basins are referred to as the Western Sub-Basin, the Southern Sub-Basin and the Northern Sub-Basin, and their boundaries are delineated on the map of the region in Figure 1-3. For the existing conditions model, the area of three sub-basins includes the surface area that is to be inundated by Lake Ralph Hall at its normal maximum pool level, i.e., at elevation 551.0 feet msl. For the reservoir conditions model, the area of each of the three sub-basins is reduced by an amount equal to the actual surface area that is to be inundated by Lake Ralph Hall, and a separate (fourth) sub-basin is included in the reservoir conditions model to represent the entire surface area of the reservoir at its normal maximum pool level, i.e., 11.9 square miles.

To model runoff from the Lake Ralph Hall watershed for specified amounts and patterns of rainfall, various hydrologic parameters have been determined and specified as input data to the HEC-1 models. To account for infiltration losses and surface retention within the watershed, the "curve number" method developed by the U. S. Soil Conservation Service ("SCS") has been applied. Soil types and conditions throughout the watershed have been examined using GIS techniques with the SCS's digitized soil classification data base (STATSGO), and this information has been combined with electronic land use data and digital elevation data from the Texas Natural Resources Information System to establish the appropriate runoff curve numbers for each of the sub-basins. For normal antecedent moisture conditions, the resulting curve number values for all the sub-basins have been determined to be approximately 70, and this is the value that has been used each of the sub-basins in the HEC-1 models for all rainfall events except the probable maximum flood. For the PMF, the curve number has been adjusted to reflect wet antecedent moisture conditions, and the adopted value that has been used is 85. For modeling the runoff associated with rainfall directly on the reservoir surface, a curve number value of 100 has been used.

To translate the specified rainfall distribution for a particular storm event to a runoff hydrograph with the HEC-1 model, several different unit hydrograph techniques have been considered, including the SCS dimensionless unit hydrograph approach and the Snyder unit hydrograph method. The Snyder unit hydrograph method was previously used by the Corps of Engineers for developing flood inflow hydrographs for Lakes Jim Chapman and Wright Patman, both of which are located in the Sulphur Basin; therefore, to facilitate comparison and validation of the unit hydrograph parameters for Lake Ralph Hall, the Snyder method also has been adopted for simulating flood inflows to Lake Ralph hall. Values of the required Snyder coefficients for each of the three sub-basins in the Lake Ralph Hall watershed have been established through a process involving detailed analysis of runoff travel times (times of concentration) and watershed characteristics for each of the three sub-basins and consideration of specific Snyder coefficient information for other watersheds in the region. Particular relevance has been given to the parameters developed by the Corps for Lake Jim Chapman, since its watershed is immediately adjacent to the Lake Ralph Hall watershed. The following Snyder coefficients were developed and used by the Corps for Lake Jim Chapman: Ct = 2.5 and Cp640 = 350 (Cp = 0.55).

The time of concentration ("tc") of each of the three sub-basins in the Lake Ralph Hall watershed has been estimated using the SCS procedures outlined in the SCS Technical Release 55 report titled "Urban Hydrology for Small Watersheds" (1986). In accordance with this method, travel time calculations have been made for conditions of sheet flow, shallow concentrated flow and channel flow for each of the sub-basins, and these results have been combined with the wave propagation time for the reservoir to estimate the total time of concentration and SCS lag time (0.6 x tc) for each of the sub-basins. Appendix A of this report contains the spreadsheet calculations that were performed in applying the SCS TR-55 method for estimating the time of concentration for each of the sub-basins, assuming that the proposed reservoir is in place. The resulting time of concentration values, the corresponding SCS lag times and the corresponding Snyder Ct values, based on the standard Snyder equation for lag time ("tp"), are summarized in the following table.

TABLE 4-1
RUNOFF TRAVEL TIME PARAMETERS FOR LAKE RALPH HALL
BASED ON SCS TR-55 METHOD

SUB-BASIN	TIME OF CONCENTRATION (hours)	SCS LAG TIME (hours)	SNYDER Ct COEF
Western	5.34	3.20	1.99
Southern	1.50	0.90	1.34
Northern	4.09	2.45	1.85

The runoff travel time parameters for the Lake Ralph Hall sub-basins also have been derived based on the Snyder Ct value of 2.5 that was adopted and used by the Corps for determining flood inflow hydrographs for Lake Jim Chapman. Using this coefficient value with the standard Snyder tp equation for lag time, the resulting lag times and times of concentrations for the three sub-basins in the Lake Ralph Hall watershed have been determined and are summarized below in Table 4-2.

TABLE 4-2
RUNOFF TRAVEL TIME PARAMETERS FOR LAKE RALPH HALL
BASED ON SNYDER STANDARD LAG TIME EQUATION AND Ct = 2.5

SUB-BASIN	TIME OF CONCENTRATION (hours)	SCS LAG TIME (hours)	SNYDER Ct COEF
Western	6.70	4.02	2.5
Southern	2.78	1.67	2.5
Northern	5.52	3.31	2.5

As noted, the travel time parameters based on the Snyder lag time equation and the Corps' Lake Jim Chapman Ct value are slightly higher than those that were derived based on application of the SCS TR-55 method, but they generally are of the same magnitude. Since Corps guidelines regarding the selection of watershed runoff parameters and other applications of the Snyder unit hydrograph method suggest that values of the Snyder coefficients should be generally consistent within a given region, the final values of the time of concentration and the SCS lag time that have been adopted for simulating flood inflow hydrographs for Lake Ralph Hall have been established based on approximate averages of the values presented in Tables 4-1 and 4-2. The adopted travel time parameters for the Lake Ralph Hall sub-basins with the reservoir in place are listed in the following table.

TABLE 4-3
ADOPTED RUNOFF TRAVEL TIME PARAMETERS FOR LAKE RALPH HALL

SUB-BASIN	TIME OF CONCENTRATION (hours)	SCS LAG TIME (hours)	SNYDER Ct COEF
Western	6.00	3.60	2.24
Southern	2.00	1.20	1.80
Northern	5.00	3.00	2.27

The above travel time parameters for the Lake Ralph Hall sub-basins are specifically applicable to the condition with the proposed reservoir in place. The travel time for flood wave propagation through the reservoir was included in the derivation of the SCS times of concentration. Hence, in order to derive appropriate travel time parameters for the three sub-basins for existing watershed conditions without the reservoir in place, the effects of the flood wave propagation travel time have been removed. As noted in the TR-55 spreadsheet calculations for time of concentration that are included in Appendix A, the travel times associated with flood wave propagation through the reservoir for the three sub-basins were determined to be 0.26 hours for the Western Sub-Basin and 0.10 hours for the Southern and Northern Sub-Basins. Applying these corrections to the adopted travel time parameters for conditions with the reservoir in place that are presented in Table 4-3 produces the corresponding travel time parameters for existing conditions without the reservoir in place as listed in Table 4-4.

TABLE 4-4
ADOPTED EXISTING CONDITIONS RUNOFF TRAVEL TIME PARAMETERS

SUB-BASIN	TIME OF CONCENTRATION (hours)	SCS LAG TIME (hours)	SNYDER Ct COEF
Western	5.74	3.44	2.14
Southern	1.90	1.14	1.71
Northern	4.90	2.94	2.22

As noted previously, the value of the Snyder Cp coefficient that was derived and used by the Corps for Lake Jim Chapman was 0.55, which is equivalent to a Cp640 value of 350. Since this parameter is particularly related to basin storage characteristics that generally tend to be regionally similar and consistent, the same value used by the Corps for Lake Jim Chapman has been adopted for application to all of the Lake Ralph Hall sub-basins.

4.3 Rainfall Data

Rainfall amounts and patterns have been specified in the HEC-1 models using different procedures depending on the magnitude of storm event being simulated and the purpose for which the models were being operated relative to the overall dam and spillway design process. In accordance with SCS and Corps guidelines for simulating runoff from watersheds associated with reservoirs the size of Lake Ralph Hall and for designing these types of structures, the 24-hour rainfall duration has been adopted and used for evaluating alternative spillway designs. Flood inflow hydrographs for the 100-year rainfall event and the probable maximum storm have been simulated with the HEC-1 models and used in the analyses for designing the principal and emergency spillways, respectively. More frequent storm events on the order of the one-year and two-year storms have been used for evaluating the service spillway (low-flow outlet).

Rainfall data for storm magnitudes equal to or less than the 100-year storm have been obtained for the Lake Ralph Hall site from the U. S. Weather Bureau's Technical Paper No. 40[1]. These 24-hour rainfall amounts for different storm return periods are listed in Table 4-5. These data represent historical rainfall conditions at the Lake Ralph Hall site.

TABLE 4-5
24-HOUR RAINFALL AMOUNTS FOR DIFFERENT RETURN PERIODS
AT THE LAKE RALPH HALL SITE

1-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
3.34	4.08	5.50	6.47	7.61	8.56	9.62

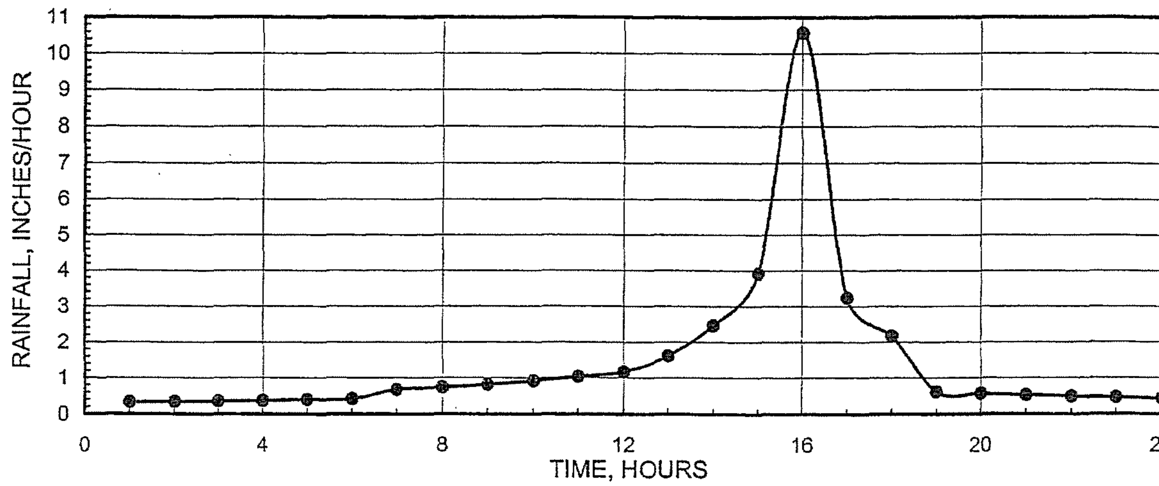
For modeling storm magnitudes equal to or less than the 100-year event, the total 24-hour rainfall amounts have been distributed over the 24-hour duration of the storms using the "balanced storm" method (PH Card) included in the HEC-1 program. In applying this method, rainfall depths for durations of 5, 15 and 60 minutes and 2, 3, 6, 12 and 24 hours have been specified in the HEC-1 data files for each of the storms analyzed. The HEC-1 program automatically constructs a rainfall pattern that positions the higher rainfall intensities during the central part of the storm duration. In effect, this approach produces a temporal rainfall pattern for a given return period that includes in a single storm event all of the rainfall intensities ranging from the 5-minute intensity up to the 24-hour intensity for the same return period, which is very likely less frequent (more extreme) than the return period of the storm actually being analyzed.

For modeling the probable maximum storm ("PMS") event, the procedures outlined in the Corps Hydrologic Engineering Center's "HMR52 Probable Maximum Storm Users Manual" (1983) and included in the HMR-52 computer program (as modified, 1988) have been applied to develop the PMS rainfall characteristics for the Lake Ralph Hall site. The basin boundaries for the watershed upstream of the Ralph Hall Dam have been digitized and used as input to the HMR-52 program along with the basin size and the orientation of the PMS relative to the basin. Rainfall depth-area-duration data for the Lake Ralph Hall watershed have been compiled from the HMR-51 joint report of the Corps and the U. S. Department of Commerce[2]. The HMR-52 program has been operated to generate the 72-hour PMS rainfall pattern for the Lake Ralph Hall site, and in accordance with Corps guidelines, the most severe second-day rainfall distribution has been adopted for simulating the PMF inflows to Lake Ralph Hall. This 24-hour PMS rainfall pattern is plotted on the graph in Figure 4-3 in terms of one-hour rainfall amounts. As shown, the most intense rainfall occurs at hour 16 of the 24-hour period with a maximum of 10.58 inches falling in one hour. The total rainfall for the 24-hour PMS is 34.7 inches.

[1] Hershfield, D.M.; "Rainfall Frequency Atlas for the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years"; U. S. Department of Commerce, Weather Bureau; Washington, D.C.; 1961.

[2] Schreiner, L.D. and J. T. Riedel; "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian"; Hydrometeorological Branch, Office of Hydrology, National Weather Service, U.S. Department of Commerce and Corps of Engineers, U.S. Department of the Army; Washington, D.C.; 1978.

FIGURE 4-3
PATTERN OF HOURLY RAINFALL FOR 24-HOUR PROBABLE MAXIMUM STORM



4.4 Flood Hydrographs

The HEC-1 models have been operated to simulate flood flow hydrographs at the Ralph Hall Dam site under existing conditions without Lake Ralph Hall in place and under reservoir conditions with Lake Ralph Hall in place (but without the flood being routed through the reservoir and proposed spillways). These results are plotted on the graph in Figure 4-4 for the 100-year storm event and in Figure 4-5 for the PMS.

The effect of rainfall directly on the surface of the reservoir is readily apparent on these graphs. With the reservoir in place, the peak flow due to rainfall directly on the reservoir surface occurs before the peak flow due to runoff from the upstream watershed; consequently, the hydrographs exhibits two peaks. Furthermore, the peak flow for the 100-year flood at the dam site is increased from 36,312 cfs under existing conditions to 46,219 cfs with the reservoir in place because of the additional volume of flow produced with rainfall directly on the reservoir. Similarly, for the PMS, the peak flood flow is increased from 176,482 cfs to 206,719 cfs. As discussed in the next section, the combined effects of the reservoir and the proposed spillways substantially reduce the peak outflows from the dam as a result of the temporary storage of a significant portion of the flood inflows as surcharge above the conservation pool.

5.0 DAM AND SPILLWAY DESIGN

For the proposed height of Ralph Hall Dam (approximately 100 feet) and the proposed maximum conservation storage capacity (160,235 acre-feet), the dam safety rules of the TCEQ (Texas Administrative Code, Chapter 299) stipulate that the proposed facility is classified as a "Large" dam and reservoir, which means that the structure must be designed to safely pass the probable maximum flood ("PMF"). Pursuant to this requirement, a system of spillways has been configured and sized for Ralph Hall Dam such that the PMF for the region can be passed through the reservoir without overtopping of the dam structure.

FIGURE 4-4
COMPARISON OF INFLOW HYDROGRAPHS FOR 100-YEAR FLOOD UNDER CONDITIONS WITHOUT AND WITH RALPH HALL RESERVOIR

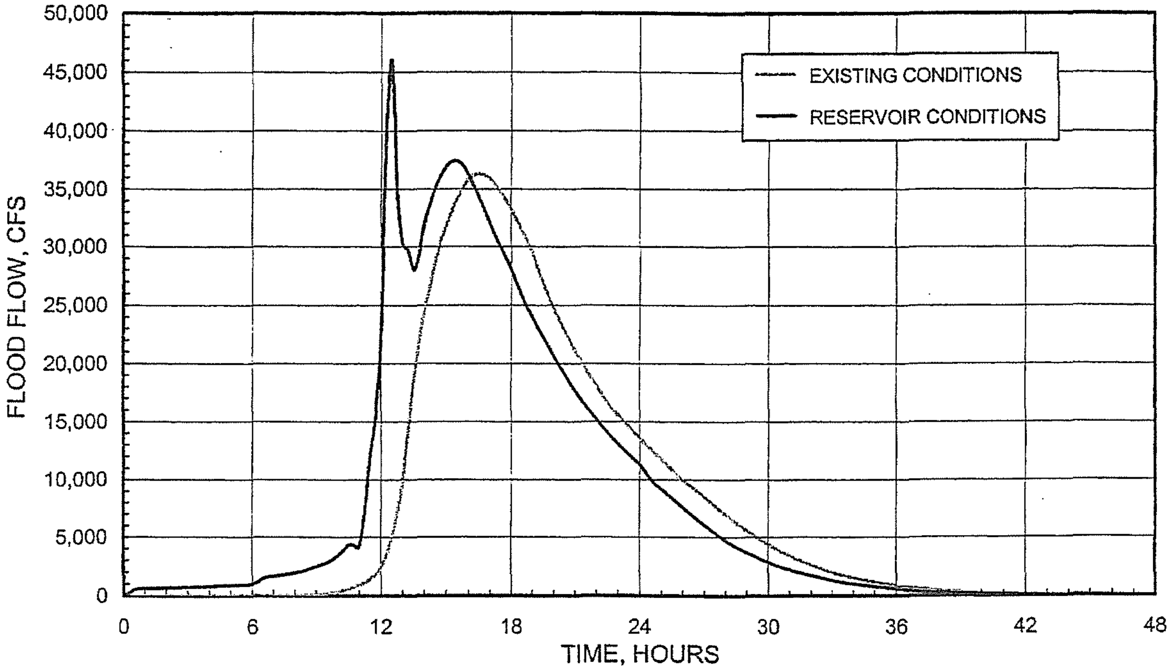
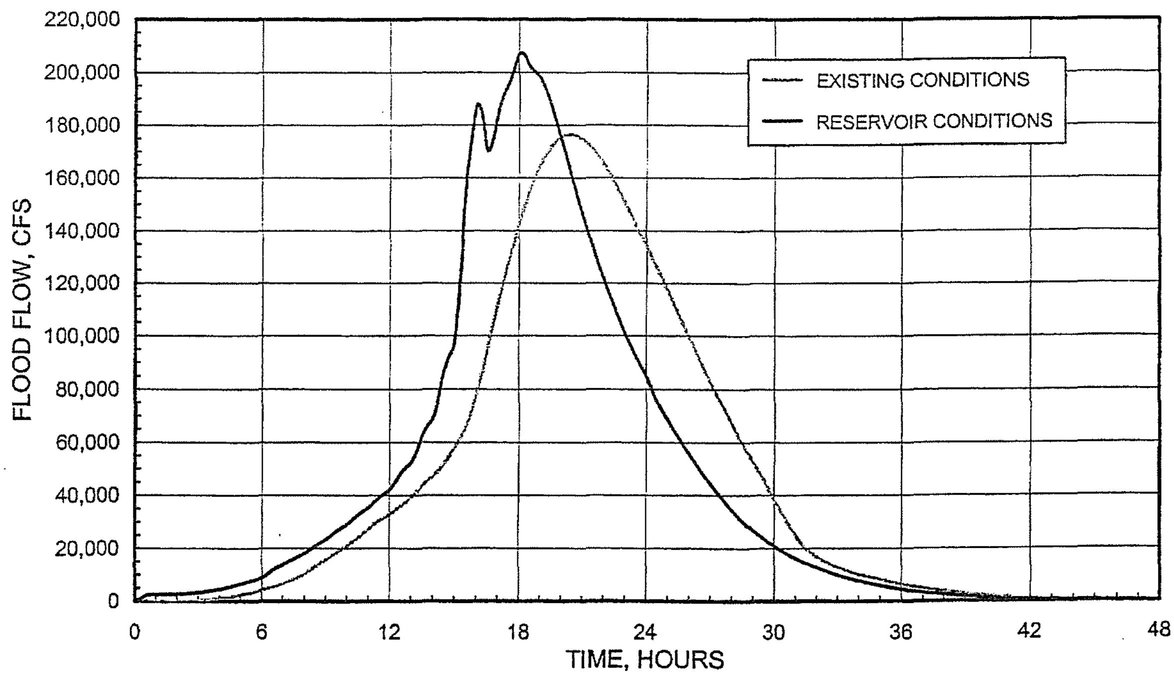


FIGURE 4-5
COMPARISON OF INFLOW HYDROGRAPHS FOR PROBABLE MAXIMUM FLOOD UNDER CONDITIONS WITHOUT AND WITH RALPH HALL RESERVOIR



Analyses using the HEC-1 reservoir conditions model with various sizes, shapes, configurations, and combinations of principal and emergency spillways have been undertaken to establish spillway designs that satisfy the following specific design criteria for the dam.

1) Maximum water surface elevation of the reservoir under PMF design conditions no higher than 560.0 feet msl.
2) Normal maximum operating level of the conservation pool of the reservoir at or above elevation 548.0 feet msl in order to provide acceptable Project yield.
3) Peak outflows from the dam no greater than corresponding peak river flows under existing conditions for similar magnitude storm events.
4) General reduction in peak river flows downstream of the dam to reduce erosion of the existing river channel.
5) Principal spillway capacity adequate to safely pass the 100-year flood, with no flow through the emergency spillway.
6) Principal spillway located within the existing river channel with the spillway design discharge confined to the existing river channel downstream and with an appropriate stilling basin to dissipate outflow energy to acceptable levels.
7) Emergency spillway capacity adequate to safely pass the PMF with at least 2.0 feet of freeboard below the top of the dam structure.
8) Emergency spillway either incorporated into the principal spillway or located separately within the dam on the floodplain of river in a manner that minimizes downstream flooding and erosion impacts.
9) To the extent possible, entirely uncontrolled (ungated) spillways to minimize requirements for onsite operation and monitoring of the dam.

5.1 Dam Structure

The proposed structure for Ralph Hall Dam will consist of an earth-filled embankment with an impervious core. A conceptual drawing showing a typical section of the dam structure is contained in Appendix B as Figure B-1. As shown, the upstream face of the embankment will be constructed with a 3:1 slope (horizontal-to-vertical) and will be protected from wave erosion with a rock riprap blanket. The downstream face will be constructed with a 4:1 slope to improve stability and to facilitate maintenance and mowing activities. The overall top width of the embankment will be 20 feet. Internal drains will be provided to remove any seepage that may accumulate within the downstream slope of the embankment.

5.2 Principal Spillway

As noted earlier, the existing river channel at and below the proposed dam site has the capacity to fully contain and convey the 100-year flood flow. Hence, it is desirable to align the principal spillway with the existing channel of the river in order to be able to discharge outflows from the dam for all flood events up to and including the 100-year flood directly into the existing river channel. This type of spillway configuration has been investigated, and it has been determined that a simple uncontrolled linear ogee crest cannot be used because of the significant crest length required to pass flows on the order of the maximum 100-year flood flow within the maximum head limitations imposed by the design criteria. For example, to pass 30,000 cfs with a maximum head of 4.0 feet requires a crest length on the order of 1,000 feet, which is too long for an effective flow transition from the spillway to the 300-foot wide existing river channel. To align the principal spillway with the river channel requires a spillway width that is generally consistent with the width of the existing channel.

Recognizing this limitation, an alternative design involving the use of a labyrinth weir has been investigated for the principal spillway. For analyzing this type of weir, the design procedures and criteria developed by Tullis, et al[3] at Utah State University have been applied. Numerous combinations of the parameters defining the shape, height, width and number of cycles for trapezoidal labyrinth weirs have been analyzed, and a final design has been adopted that satisfies the specific Tullis design criteria for these types of weirs, as well as the specific design criteria for Ralph Hall Dam. The spreadsheet calculations summarizing the design analyses for the adopted labyrinth weir configuration are presented in Table 5-1. This design provides for a five-cycle trapezoidal labyrinth weir with a cycle width of 60 feet (total spillway width of 300 feet), a weir depth of 70 feet (perpendicular to the axis of the dam), and a wall height for the weir of 10 feet (above a flat approach apron). The total crest length of this labyrinth weir is 827 feet, with the crest of the weir set at elevation 552.0 feet msl, one foot above the top of the conservation pool of Lake Ralph Hall. This one foot of depth in the reservoir provides approximately 7,000 acre-feet of detention storage capacity that is effective in reducing the peak outflow from the reservoir for the 100-year design flood, which, in turn, reduces the required length and discharge capacity of the principal spillway. As indicated by the discharge rating in Table 5-1, the outflow ranges up to almost 45,000 cfs with 8.0 feet of head, i.e., 560.0 feet msl reservoir level.

The discharge rating curve for the principal spillway in Table 5-1 has been incorporated into the reservoir conditions HEC-1 model, and the model has been operated to simulate the behavior of the reservoir and spillway for the 100-year flood. The simulated outflow hydrograph for the 100-year flood is plotted on the graph in Figure 5-1, along with the corresponding hydrograph from the existing conditions HEC-1 model. As shown, the detention storage effects of the reservoir, particularly with the crest of the principal spillway set one foot above the top of the conservation pool, are significant and result in the 100-year peak flow at the dam site being reduced from 36,312 cfs under existing conditions down to only 7,993 cfs with the dam and spillway in place. It is likely that this substantial reduction in peak flood flows downstream of the dam will significantly reduce the potential for erosion of the river channel. For the 100-year flood, the average velocity in the river channel as simulated with the HEC-RAS model is reduced from approximately 6.0 feet per second ("fps") downs to about 4.0 fps as a result of the reservoir.

With the adopted principal spillway in place, the water surface of the reservoir as simulated with the HEC-1 model for the 100-year flood temporarily rises approximately 3.1 feet above the top of the conservation pool to elevation 554.1 feet msl. In accordance with the design criteria for the dam, this is the elevation that has been used to establish the elevation of the crest of the emergency spillway. With this configuration, all reservoir inflows associated with flood

[3] Tullis, J. P., N. Amanian and D. Waldron; "Design of Labyrinth Spillways"; American Society of Civil Engineers, Journal of Hydraulic Engineering, Vol. 121, No. 3; March, 1995.

TABLE 5-1
DESIGN CALCULATIONS FOR DEVELOPING DISCHARGE RATING FOR TRAPEZOIDAL LABYRINTH WEIR

RESERVOIR WATER SURFACE ELEV. feet msl	H U/S HEAD feet	a APEX HALF LENGTH feet	W CYCLE WIDTH feet	2a/W APEX RATIO < 0.08	B SIDE-WALL LENGTH feet	S DEPTH OF WEIR feet	L CYCLE CREST LENGTH feet	M =L/W RATIO 2 ? M ? 10	α WALL ANGLE > 6° degrees	Ld DISTURB LENGTH feet	Ld/B DISTURB LENGTH RATIO ? 0.3	P U/S WALL HEIGHT feet	H/P RATIO < 0.9	W/P RATIO > 2.5	Ct DISCHG COEF α (23.3)	Ct DISCH COEF α (90°)	ε EFFI-CACY	Q DISCHG PER CYCLE cfs	N NO. OF CYCLES	LT TOTAL CREST LENGTH feet	TOTAL DISCHG FOR WEIR cfs
552.0	0.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	0.0	0.00	10	0	6.0	0.49	0.49	2.76	0	5	827	0
552.5	0.5	4	60	0.13	74.7	70.0	165.4	2.8	17.4	1.2	0.02	10	0.05	6.0	0.54	0.56	2.69	170	5	827	850
553.0	1.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	2.5	0.03	10	0.1	6.0	0.58	0.61	2.61	513	5	827	2,565
554.0	2.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	4.9	0.07	10	0.2	6.0	0.61	0.69	2.44	1,532	5	827	7,658
554.1	2.1	4	60	0.13	74.7	70.0	165.4	2.8	17.4	5.2	0.07	10	0.21	6.0	0.61	0.70	2.42	1,650	5	827	8,251
554.5	2.5	4	60	0.13	74.7	70.0	165.4	2.8	17.4	6.2	0.08	10	0.25	6.0	0.61	0.72	2.35	2,143	5	827	10,716
555.0	3.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	7.4	0.10	10	0.3	6.0	0.61	0.74	2.27	2,787	5	827	13,936
556.0	4.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	9.9	0.13	10	0.4	6.0	0.58	0.76	2.11	4,096	5	827	20,478
557.0	5.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	12.3	0.16	10	0.5	6.0	0.54	0.76	1.96	5,358	5	827	26,792
558.0	6.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	14.8	0.20	10	0.6	6.0	0.50	0.76	1.84	6,560	5	827	32,799
559.0	7.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	17.2	0.23	10	0.7	6.0	0.47	0.75	1.73	7,741	5	827	38,707
560.0	8.0	4	60	0.13	74.7	70.0	165.4	2.8	17.4	19.7	0.26	10	0.8	6.0	0.45	0.76	1.63	8,959	5	827	44,794

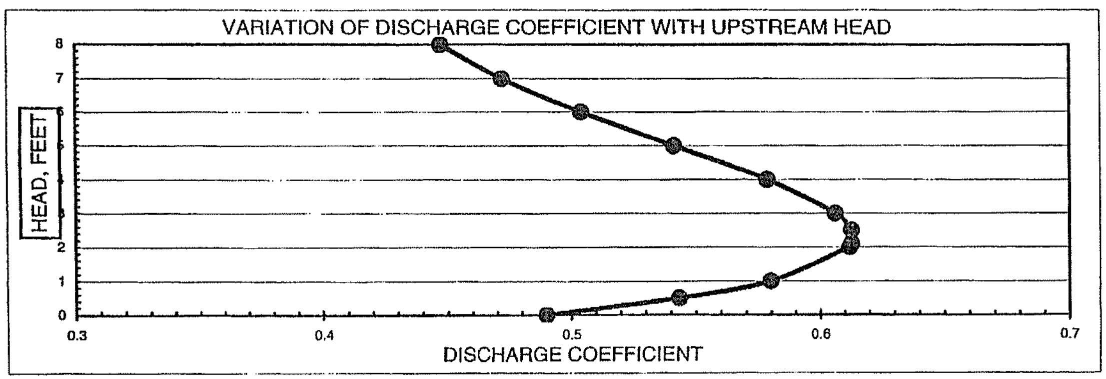
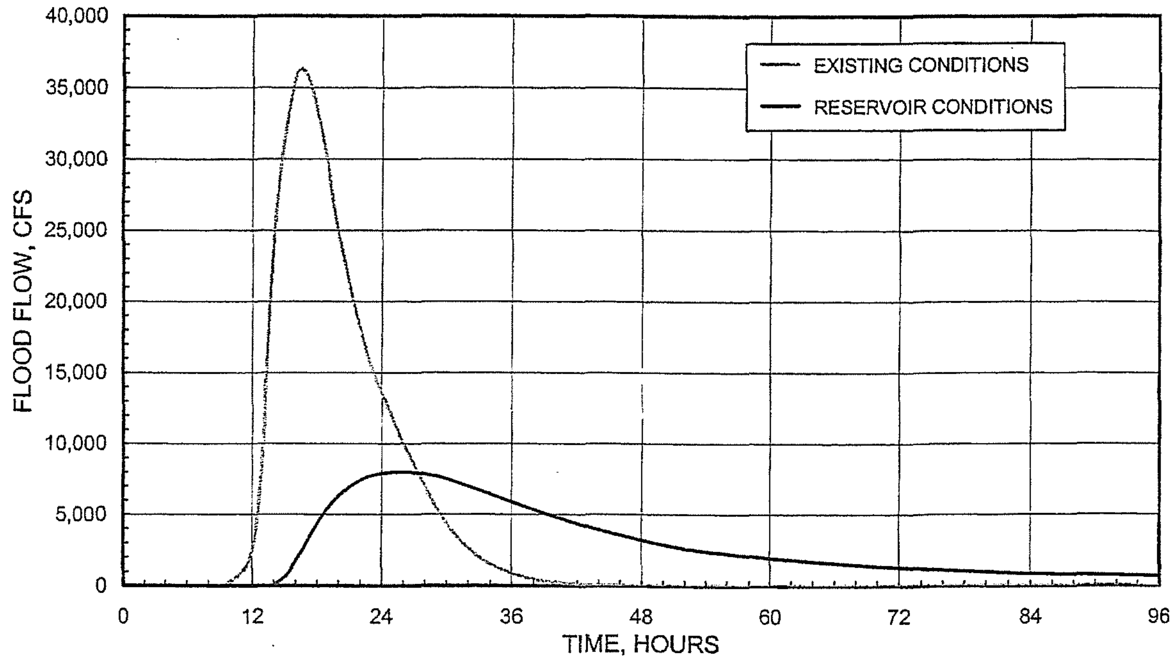


FIGURE 5-1
COMPARISON OF OUTFLOW HYDROGRAPH FROM PRINCIPAL SPILLWAY
WITH EXISTING RIVER HYDROGRAPH FOR 100-YEAR FLOOD



magnitudes up to and including the 100-year flood will be passed through the reservoir and discharged entirely through the principal spillway. Reservoir inflows from larger storms will be discharged through both the principal spillway and the emergency spillway.

Conceptual drawings showing the primary features and general dimensions of the principal spillway are included in Appendix B. The plan view in Figure B-2 shows a segment of the dam embankment, the five-cycle trapezoidal labyrinth weir that serves as the primary flow control structure, the discharge chute that provides the transition section between the weir and the stilling basin, and the stilling basin (U.S. Bureau of Reclamation Type II) where energy associated with the high velocity chute flows is dissipated prior to the flows being discharged downstream. As shown, approximately 400 feet of rock riprap is provided downstream of the stilling basin to protect the natural river channel. A cross section view of these same features is presented on the drawing in Figure B-3.

5.3 Service Spillway

As shown on the plan view of the principal spillway in Figure B-2 in Appendix B, the crest of the downstream end of the center cycle of the labyrinth weir is to be lowered one foot to elevation 551.0 feet msl (the top of the conservation pool) to provide a service spillway for the dam. This service spillway section is to have a total length of 80.0 feet (36.0 feet on each wall of the central weir plus 8.0 feet at the end of the central weir). With normal inflows to the reservoir, the service spillway will limit the normal maximum level of the reservoir to the top of the conservation pool. Simulations with the reservoir conditions HEC-1 model with this service spillway included indicate that the spillway, with one foot of head, will be able to pass the peak flow for approximately the two-year flood event.

5.4 Low-Flow Outlet

A low-flow pipe outlet with a gate tower is to be installed as part of the dam to provide a means for passing river flows through the reservoir when the normal overflows through the service spillway are not sufficient to satisfy downstream flow requirements. This pipe outlet will have the capacity to discharge sufficient flow as may be required to satisfy downstream minimum environmental flows and/or flows for downstream senior water rights, and it will discharge directly into the stilling basin below the principal spillway to allow the flows to pass downstream in the river. A separate pipe with a control valve may be incorporated into the low-flow pipe outlet to provide a mechanism for passing reservoir inflows into an abandoned segment of the old river channel immediately downstream of the dam that is being considered for restoration as part of the Project for environmental mitigation purposes.

5.5 Emergency Spillway

The emergency spillway for the dam has been designed to provide the additional outflow capacity, above that provided by the principal spillway, necessary to safely pass the PMF without causing the maximum level of the reservoir to exceed elevation 560.0 feet msl. The adopted design consists of a concrete ogee spillway within the northern embankment of the dam with a crest elevation of 554.1 feet msl, i.e., the 100-year flood level. To pass the PMF, the required length of the ogee crest of the emergency spillway has been determined to be 1,550 feet. The calculations for the discharge rating of this spillway are summarized in Table 5-2.

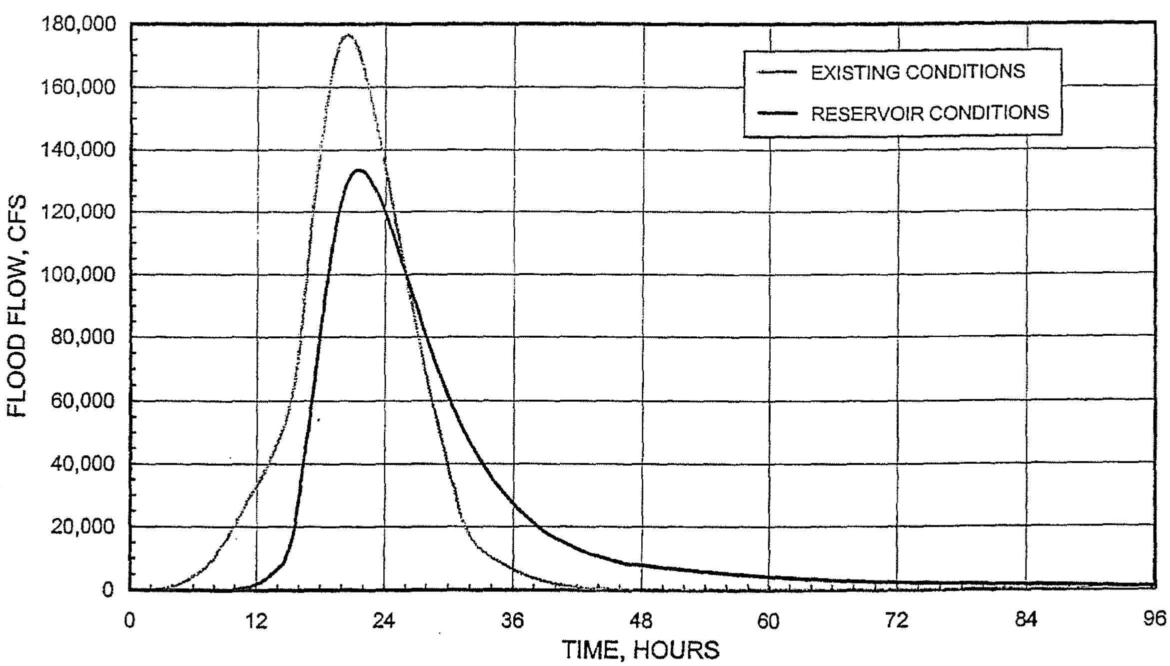
TABLE 5-2
DISCHARGE RATING CALCULATIONS FOR EMERGENCY SPILLWAY

RESERVOIR WATER SURFACE ELEVATION feet msl	HEAD ABOVE SPILLWAY CREST feet	HEAD-TO MAXIMUM HEAD RATIO	OGEE DISCHARGE COEF.	LENGTH OF WEIR feet	DISCHARGE OVER WEIR cfs
554.1	0.0	0.00	3.00	1,550	0
554.5	0.4	0.07	3.00	1,550	1,176
555.0	0.9	0.15	3.05	1,550	4,036
556.0	1.9	0.32	3.37	1,550	13,680
557.0	2.9	0.49	3.59	1,550	27,480
558.0	3.9	0.66	3.77	1,550	45,006
559.0	4.9	0.83	3.90	1,550	65,568
560.0	5.9	1.00	4.00	1,550	88,853

With this emergency spillway incorporated into the reservoir conditions HEC-1 model, along with the principal spillway, the PMF has been simulated and routed through the reservoir and spillway system. The resulting outflow hydrograph is plotted on the graph in Figure 5-2 along with the corresponding hydrograph at the dam site for existing conditions without the reservoir in place. As shown, the combined effects of the outflow control provided by the principal and emergency spillways and the corresponding detention storage provided by the reservoir cause the peak flow of the PMF to be reduced from 176,482 cfs under existing conditions down to 133,571 cfs with Lake Ralph Hall in place. By design, the maximum water surface elevation of the reservoir during passage of the PMF as simulated with the HEC-1 model is 560.0 feet msl, which is 2.0 feet below the proposed top of the dam.

The location and general layout of the emergency spillway within the northern embankment of the dam are shown on the drawing in Figure B-4 in Appendix B. As indicated, the spillway is located where natural ground elevations are not substantially lower than the top of the embankment, thus minimizing the spillway height and stilling basin requirements. Training berms are to be constructed downstream of the spillway to direct floodwaters discharged from the spillway toward the existing river channel. Some grading of the area within the training berms may be required to provide a more uniform flow transition to the river channel, and this grading will be finalized as part of the development of the material balance for the Project. Details and dimensions of the various features of the emergency spillway are shown on the plan view drawing in Figure B-5 and the section view drawing in Figure B-6. As with the principal spillway, the emergency spillway includes a stilling basin (U.S. Bureau of Reclamation Type III) immediately below the ogee weir and rock riprap for 150 feet downstream of the stilling basin to protect the natural ground from erosion by the spillway discharges. Figure B-7 shows plan and profile views of the entire embankment of the dam with the different spillways identified.

FIGURE 5-2
COMPARISON OF OUTFLOW HYDROGRAPH FROM RALPH HALL DAM
WITH EXISTING RIVER HYDROGRAPH FOR PROBABLE MAXIMUM FLOOD



APPENDIX A

TIME OF CONCENTRATION CALCULATIONS FOR LAKE RALPH HALL SUB-BASINS USING SCS TR-55 METHODS

TIME OF CONCENTRATION CALCULATIONS BASED ON SCS TR55 METHOD

(adjusted based on experience and engineering judgement)

PROJECT: **Lake Ralph Hall** WATERSHED: **1 - Western Drainage Area**

SUMMARY OF TIME OF CONCENTRATION CALCULATIONS

SHEET FLOW	0.75	hours
SHALLOW FLOW	1.03	hours
CHANNEL FLOW	3.56	hours
RESERVOIR	0.26	hours
Total Tc	5.34	hours
SCS LAG TIME	3.20	hours

SHEET FLOW:

MANNING'S "N" CALCULATION

Undeveloped Land Use	n value	% Land use	Inc n
Conc.,gravvel,asphalt,bare soil	0.011	**0**	0.000
Grass Short Prairie	0.150	**10**	0.015
Grass dense	0.240	**40**	0.096
Grass bermuda	0.410	**10**	0.041
Woods Light Underbrush	0.400	**30**	0.120
Woods Dense Underbrush	0.800	**10**	0.080
		100	0.352

COMPUTED WEIGHTED "N" VALUE	0.352		
FLOW PATH LENGTH	**300**	feet	MAX 300'
2 YR 24 HOUR PRECIP	**4.1**	inches	FROM TP40
SLOPE	**0.01000**	feet/foot	
COMPUTED TRAVEL TIME	0.91	hours	USE **0.75**

SHALLOW CONCENTRATED FLOW:

1=PAVED; 2=UNPAVED	**2**	
FLOW PATH LENGTH	**5,300**	feet
SLOPE	**0.00792**	feet/foot
VELOCITY FROM FIGURE 3.1=	1.4	feet/sec
COMPUTED TRAVEL TIME	1.03	

PROJECT: **Lake Ralph Hall** WATERSHED: **1 - Western Drainage Area**

CHANNEL FLOW:

REACH 1

BOTTOM WIDTH	**20**	feet
DEPTH	**3**	feet
TOPWIDTH	**35**	feet
CALCULATED SIDE SLOPE (X:1)	2.50	feet/foot
CALCULATED CROSS-SECTION ARE	82.5	sq. feet
CALCULATED WETTED PERIMETER	36.2	feet
CHANNEL SLOPE	**0.00617**	feet/foot
MANNINGS N	**0.085**	
COMPUTED VELOCITY	2.4	feet/sec
CHANNEL LENGTH	**8,100**	feet
COMPUTED TRAVEL TIME	0.94	hours

REACH 2

BOTTOM WIDTH	**30**	feet
DEPTH	**4**	feet
TOPWIDTH	**50**	feet
CALCULATED SIDE SLOPE (X:1)	2.50	feet/foot
CALCULATED CROSS-SECTION ARE	160	sq. feet
CALCULATED WETTED PERIMETER	51.5	feet
CHANNEL SLOPE	**0.00495**	feet/foot
MANNINGS N	**0.080**	
COMPUTED VELOCITY	2.8	feet/sec
CHANNEL LENGTH	**10,100**	feet
COMPUTED TRAVEL TIME	1.01	hours

REACH 3

BOTTOM WIDTH	**50**	feet
DEPTH	**5**	feet
TOPWIDTH	**60**	feet
CALCULATED SIDE SLOPE (X:1)	1.00	feet/foot
CALCULATED CROSS-SECTION ARE	275	sq. feet
CALCULATED WETTED PERIMETER	64.1	feet
CHANNEL SLOPE	**0.00370**	feet/foot
MANNINGS N	**0.075**	
COMPUTED VELOCITY	3.2	feet/sec
CHANNEL LENGTH	**8,100**	feet
COMPUTED TRAVEL TIME	0.71	hours

PROJECT: **Lake Ralph Hall** WATERSHED: **1 - Western Drainage Area**

REACH 4			
HEC-RAS COMPUTED VELOCITY	**4.3**	feet/sec	(HEC-RAS, Q=120,000 (
CHANNEL LENGTH	**14,000**	feet	
COMPUTED TRAVEL TIME	0.90	hours	
RESERVOIR:			
AVE. RESERVOIR DEPTH OVER REA(	**45**	feet	~ (550-465)/2
GRAVITY ACCELERATION	**32.2**	feet/sec-sec	
WAVE CELERITY	38.1	feet/sec	c =(g*Davg)^0.5
LENGTH	**35,000**	feet	
COMPUTED TRAVEL TIME	0.26	hours	

TIME OF CONCENTRATION CALCULATIONS BASED ON SCS TR55 METHOD

(adjusted based on experience and engineering judgement)

PROJECT: **Lake Ralph Hall** WATERSHED: **2 - Southern Drainage Area**

SUMMARY OF TIME OF CONCENTRATION CALCULATIONS

SHEET FLOW	0.75	hours
SHALLOW FLOW	0.17	hours
CHANNEL FLOW	0.58	hours
RESERVOIR	0.10	hours
Total Tc	1.50	hours
SCS LAG TIME	0.90	hours

SHEET FLOW:

MANNING'S "N" CALCULATION

Undeveloped Land Use	n value	% Land use	Inc n
Conc.,gravvel,asphalt,bare soil	0.011	**0**	0.000
Grass Short Prairie	0.150	**10**	0.015
Grass dense	0.240	**40**	0.096
Grass bermuda	0.410	**10**	0.041
Woods Light Underbrush	0.400	**30**	0.120
Woods Dense Underbrush	0.800	**10**	0.080
		100	0.352

COMPUTED WEIGHTED "N" VALUE	0.352			
FLOW PATH LENGTH	**300**	feet		MAX 300'
2 YR 24 HOUR PRECIP	**4.1**	inches		FROM TP40
SLOPE	**0.00500**	feet/foot		
COMPUTED TRAVEL TIME	1.20	hours	USE:	**0.75**

SHALLOW CONCENTRATED FLOW:

1=PAVED; 2=UNPAVED	**2**	
FLOW PATH LENGTH	**1,400**	feet
SLOPE	**0.02140**	feet/foot
VELOCITY FROM FIGURE 3.1=	2.4	feet/sec
COMPUTED TRAVEL TIME	0.17	

PROJECT: **Lake Ralph Hall** WATERSHED: **2 - Southern Drainage Area**

CHANNEL FLOW:

REACH 1

BOTTOM WIDTH	**20**	feet
DEPTH	**3**	feet
TOPWIDTH	**35**	feet
CALCULATED SIDE SLOPE (X:1)	2.50	feet/foot
CALCULATED CROSS-SECTION AREA	83	sq. feet
CALCULATED WETTED PERIMETER	36.2	feet
CHANNEL SLOPE	**0.0161**	feet/foot
MANNINGS N	**0.075**	
COMPUTED VELOCITY	4.4	feet/sec
CHANNEL LENGTH	**6,100**	feet
COMPUTED TRAVEL TIME	0.39	hours

REACH 2

BOTTOM WIDTH	**70**	feet
DEPTH	**8**	feet
TOPWIDTH	**100**	feet
CALCULATED SIDE SLOPE (X:1)	1.88	feet/foot
CALCULATED CROSS-SECTION AREA	680	sq. feet
CALCULATED WETTED PERIMETER	104.0	feet
CHANNEL SLOPE	**0.00500**	feet/foot
MANNINGS N	**0.065**	
COMPUTED VELOCITY	5.7	feet/sec
CHANNEL LENGTH	**4,000**	feet
COMPUTED TRAVEL TIME	0.20	hours

RESERVOIR:

AVE. RESERVOIR DEPTH	**55**	feet	
GRAVITY ACCELERATION	**32.2**	feet/sec-sec	
WAVE CELERITY	42.1	feet/sec	c =(g*Davg)^0.5
LENGTH	**15,000**	feet	
COMPUTED TRAVEL TIME	0.10	hours	

TIME OF CONCENTRATION CALCULATIONS BASED ON SCS TR55 METHOD

(adjusted based on experience and engineering judgement)

PROJECT: **Lake Ralph Hall** WATERSHED: **3 - Northern Drainage Area**

SUMMARY OF TIME OF CONCENTRATION CALCULATIONS

SHEET FLOW	0.75	hours
SHALLOW FLOW	0.35	hours
CHANNEL FLOW	2.99	hours
RESERVOIR	0.10	hours
Total Tc	4.09	hours
SCS LAG TIME	2.45	hours

SHEET FLOW:

MANNING'S "N" CALCULATION

Undeveloped Land Use	n value	% Land use	Inc n
Conc.,gravvel,asphalt,bare soil	0.011	**0**	0.000
Grass Short Prairie	0.150	**10**	0.015
Grass dense	0.240	**40**	0.096
Grass bermuda	0.410	**10**	0.041
Woods Light Underbrush	0.400	**30**	0.120
Woods Dense Underbrush	0.800	**10**	0.080
		100	0.352

COMPUTED WEIGHTED "N" VALUE	0.352			
FLOW PATH LENGTH	**300**	feet		MAX 300'
2 YR 24 HOUR PRECIP	**4.1**	inches		FROM TP40
SLOPE	**0.01670**	feet/foot		
COMPUTED TRAVEL TIME	0.74	hours	USE:	**0.75**

SHALLOW CONCENTRATED FLOW:

1=PAVED; 2=UNPAVED	**2**	
FLOW PATH LENGTH	**2,000**	feet
SLOPE	**0.01000**	feet/foot
VELOCITY FROM FIGURE 3.1=	1.6	feet/sec
COMPUTED TRAVEL TIME	0.35	

PROJECT: **Lake Ralph Hall** WATERSHED: **3 - Northern Drainage Area**

CHANNEL FLOW:

REACH 1

BOTTOM WIDTH	**35**	feet
DEPTH	**4**	feet
TOPWIDTH	**45**	feet
CALCULATED SIDE SLOPE (X:1)	1.25	feet/foot
CALCULATED CROSS-SECTION AREA	160	sq. feet
CALCULATED WETTED PERIMETER	47.8	feet
CHANNEL SLOPE	**0.0038**	feet/foot
MANNINGS N	**0.075**	
COMPUTED VELOCITY	2.7	feet/sec
CHANNEL LENGTH	**18,300**	feet
COMPUTED TRAVEL TIME	1.86	hours

REACH 2

BOTTOM WIDTH	**45**	feet
DEPTH	**5**	feet
TOPWIDTH	**55**	feet
CALCULATED SIDE SLOPE (X:1)	1.00	feet/foot
CALCULATED CROSS-SECTION AREA	250	sq. feet
CALCULATED WETTED PERIMETER	59.1	feet
CHANNEL SLOPE	**0.00448**	feet/foot
MANNINGS N	**0.065**	
COMPUTED VELOCITY	4.0	feet/sec
CHANNEL LENGTH	**16,400**	feet
COMPUTED TRAVEL TIME	1.14	hours

RESERVOIR:

AVE. RESERVOIR DEPTH	**55**	feet	
GRAVITY ACCELERATION	**32.2**	feet/sec-sec	
WAVE CELERITY	42.1	feet/sec	c =(g*Davg)^0.5
LENGTH	**15,000**	feet	
COMPUTED TRAVEL TIME	0.10	hours	

TIME OF CONCENTRATION CALCULATIONS BASED ON HEC-RAS VELOCITIES

(adjusted based on experience and engineering judgement)

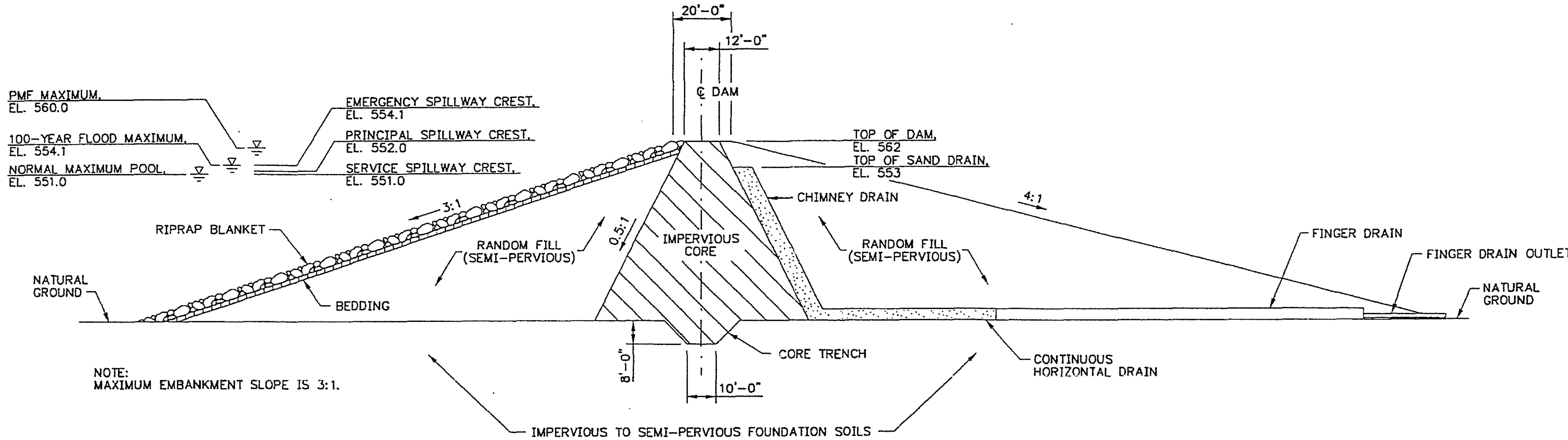
PROJECT: **Lake Ralph Hall** WATERSHED: **4 - Reservoir**

RESERVOIR:

AVE. RESERVOIR DEPTH OVER REACH	**45**	feet	~ (550-465)/2
GRAVITY ACCELERATION	**32.2**	feet/sec-sec	
WAVE CELERITY	38.1	feet/sec	c =(g*Davg)^0.5
LENGTH	**35,000**	feet	
COMPUTED TRAVEL TIME	0.26	hours	

APPENDIX B

CONCEPTUAL DRAWINGS OF RALPH HALL DAM AND SPILLWAYS



TYPICAL DAM EMBANKMENT SECTION

0 20 40
SCALE IN FEET

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APRIL 29 2004

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TYPICAL DAM EMBANKMENT - SECTION

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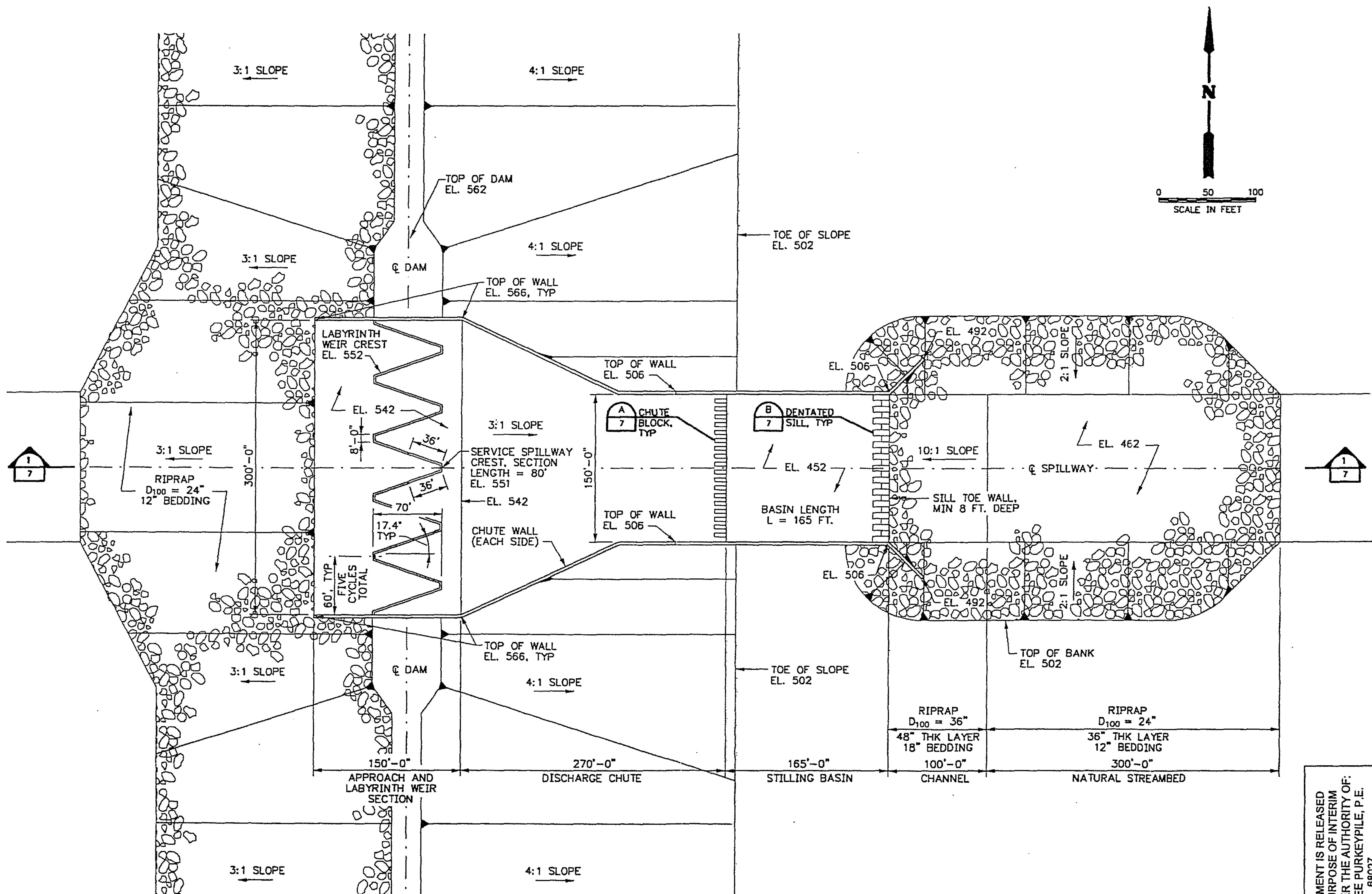
FIGURE

B-1



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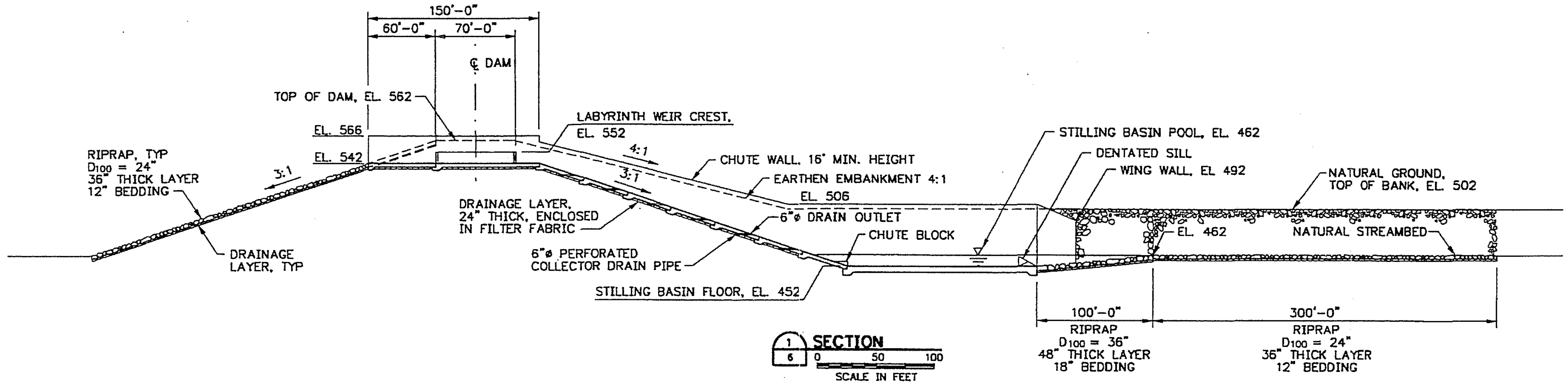
RESERVOIR PRINCIPAL SPILLWAY - PLAN

FIGURE

B–2



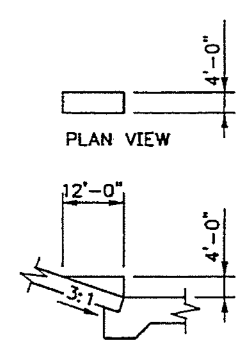
1/6 SECTION

0 50 100
SCALE IN FEET

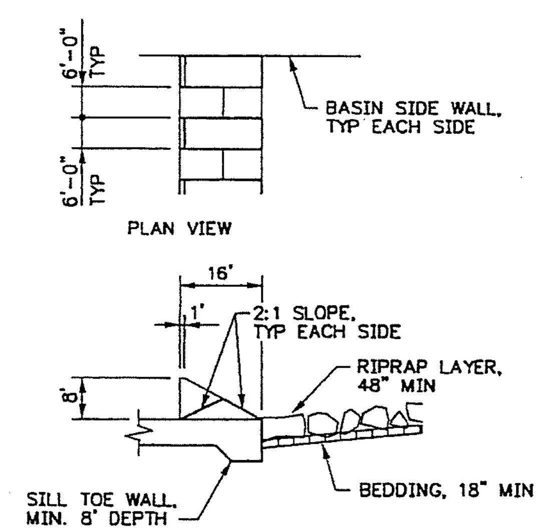
NOTES:

1. SPACE CHUTE BLOCKS AT 8'-0" O.C. FOR ENTIRE WIDTH OF STILLING BASIN.

2. PROVIDE 5' GAP EACH SIDE OF BASIN.



A/6 CHUTE BLOCK DETAIL
NTS



B/6 DENTATED SILL DETAIL
NTS

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RESERVOIR PRINCIPAL SPILLWAY - SECTION

FIGURE
B-3

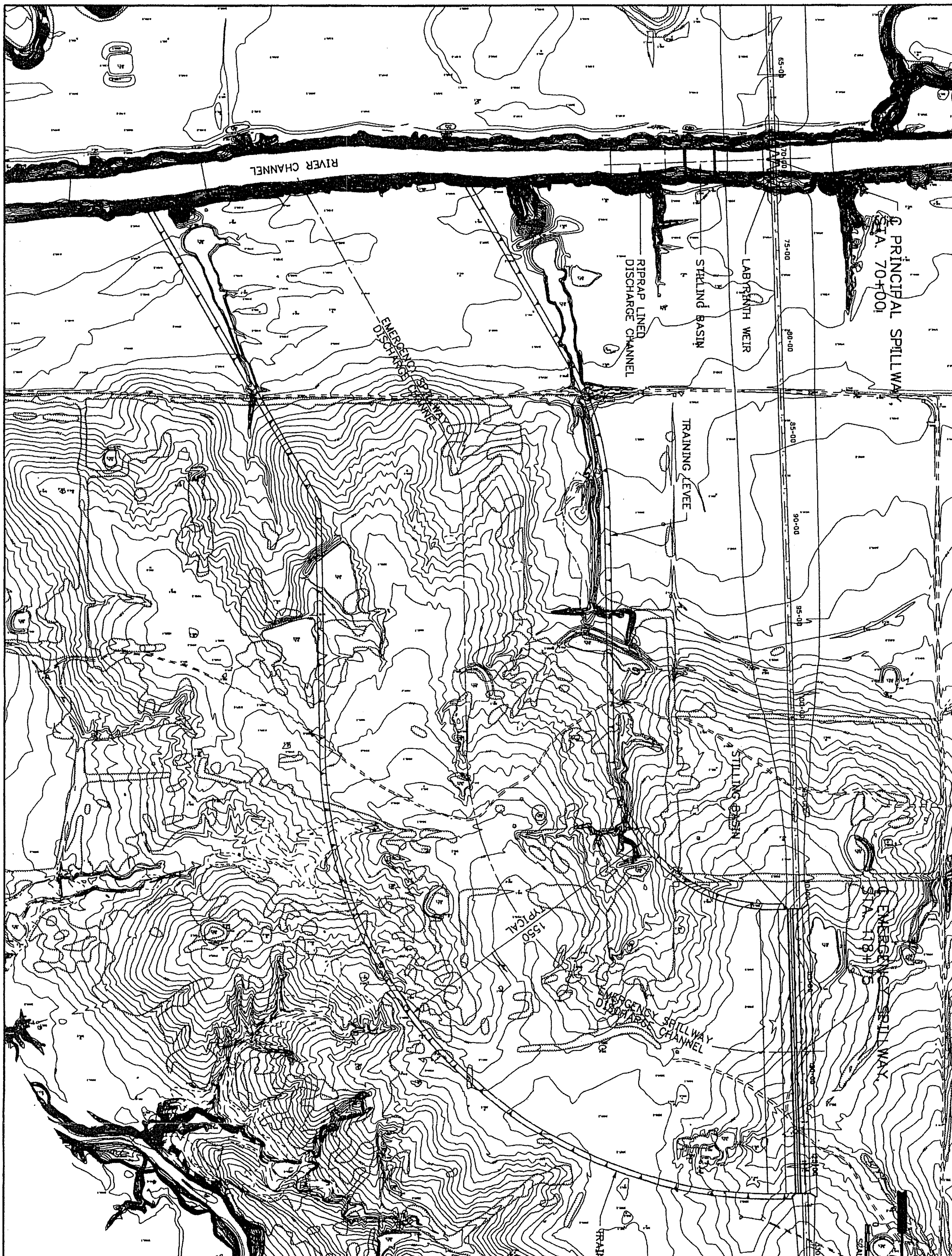

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FIGURE B-4

APPLICANT: UPPER TRINITY REGIOANL WATER DISTRICT
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EMERGENCY SPILLWAY - LOCATION MAP

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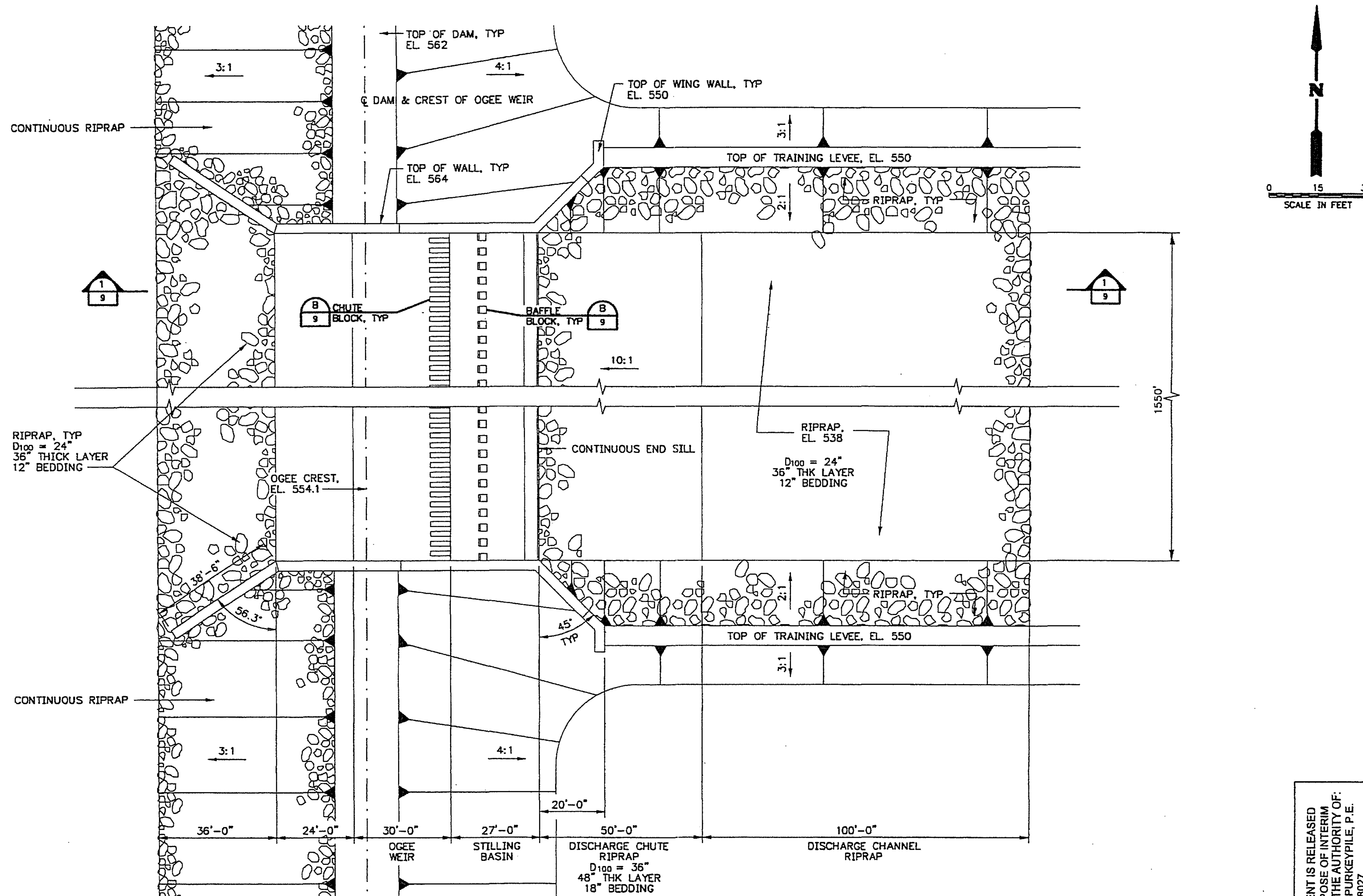

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EMERGENCY SPILLWAY - PLAN

FIGURE

B-5

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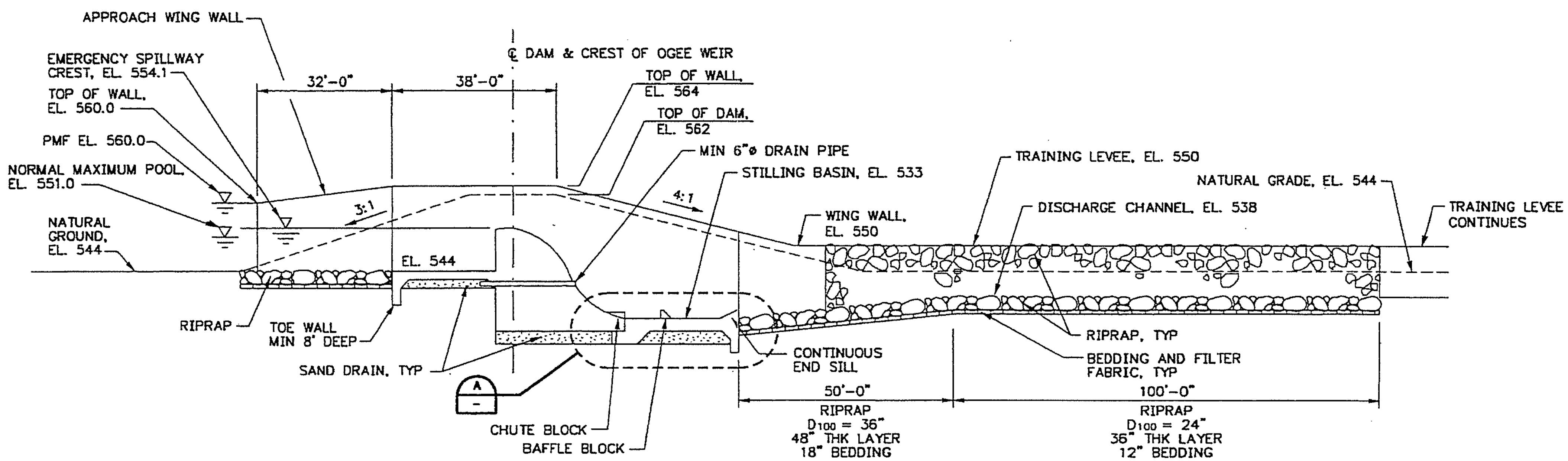
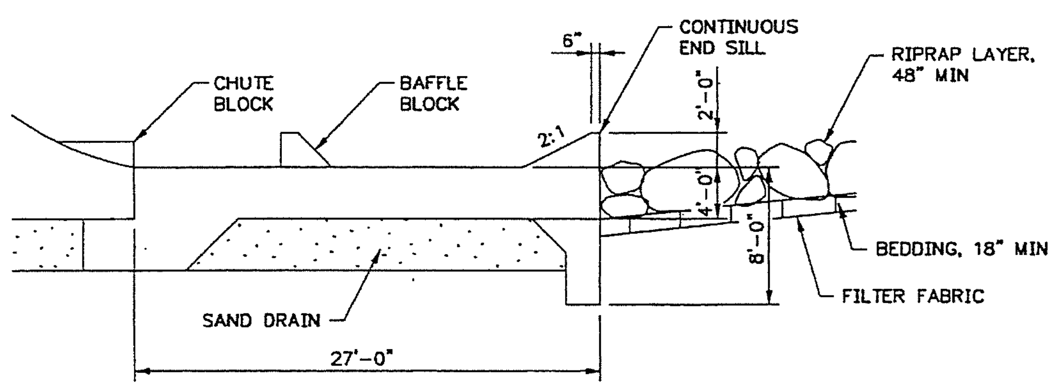
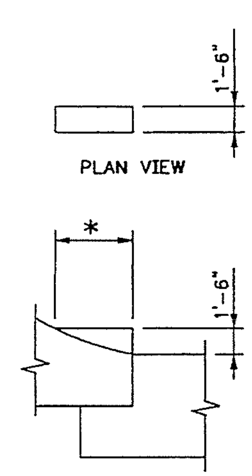


1/8 **SECTION**

0 15 30
SCALE IN FEET



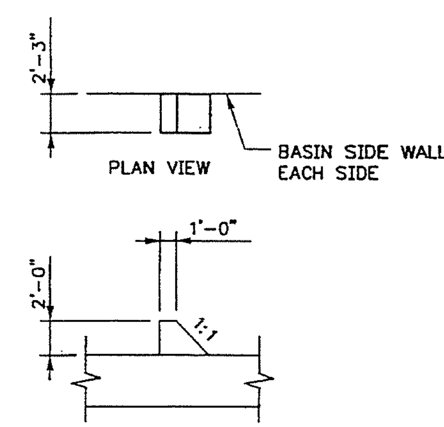
A/- **DETAIL**
NTS



NOTES:

1. * DIMENSION TO BE DETERMINED BY CONTOUR OF WEIR.
2. SPACE CHUTE BLOCKS AT 3'-0" O.C. FOR ENTIRE WIDTH OF STILLING BASIN.
3. PROVIDE 1'-6" GAP EACH SIDE OF BASIN.

B/8 **CHUTE BLOCK DETAIL**
NTS



NOTE:

SPACE BAFFLE BLOCKS AT 2'-3" O.C. FOR ENTIRE WIDTH OF STILLING BASIN.

C/8 **BAFFLE BLOCK DETAIL**
NTS

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WATER RIGHTS PERMIT APPLICATION

EMERGENCY SPILLWAY - SECTION & DETAILS

FIGURE
B-6

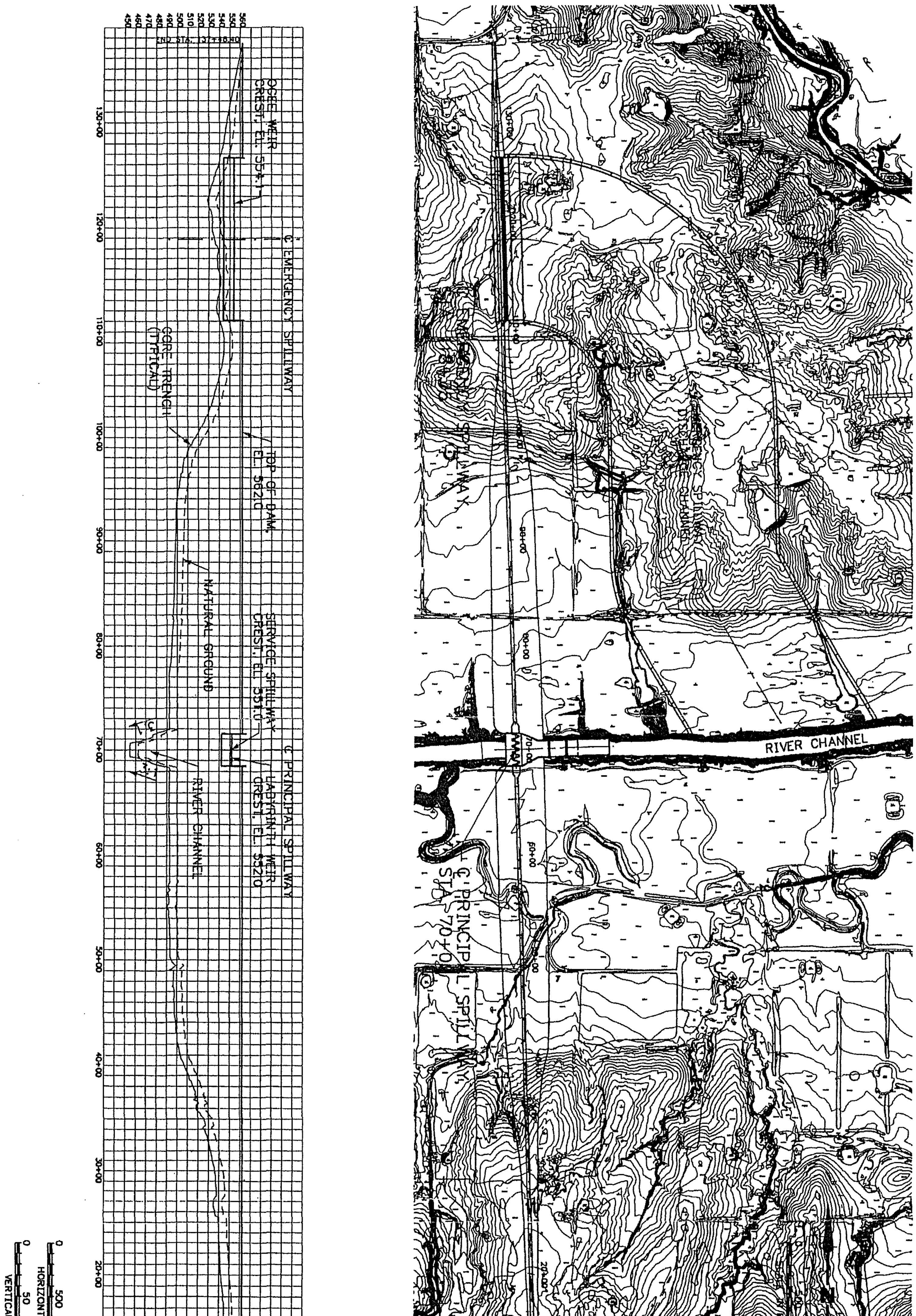

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FIGURE B-7	APPLICANT: UPPER TRINITY REGIOANL WATER DISTRICT WATER RIGHTS PERMIT APPLICATION **EMBANKMENT PLAN AND PROFILE**	R. J. BRANDES COMPANY Chiang, Patel & Yerby, Inc. APRIL 29, 2004

D-3: RiverWare Modeling

Robert J. Brandes Consulting

MEMORANDUM

To: Ed Motley
CH2M-Hill

From: Bob Brandes
Kirk Kennedy

Subject: Lake Ralph Hall
RiverWare Modeling

Date: June 29, 2015

As directed by the Upper Trinity Regional Water District (UTRWD), we have responded to the request from Corps of Engineers Fort Worth Office (Corps) to operate the Corps' daily RiverWare model of the Sulphur, Cypress and Red River Basins under conditions without and with the Lake Ralph Hall Project. From the modeling results, we have extracted daily river flows at locations along the North Sulphur and Sulphur Rivers where computational nodes exist in the model, and we have analyzed these flows with regard to frequency of occurrence and the frequency of filling river channel pools along the segment of the North Sulphur River from the proposed Lake Ralph Hall dam site downstream to the USGS streamflow gage near Cooper (Gage No. 07343000). We also have extracted and analyzed the daily storage and diversions for Lake Ralph Hall as simulated with the RiverWare model.

The version of the RiverWare model provided by the Corps included the physical representation of Lake Ralph Hall, but it did not have any diversions specified for withdrawing water from the reservoir as proposed by the UTRWD. We incorporated the same diversion routine that was used in the WAM for the previous analyses of the impacts of Lake Ralph Hall on monthly river flows that were conducted in July of 2014. This routine allows monthly diversions equivalent to 45,000 acre-feet per year to be made from Lake Ralph Hall provided the beginning-of-month storage in the reservoir exceeds 27,500 acre-feet, with the monthly diversions reduced to the equivalent of 16,800 acre-feet per year when the storage falls below 27,500 acre-feet. As originally modeled with the WAM, this operating procedure was designed to protect a firm annual yield of 16,800 acre-feet for Lake Ralph Hall while allowing overdrafting of the reservoir up to the full authorized diversion amount of 45,000 acre-feet per year when adequate stored water is available in the reservoir.

The period of record for the hydrologic conditions simulated with the daily RiverWare model is 1938 through 2014, which encompasses the monthly hydrologic conditions simulated with the WAM that extend from 1940 through 1996. While the source and derivation of the monthly naturalized flows used in the WAM are well documented, we do not have information regarding the procedures used to develop the daily flows that are input into the RiverWare model; however, as will be demonstrated, it is apparent that historical flow data for the North Sulphur River from the USGS streamflow gage near Cooper, to the extent they are available, have been used for representing flow conditions in the RiverWare model for at least the upper segment of the North

Sulphur River. As we have discussed before, the RiverWare model does not apply the prior appropriation doctrine for allocating available streamflows among existing water rights in the Sulphur Basin, so in the model no streamflows are ever required to be passed downstream during water shortage periods by the more junior water rights to satisfy the demands of the more senior water rights. Furthermore, it appears that the only demands associated with existing water rights in the entire Sulphur Basin that are included in the RiverWare model are those for Lake Chapman and Lake Wright Patman; all other water rights are not represented. The WAM includes all existing water rights in the Sulphur Basin, with total authorized diversions of about 500,000 acre-feet per year, and allocates water to these water rights in order of seniority as required under Texas state law; so in the WAM, Lake Ralph Hall, with its relatively junior priority, must pass inflows downstream whenever senior water rights are not fully satisfied. These differences in the models regarding how streamflow allocations are made to existing water rights are reflected in their respective simulated river flows.

Since the WAM uses a monthly time step for performing water availability simulations, the underlying purpose for applying the daily RiverWare model was to be able to evaluate daily flow variations under conditions without and with Lake Ralph Hall. Therefore, the first set of results presented herein consists of plots of simulated daily flows, expressed in cubic feet per second (cfs), at USGS Gage No. 07343000 on the North Sulphur River near Cooper (see Attachment A) and at Gage No. 07343200 on the Sulphur River near Talco (see Attachment B). These depictions of daily flows illustrate conditions on the eroded and degraded segment of the North Sulphur River, as well as on the more natural segment of the Sulphur River below the confluence with the South Sulphur River and also below the infamous log jam. Graphs of daily flows covering one calendar year each are presented for 1956, 1980, 1992 and 2011, with two graphs with maximum flow scales of 500 cfs and 5,000 cfs provided for each year. The selected years are characterized by periods of extremely low flows (1956 and 2011), varying flows (1980), and very high flows (1992). As expected, these plots of daily flows without and with Lake Ralph Hall indicate some reduction in peak flows for individual flood events as a result of the reservoir, with these reductions more pronounced at the upper gage on the North Sulphur River. The peak flow reductions are less pronounced at the lower gage on the Sulphur River, as would be expected with the increased tributary inflows from the intervening watershed. Since the major reductions in peak flows are limited to the eroded and degraded channel of the North Sulphur River where overbanking of adjacent floodplain areas typically does not occur, the impacts of these reduced peak flows are not likely to be significant.

We have also compiled the daily simulated flows from the RiverWare model into monthly values to better provide meaningful comparisons of conditions without and with Lake Ralph Hall and to facilitate comparisons with the results from the WAM. Attachment C contains a group of plots and tables illustrating these comparisons for locations along the North Sulphur and Sulphur Rivers where the RiverWare model has computational nodes.

The first two plots on pages 1 and 2 of Attachment C show the storage in Lake Ralph Hall and the diversions from the reservoir as simulated with the RiverWare model and with the WAM. As illustrated, the simulated storage in the reservoir is considerably greater for the RiverWare model, with substantially more spills from the reservoir downstream into the North Sulphur River. As shown on the graph on page 2, during these higher storage periods, more water is able to be diverted from the reservoir since the criterion for making diversions up to the fully authorized amount of 45,000 acre-feet/year is satisfied more often.

The disparity between the storage results for Lake Ralph Hall from the RiverWare model and the WAM leads to questions as to the source and magnitude of the inflows to the reservoir as simulated with the two models, notwithstanding the fact that the RiverWare model ignores water rights and does not require junior water rights to pass flows to downstream senior water rights during times of water shortage. It is assumed that both models utilize historical flow data from the gage on the North Sulphur River near Cooper as the underlying basis for their specified river flow inputs for this segment of the overall river system network. This has been confirmed by comparing the simulated flows in the river at this gage location without Lake Ralph Hall in operation. As shown on the graph on page 3 of Attachment C, the monthly flow values from the two models at the gage location and the corresponding measured monthly flows at the gage are essentially the same over the common period of the model simulations when the gage was in operation (which began in October 1949). This analysis rules out the possibility that different sources of flow data were used for the upper segment of the North Sulphur River in the two models. However, when this same comparison is made of the simulated inflows to Lake Ralph Hall approximately 20 miles upstream from the gage, differences are noted between the two models. The graph on page 4 of Attachment C indicates that the simulated inflows to Lake Ralph Hall for the RiverWare model generally are higher than those for the WAM. This graph also indicates that apparently different base flows were used in the models prior to the existence of the gage in 1949, possibly due to the application of different data fill-in techniques. The graph on page 5 of Attachment C presents a time-series plot of the cumulative inflows to Lake Ralph Hall as simulated with the two models for the common period when the gage was in operation beginning in 1950, and it further illustrates the differences in these two sets of inflows, with the total cumulative deviation over 50 years approaching about 500,000 acre-feet. The differences in the inflows to Lake Ralph Hall during the period when gage flow records are available may be due to the fact that the RiverWare model uses a daily time step, with various flow routing parameters and lag coefficients to account for the movement of water downstream, whereas the WAM uses a monthly time step with no time adjustments other than those reflected in the flow data themselves. In any event, these differences in the inflows to Lake Ralph Hall between the two models are worthy of note, and they are likely reflected in the simulated flows downstream and must be considered when evaluating results.

A plot of the monthly simulated outflows from Lake Ralph Hall for the two models is presented on the graph on page 6 of Attachment C, again illustrating the significant spills from the reservoir as simulated with the RiverWare model. Inflows periodically passed downstream for satisfying the demands of senior water rights also are indicated on this plot by the WAM flows during dry periods. Monthly flows from the RiverWare model at the location of the first tributary downstream of Lake Ralph Hall (Baker Creek), which enters the North Sulphur River approximately one mile below the dam, are plotted with two different scales on the graphs on pages 7 and 8 of Attachment C for conditions without and with Lake Ralph Hall. Both plots illustrate the obvious; more flow is in the river downstream without Lake Ralph Hall than with it. The graph on page 9 of Attachment C depicts similar results at the location of the gage on the North Sulphur River near Cooper, but it is interesting to compare the flow magnitudes in this graph with those in the graph on page 8, both of which are plotted at the same flow scale. This comparison clearly illustrates the significant effect of flows that enter the river downstream of Lake Ralph Hall from tributaries, even with the reservoir in operation.

Finally, the tables on pages 10 through 13 present statistical results for the simulated monthly flows from the RiverWare model and from the WAM. Flows corresponding to specific percentiles and exceedance frequencies are indicated for the RiverWare model and the WAM and for conditions without and with Lake Ralph Hall in operation. These values are presented at locations where the RiverWare model has computational nodes, plus one additional location at the confluence of Baker Creek with the North Sulphur River. These locations can be identified on the map of the Sulphur River Basin in Attachment D, and they include upstream of Lake Ralph Hall for the inflow to the reservoir, below Lake Ralph Hall immediately downstream of Baker Creek (Catchment 3 on the map), at the North Sulphur River gage near Cooper (Gage No. 07343000 on the map), at the proposed site for the Parkhouse 2 Reservoir on the North Sulphur River (immediately below Catchment 14 on the map), at the Sulphur River gage near Talco (Gage No. 07343200 on the map), and at the proposed site of the Marvin Nichols Reservoir on the Sulphur River (immediately below Catchment 18 on the map). Flows from the RiverWare model at the Baker Creek location have been derived by adding to the simulated outflows from Lake Ralph Hall the incremental inflow from the watershed between the reservoir and Baker Creek, including Baker Creek. This incremental inflow was calculated by applying a drainage area ratio to the total simulated incremental inflow from the watershed between the reservoir and the North Sulphur River gage near Cooper. Comparisons of statistical results are presented for flows from the RiverWare model and from the WAM with Lake Ralph Hall (page 10) and without Lake Ralph Hall (page 11), for flows from the RiverWare model with and without Lake Ralph Hall (page 12), and for flows from the WAM with and without Lake Ralph Hall (page 13). As shown on each table, for flows at the Baker Creek location and at the North Sulphur River gage near Cooper, the exceedance frequencies have been determined for a flow of 175 acre-feet/month, which is the flow volume determined by Dr. Norman Johns of the National Wildlife Foundation as that needed to completely fill all of the downstream pools in the channel of the North Sulphur River from Baker Creek to the gage on the river near Cooper. While these exceedance frequencies provide some insight as to the effects of using the different models and the impacts of Lake Ralph Hall itself, a more in-depth analysis of downstream pool filling is discussed below.

Attachment E presents a summary of the results from the downstream pool filling analyses performed using monthly flows simulated with the RiverWare model by applying the same procedures previously employed (April 2015) for analyzing pool filling with WAM flows at the same locations. These previous results from analyzing the WAM flows also are included at the bottom of this table for reference purposes. This table presents the % of Time Pools Are Filled, on a monthly basis, under conditions without and with Lake Ralph Hall in operation for each of the reaches between tributaries for the segment of the North Sulphur River from the Lake Ralph Hall dam down to the North Sulphur River streamflow gage near Cooper. These values were derived by analyzing the monthly flows as simulated with the RiverWare model and the WAM at each of these locations to determine if they are sufficient to fill the pools in each of the downstream reaches based on Dr. Johns' pool volume estimate of 175 acre-feet for the total dam-to-gage reach. The intervening values of the flow volume required for filling the pools in each of the reaches were derived by making proportional adjustments of the 175 acre-foot value based on river channel distance below the dam. This assumes that the total pool volume is linearly distributed along this segment of the river channel. As shown in the table, and as expected, the values of Volume Required to Fill All Downstream Pools decrease with distance below the Lake Ralph Hall dam since the volume of pools decreases. The value of the % of Time Pools Are Filled at a particular location reflects the use of river flows to fill upstream pools, increases in river flows in the downstream direction with added tributary inflows, and the different pool volumes as they vary by reach. The monthly river flows from the RiverWare model at each of these locations were derived using the same approach described above for determining the river flows at the Baker

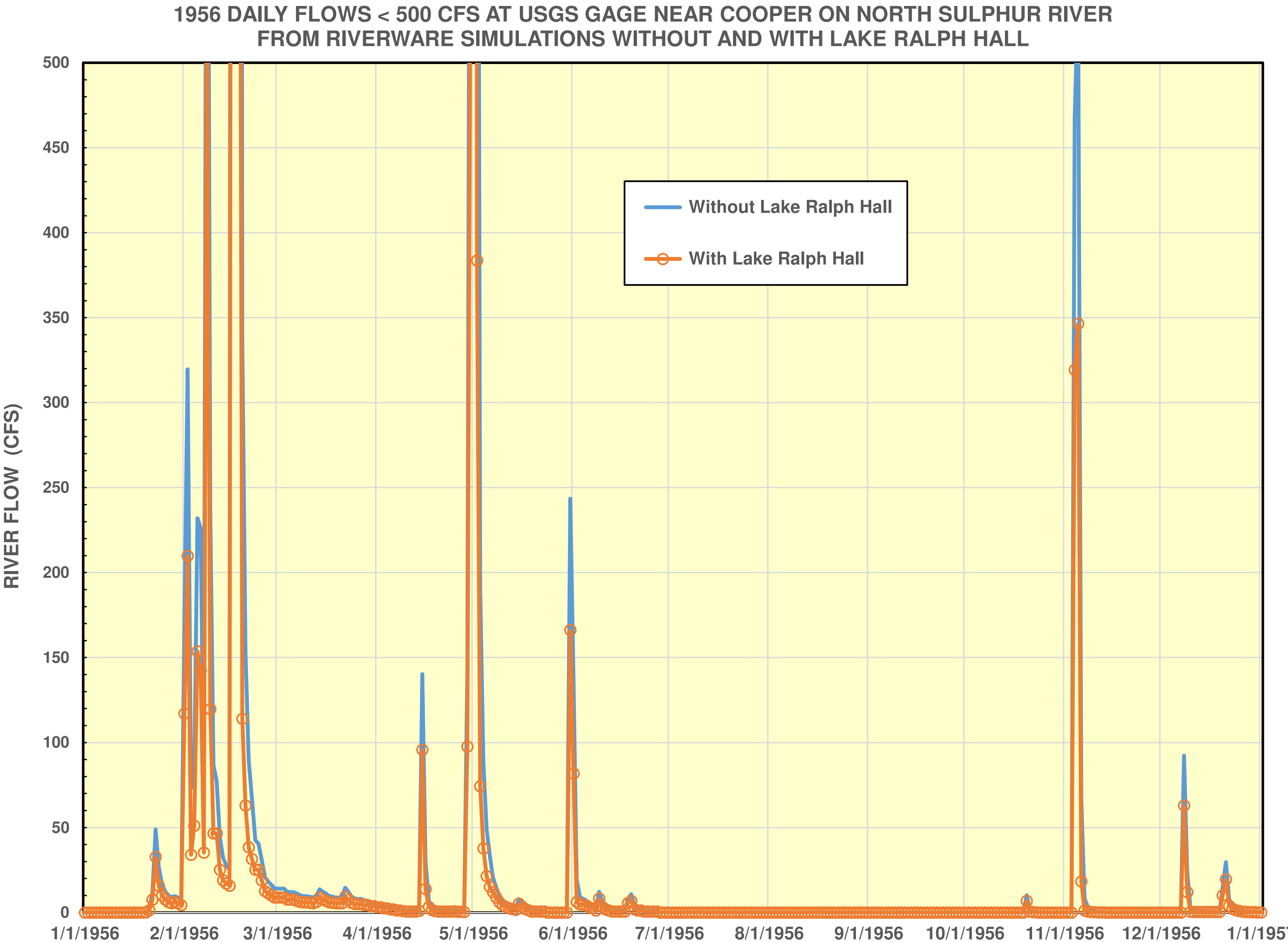
Creek location based on the simulated RiverWare flows at the dam and at the downstream gage near Cooper. As noted, the maximum reduction in the % of Time Pools Are Filled from the Without Lake Ralph Hall case to the With Lake Ralph Hall case for the RiverWare results is 13.5%, with the second largest reduction equal to 9.7%. For the WAM flows, these maximum reductions are 0.6% and 1.3%, respectively. As expected, both of these sets of higher reductions occur in reaches of the river closest to Lake Ralph Hall. Beginning at a point about half way down the river between Lake Ralph Hall and the gage, the reductions are substantially less, generally at levels considered to be within the simulation accuracy of the models considering the sources and accuracy of data and the simulation procedures used in the models. Over the entire segment of the North Sulphur River from Lake Ralph Hall down to the gage, the reach length-weighted average reduction in the % of Time Pools Are Filled from the Without Lake Ralph Hall case to the With Lake Ralph Hall case is -5.9% for the RiverWare flows and -0.5% for WAM flows.

While the RiverWare model does provide daily simulations of flows in the North Sulphur and Sulphur Rivers, it is apparent from comparisons of these flows under conditions without and with Lake Ralph Hall that the daily variations themselves really do not tell us much more, if anything, about the effects of Lake Ralph Hall than monthly flow values. From the graphs of daily flows in Attachments A and B, it is shown that flood hydrographs occur at generally the same frequency and duration without or with Lake Ralph Hall. It is only the peaks of these hydrographs that are somewhat reduced due to the effects of Lake Ralph Hall, and peak flood flows in the North Sulphur River, unless they are associated with significant flood events on the order of the 25-year flood or greater, do not produce overbanking conditions that normally might be considered important from an aquatic ecological perspective. The incised channel of the North Sulphur River upstream of and for some distance downstream of the gage near Cooper simply is too deep to allow overtopping by the vast majority of flood events and too steep-walled to support and maintain typical lower floodplain conditions. Farther downstream, as inflows continue to enter the North Sulphur River and the Sulphur River below the confluence with the South Sulphur River, the reduction of river flows caused by Lake Ralph Hall becomes relatively less significant, to the point that the reservoir likely has minimal impact on instream and floodplain conditions.

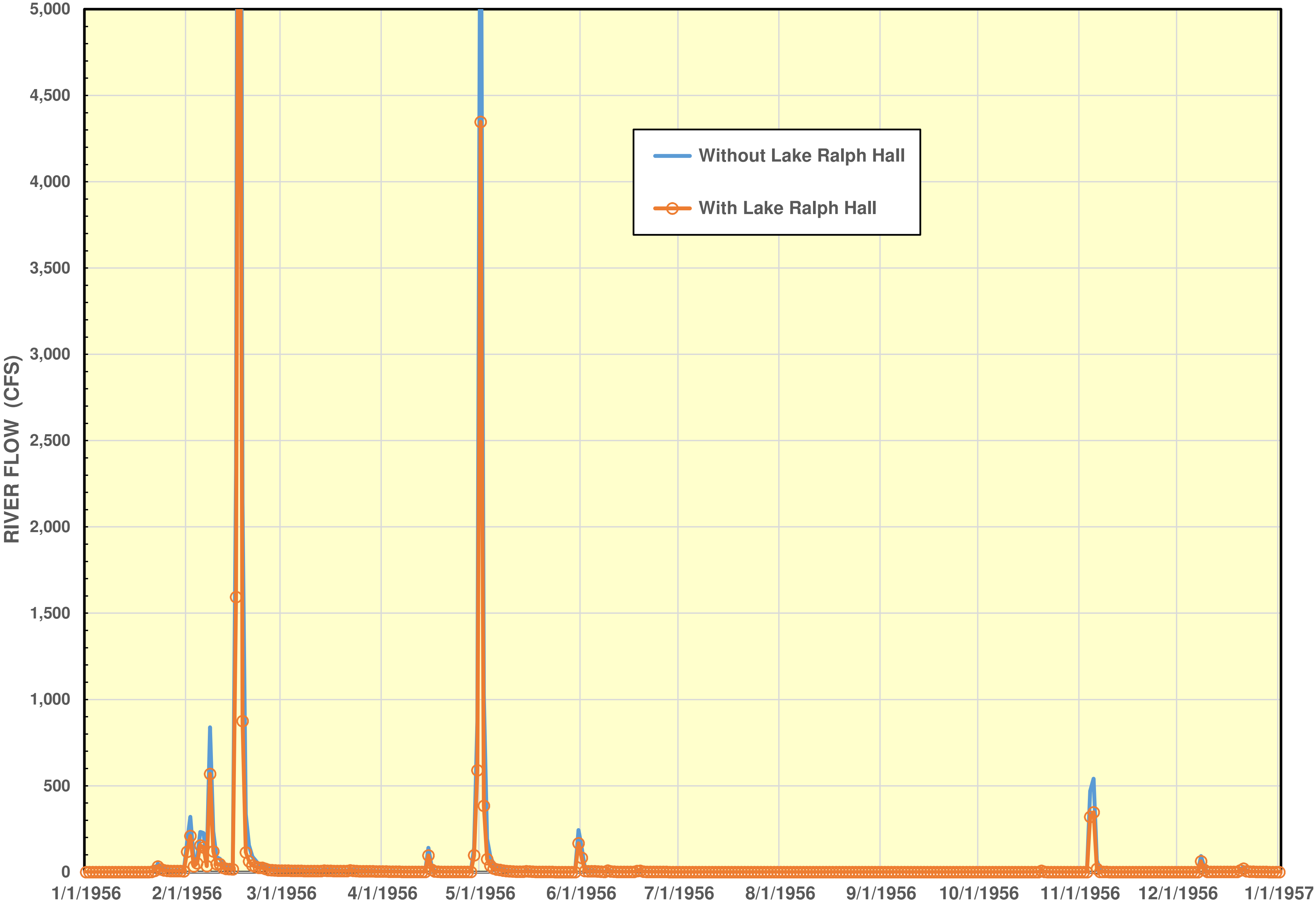
When considering the results from the RiverWare model of the Sulphur, Cypress and Red River Basins, it also is important to note that some of the deficiencies of the model could be relevant with respect to evaluating the impacts of Lake Ralph Hall. The exclusion of existing water rights from the model and the prior appropriation doctrine precludes any passing of inflows through the reservoir to satisfy the demands of downstream senior water rights. These additional flows in the river, which the WAM does model, could serve to supplement tributary inflows for filling channel pools and supporting aquatic life downstream of the reservoir. While typically the passing of flows for satisfying senior water rights only occurs during extremely dry periods when a "call" is made by the downstream senior water rights, it is not something that would never occur as the RiverWare model assumes. With the construction and operation of Lake Ralph Hall, it is very likely that owners of existing downstream water rights, especially those with large irrigation rights located near or below the confluence of the North and South Sulphur Rivers, as well as Lake Wright Patman located farther downstream on the Sulphur River, will closely monitor their available water supplies from the river and will certainly issue a call for Lake Ralph Hall to pass inflows to meet their needs if they believe Lake Ralph Hall is depriving them of flows to which they are entitled. In this regard, the WAM probably provides a better estimate of low flow conditions in the North Sulphur River with Lake Ralph Hall in operation than the daily RiverWare model does. Another point to note relates to the higher level of inflows to Lake Ralph Hall that the RiverWare model produces. It is not clear as to why this occurs, but it definitely affects the operation of the reservoir and may artificially increase the frequency of flood spills from the reservoir that flow into the river downstream.

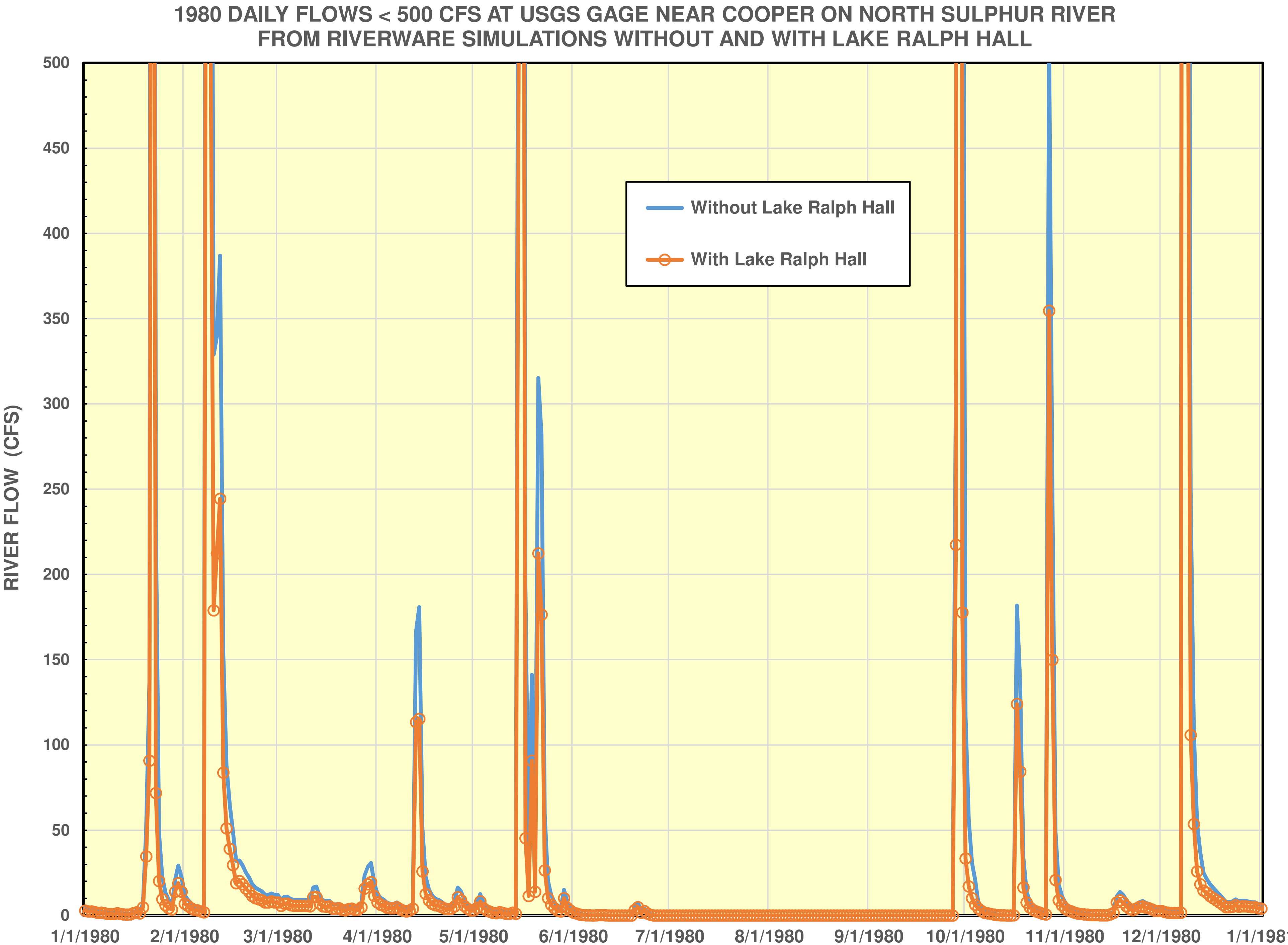
In summary, the application of the daily RiverWare model for analyzing the effects of Lake Ralph Hall on downstream river flows is considered to have been a worthwhile effort. It has provided a better understanding of the significance of daily variations in river flows and how Lake Ralph Hall might affect those flow variations and flood hydrographs, information that may be useful for further evaluating the impacts of Lake Ralph Hall. In the end, however, it remains that the place where Lake Ralph Hall will likely have its most significant effect on the flow regime of the North Sulphur and Sulphur Rivers is still the segment immediately downstream of the reservoir that is characterized by an eroded and degraded channel devoid of significant aquatic life such that reductions in river flows caused by the reservoir are not likely to result in noticeable environmental impacts. Even then, the UTRWD is proposing to develop and construct the mitigation area on the south floodplain of the North Sulphur River below the reservoir by restoring the configuration of approximately 14,000 feet of the abandoned river channel, planting native vegetation and trees, and stocking the restored pools and channel with fish and aquatic species that typically inhabited the historical river system.

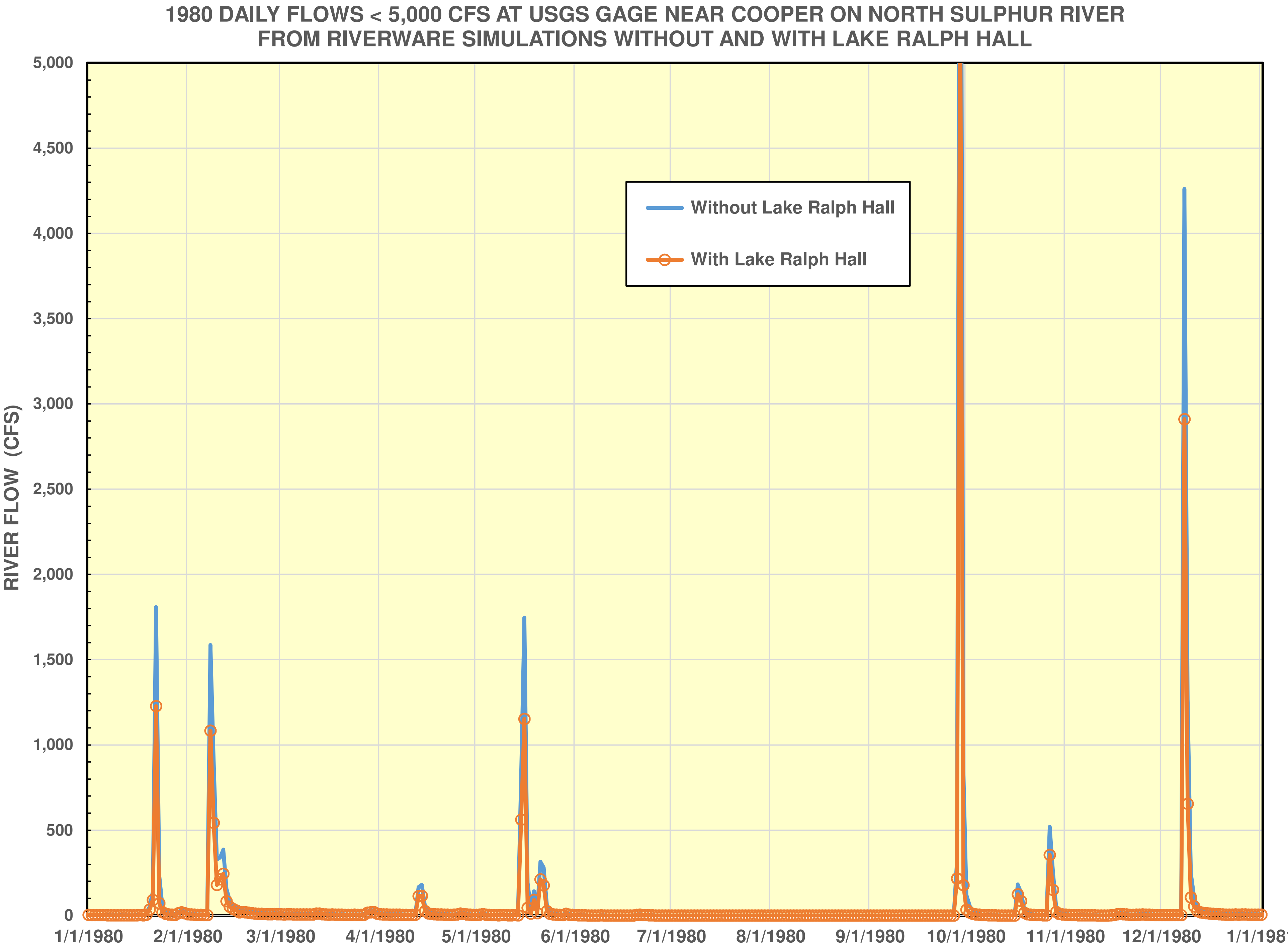
If you have any questions regarding the material presented herein or if you want to discuss these results further, please contact us at your convenience. Also, we are in the process of assembling the RiverWare results files and the various spreadsheets used in analyzing and presenting the results for delivery to the Corps.


1956 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957

1956 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL




1980 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981
Without Lake Ralph Hall
With Lake Ralph Hall


1980 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
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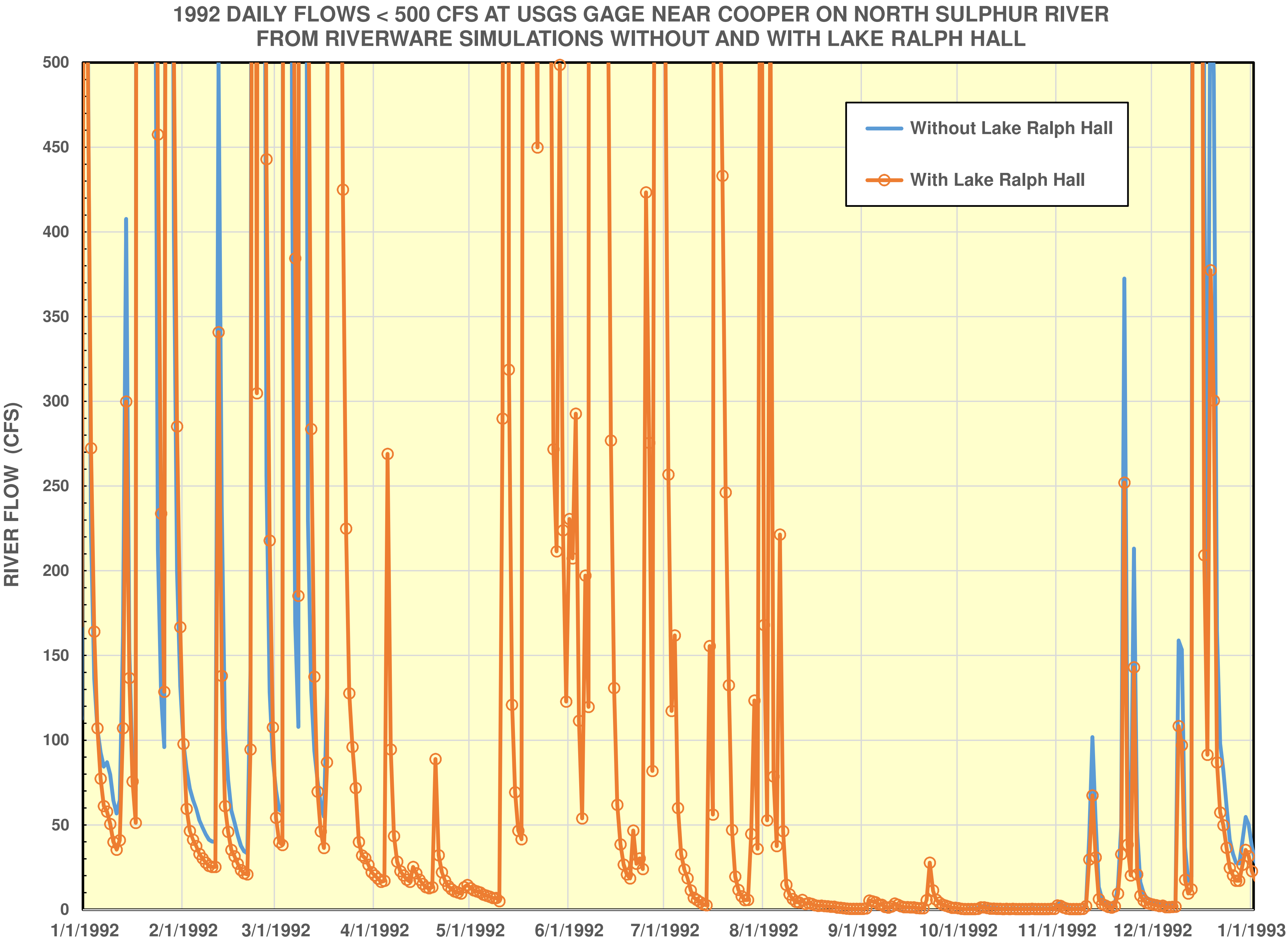
12/1/1980
1/1/1981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FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
Without Lake Ralph Hall
With Lake Ralph Hall
RIVER FLOW (CFS)
0
50
100
150
200
250
300
350
400
450
500
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
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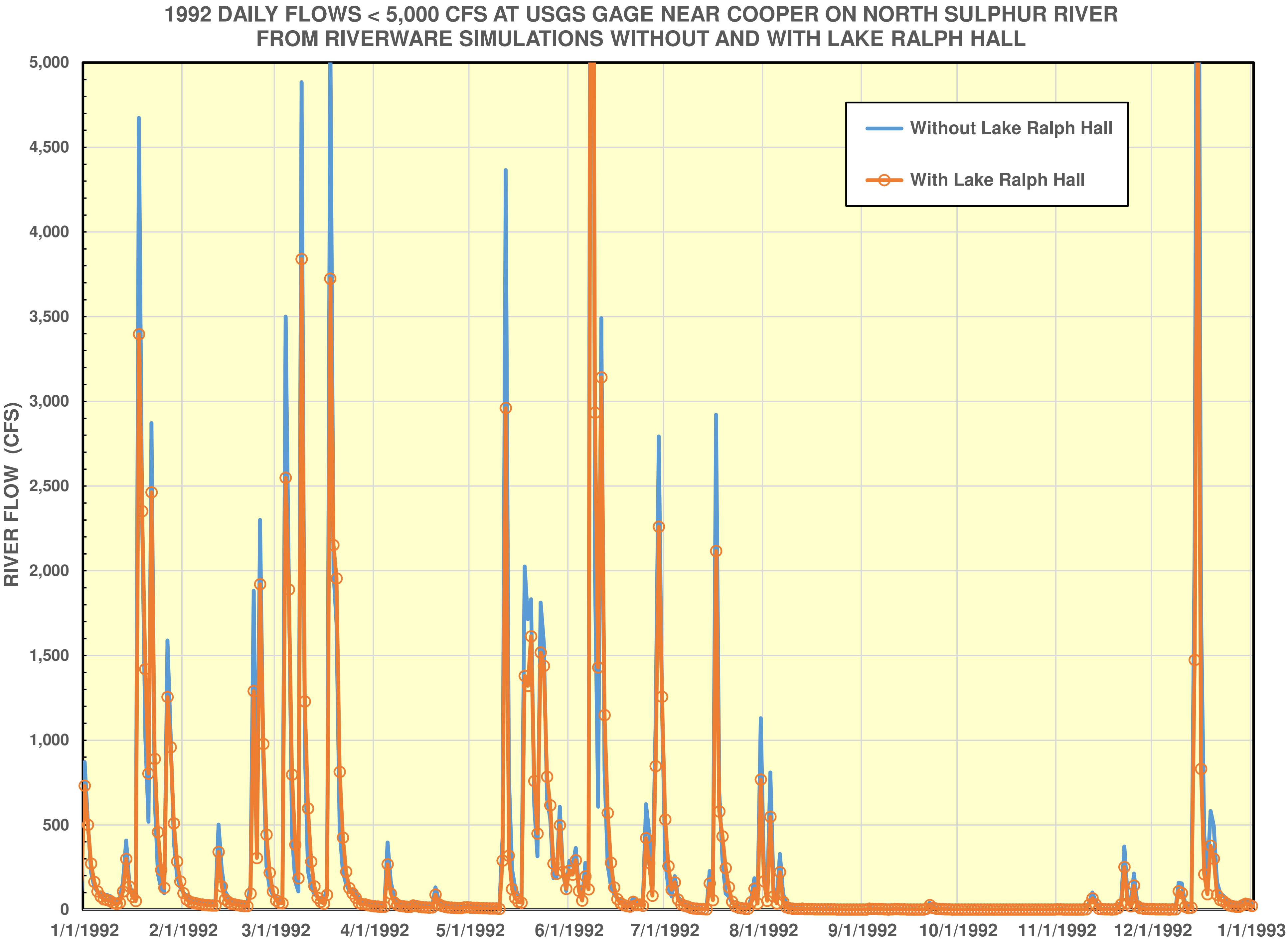
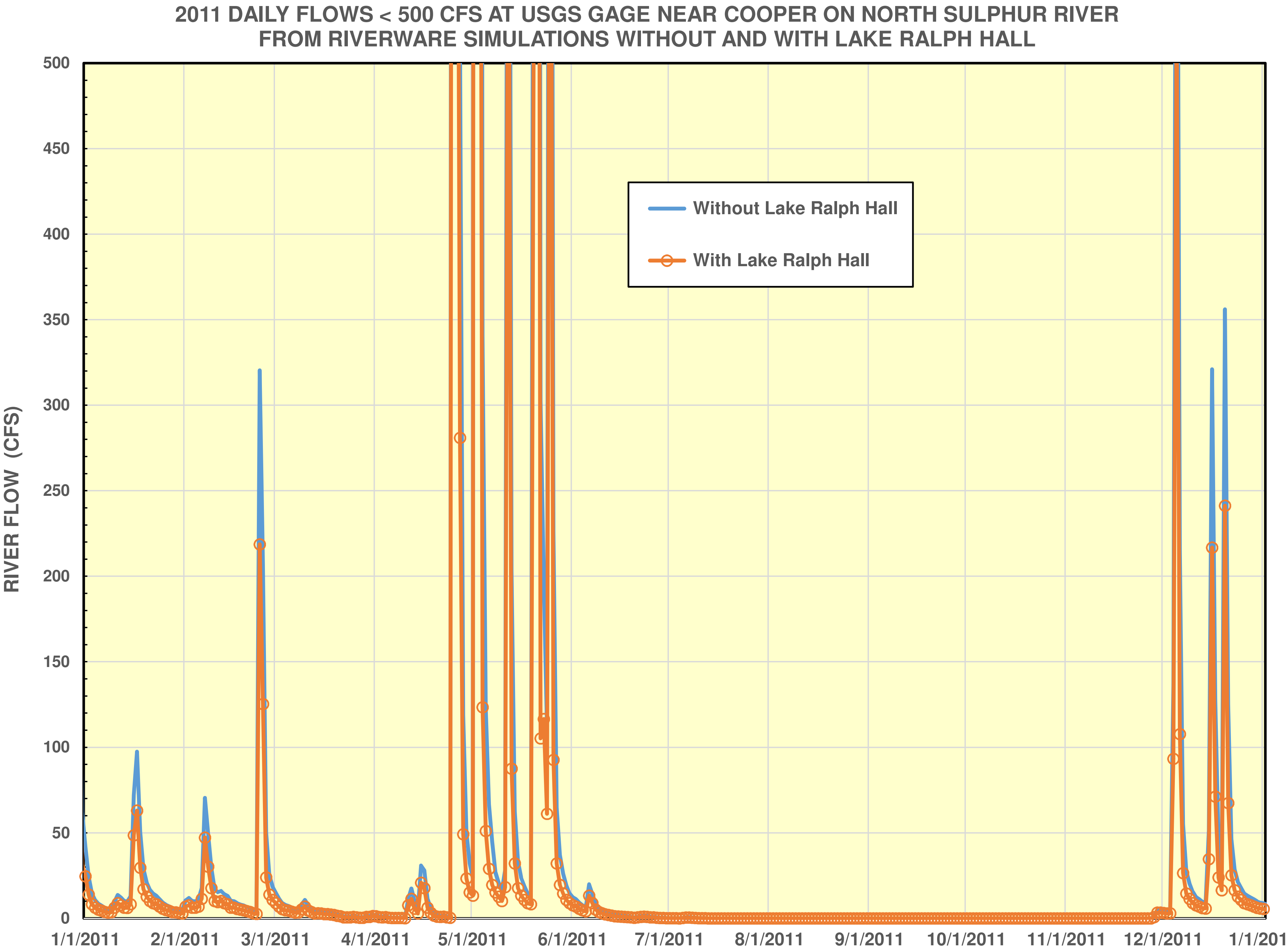
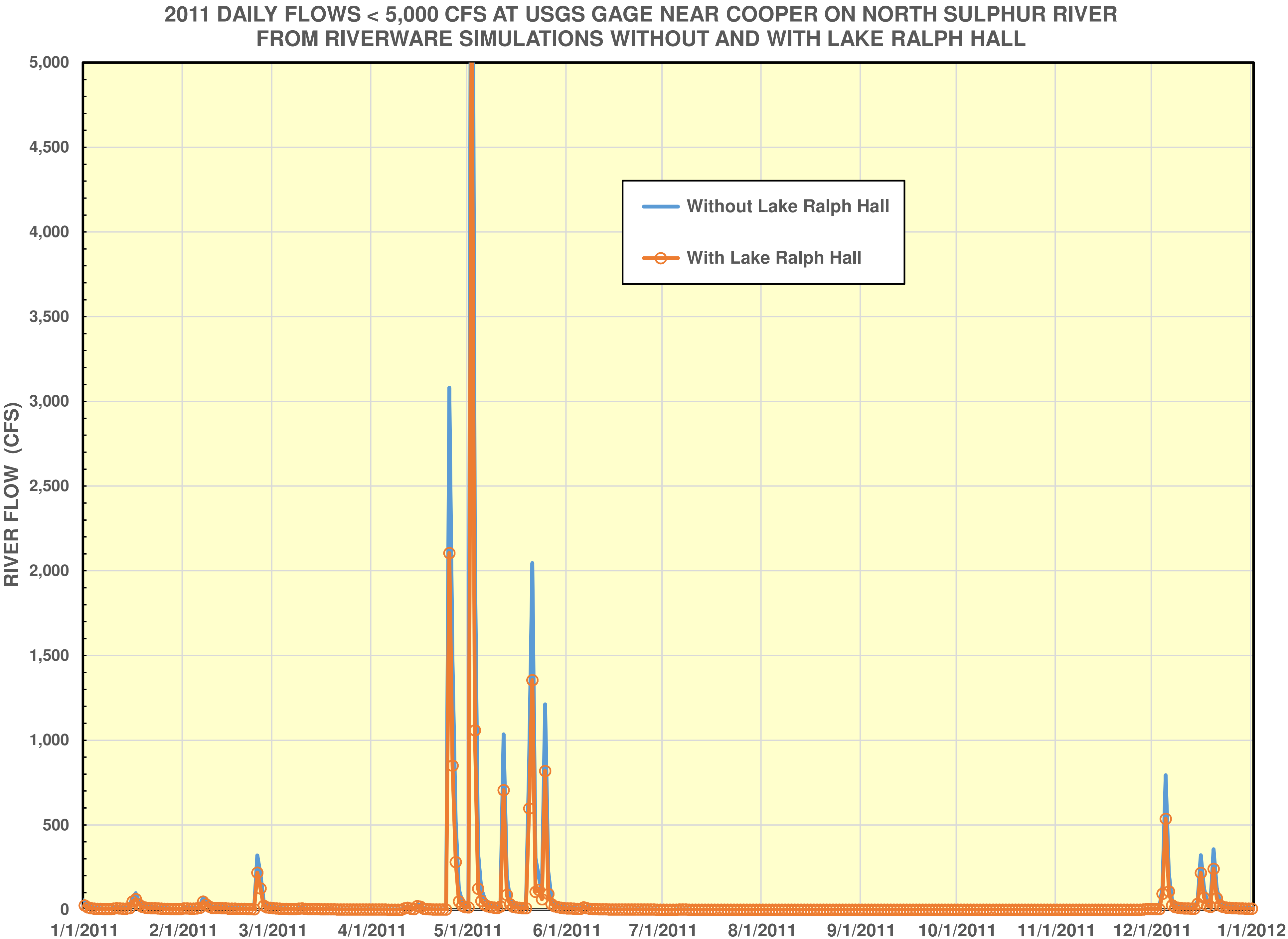
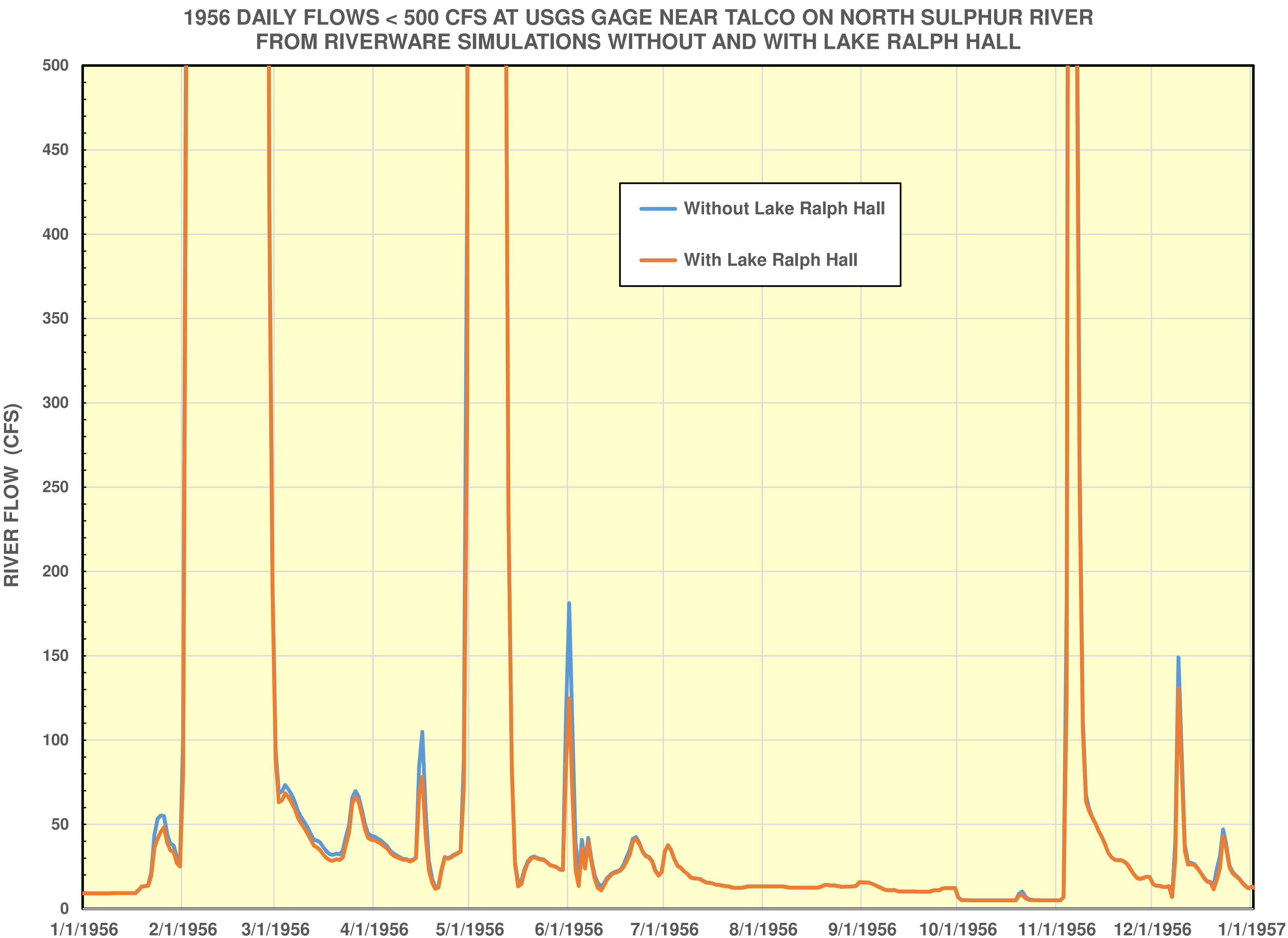
12/1/1992
1/1/1993


1992 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall


2011 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012
Without Lake Ralph Hall
With Lake Ralph Hall


2011 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012
Without Lake Ralph Hall
With Lake Ralph Hall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FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
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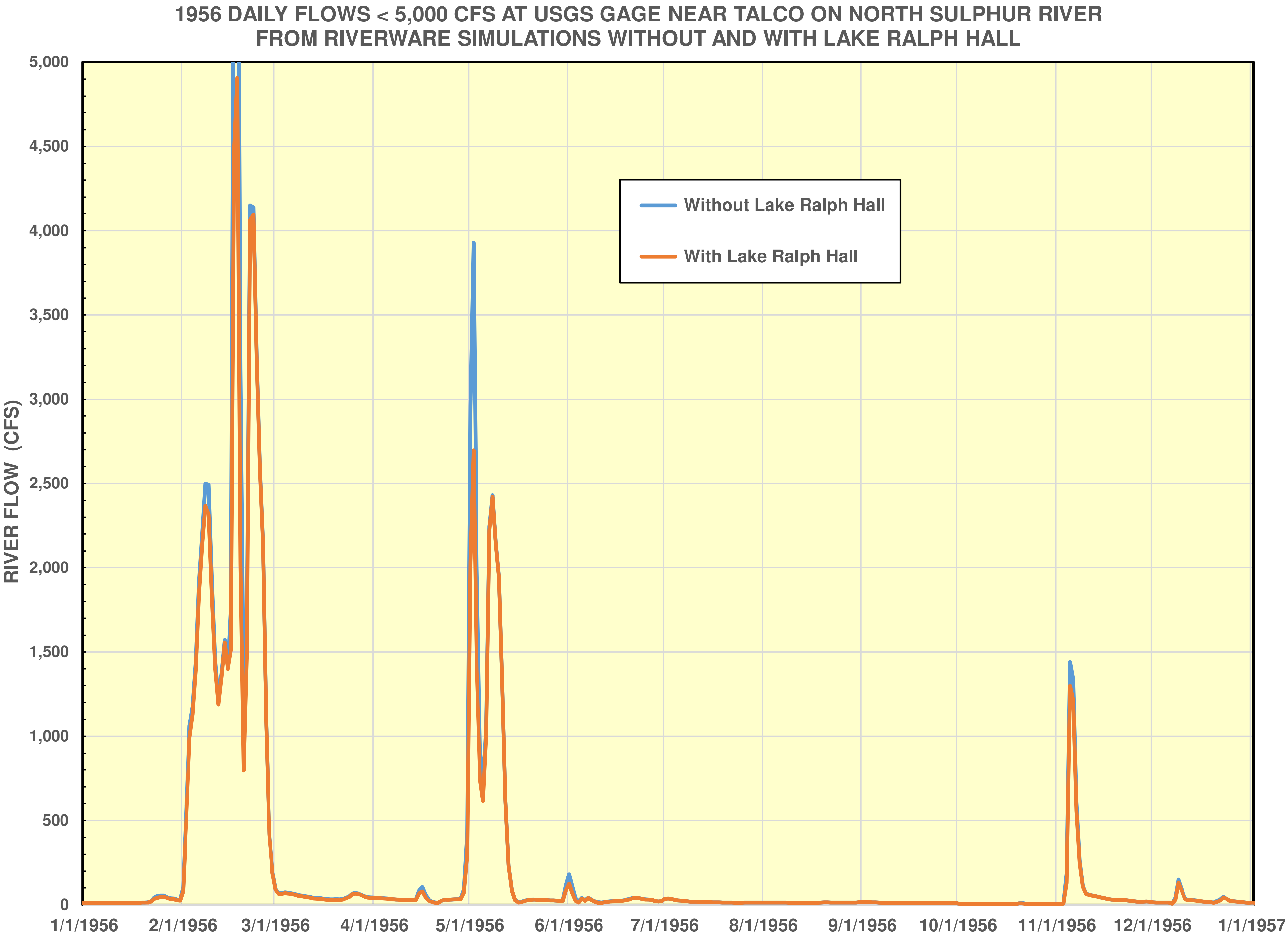
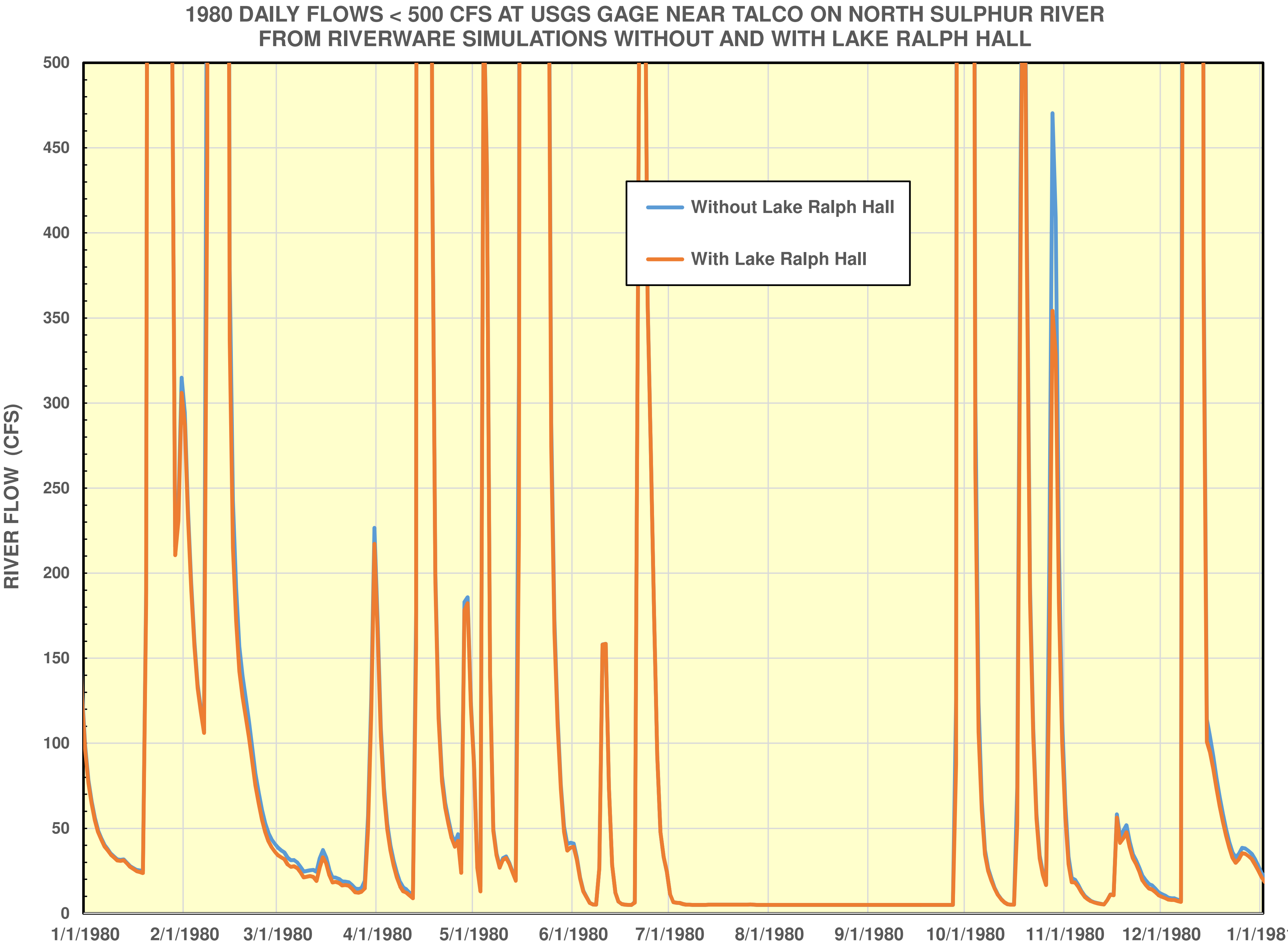
12/1/1956
1/1/1957


1956 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957
Without Lake Ralph Hall
With Lake Ralph Hall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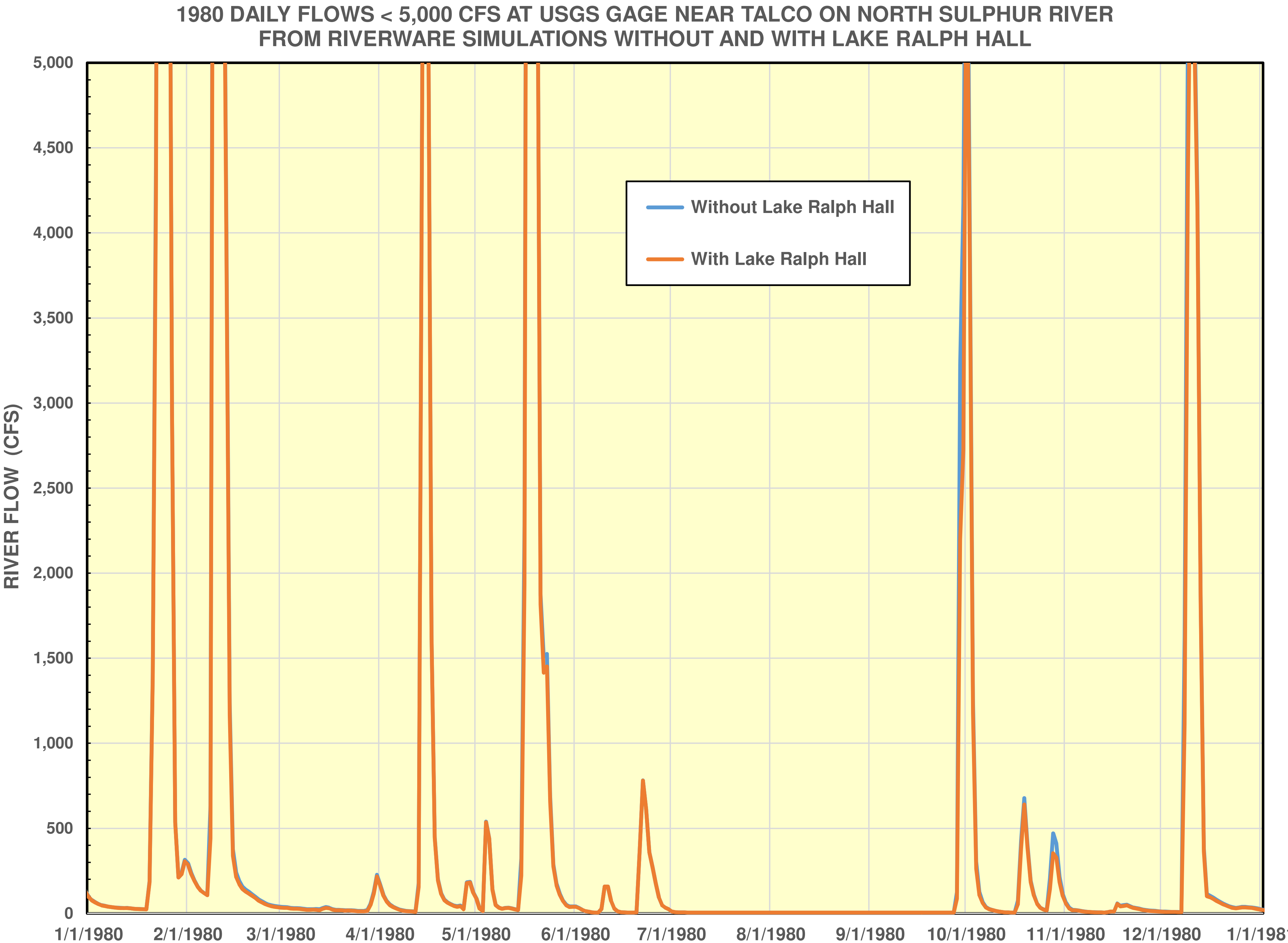
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981
Without Lake Ralph Hall
With Lake Ralph Hall


1980 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
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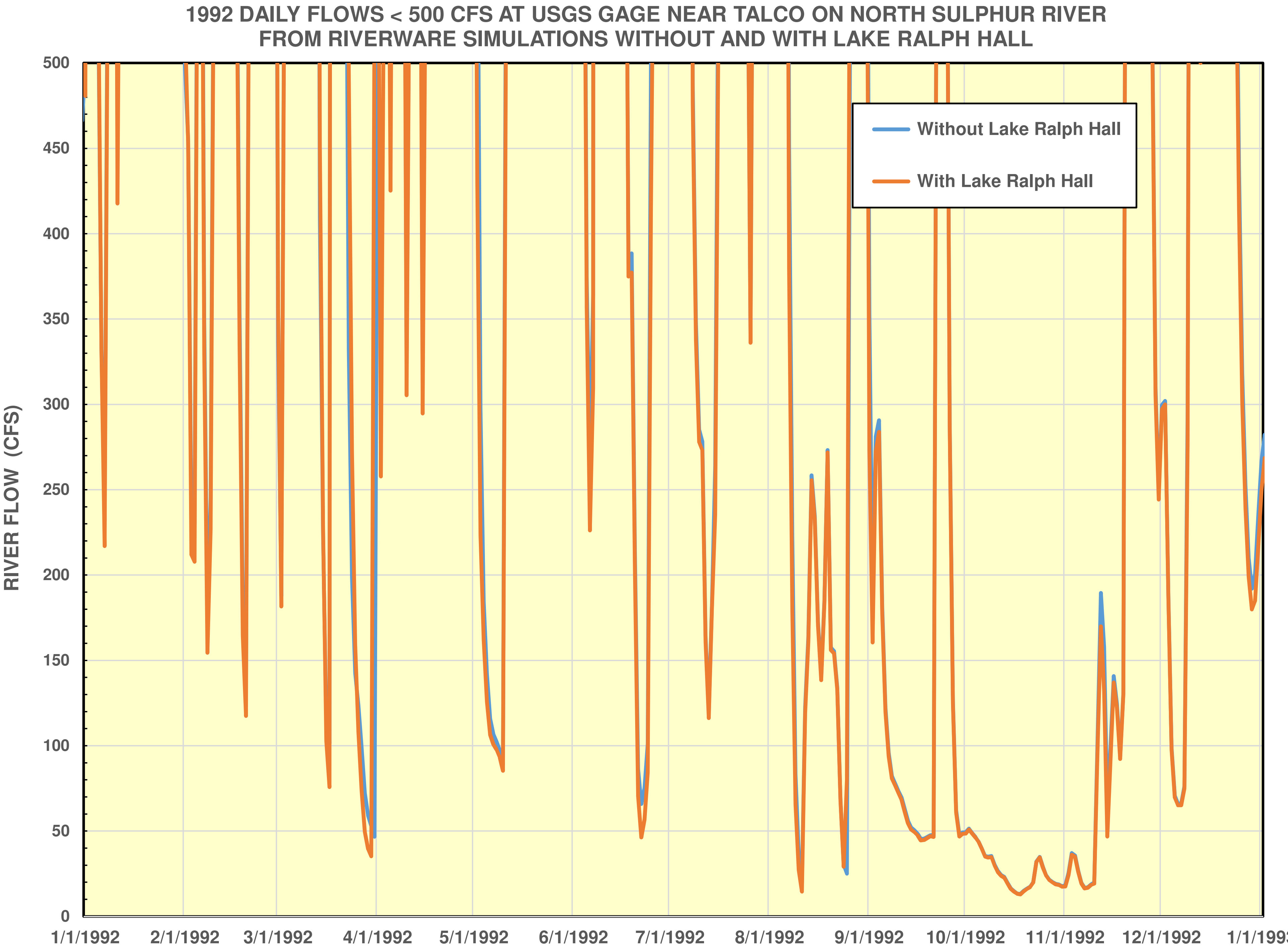
12/1/1980
1/1/1981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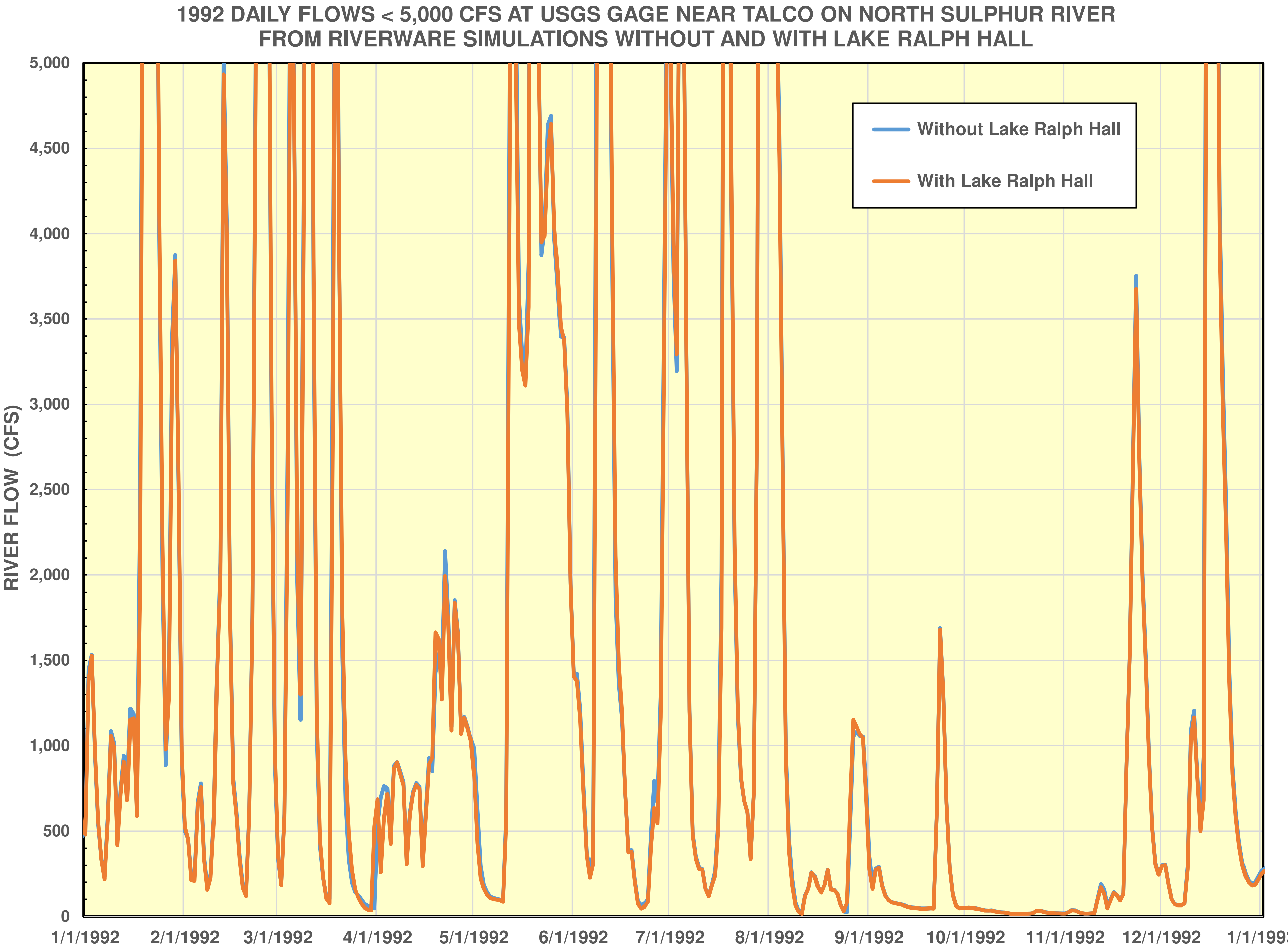
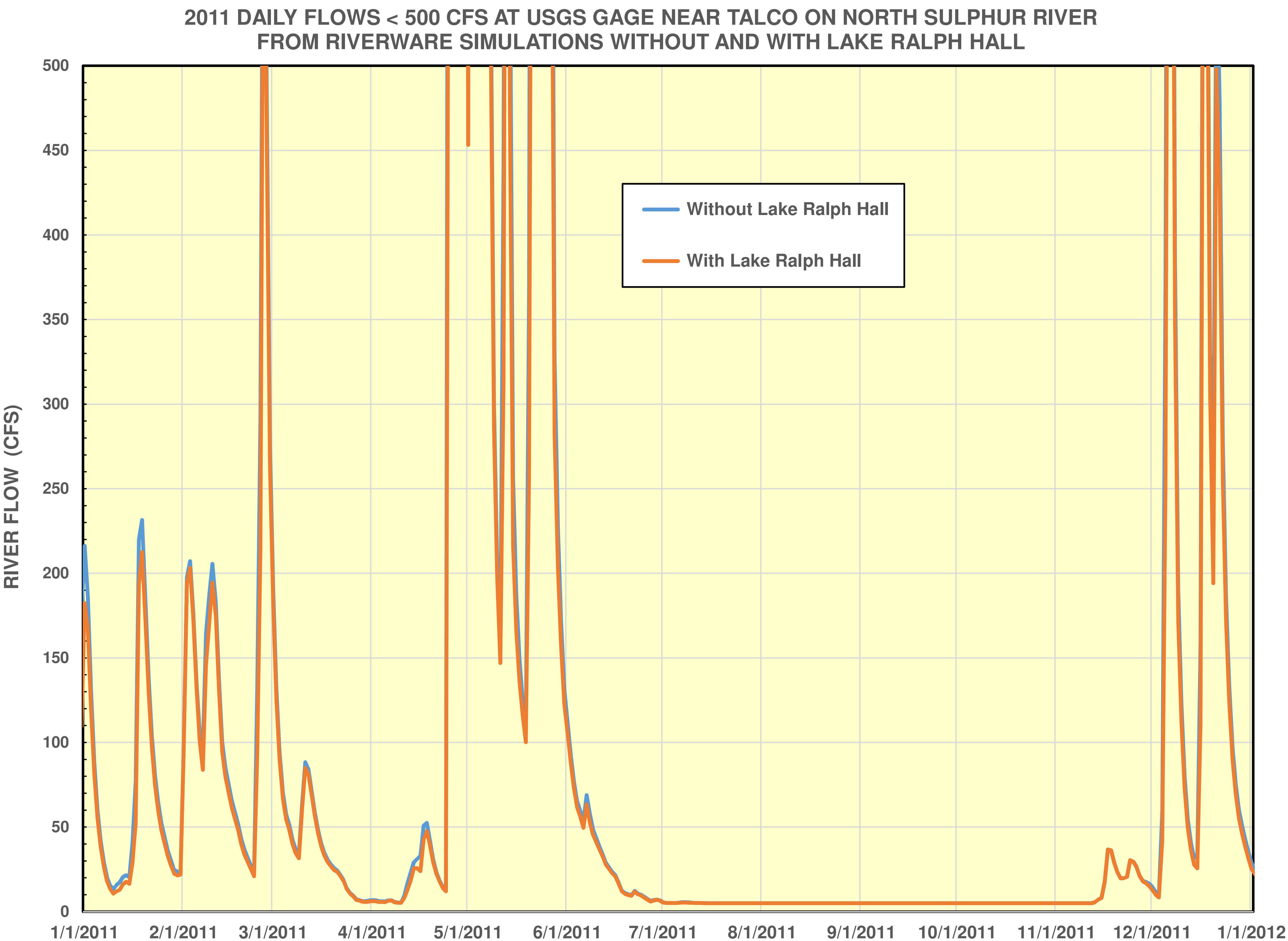
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall


1992 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall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FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
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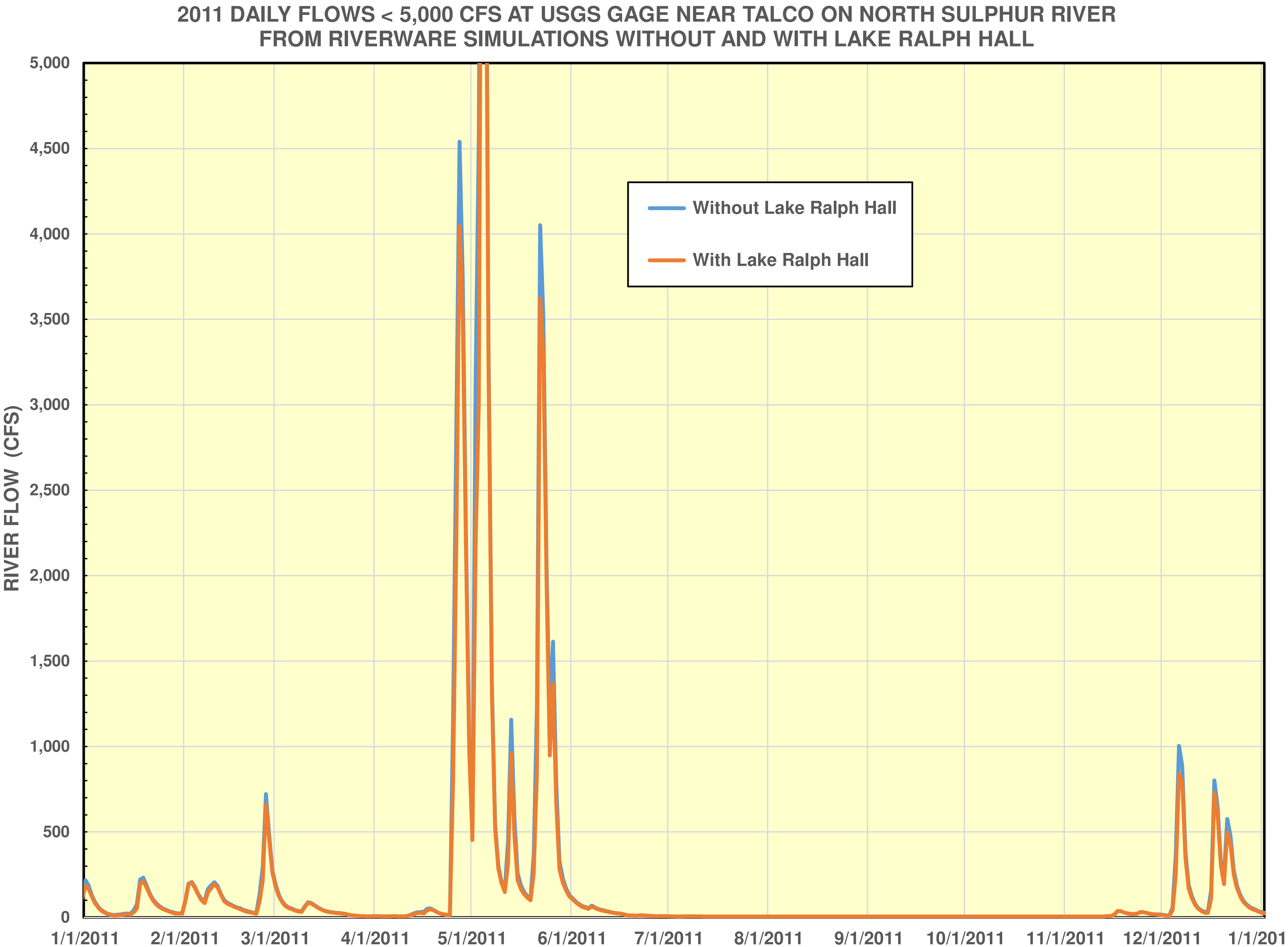
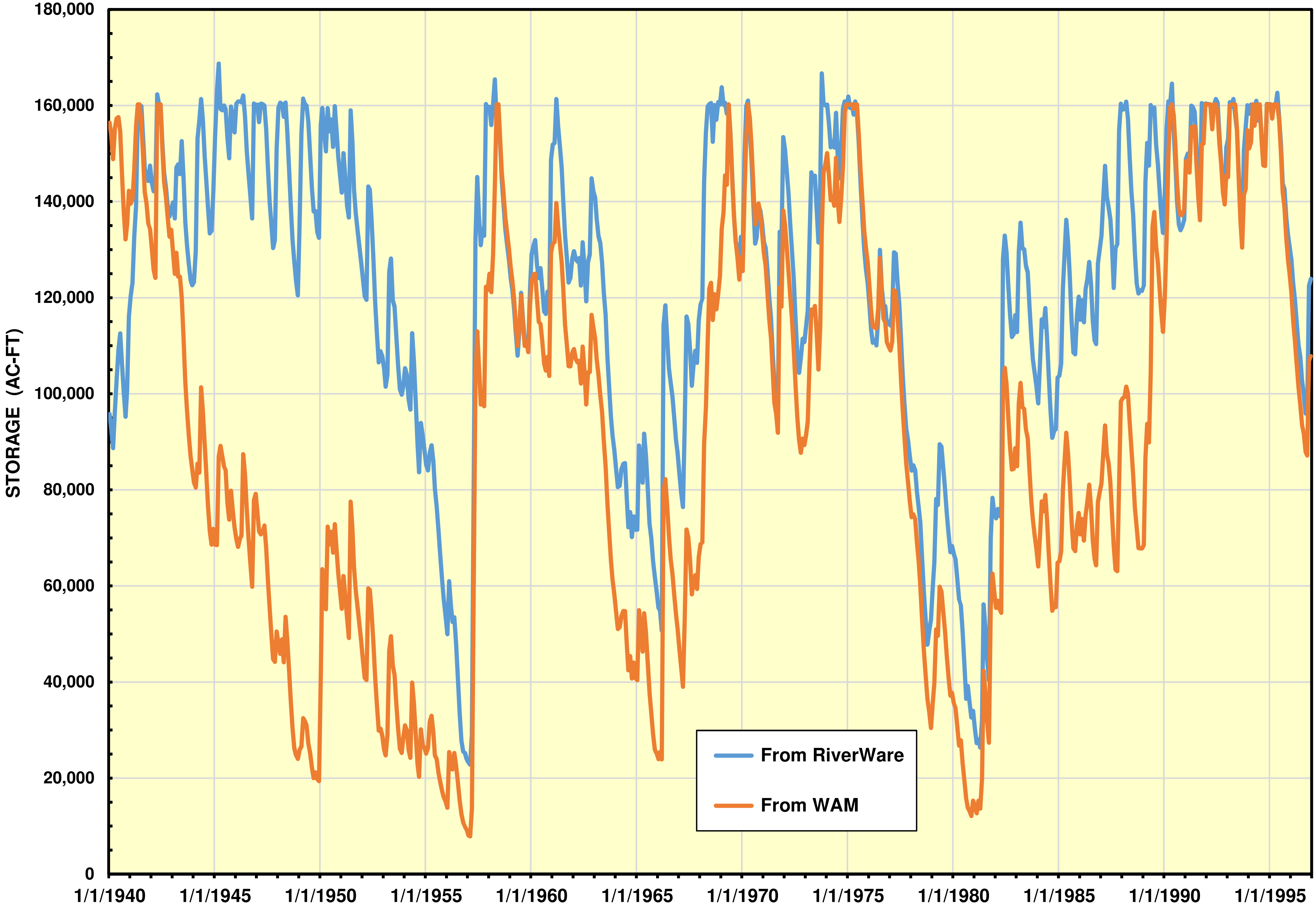
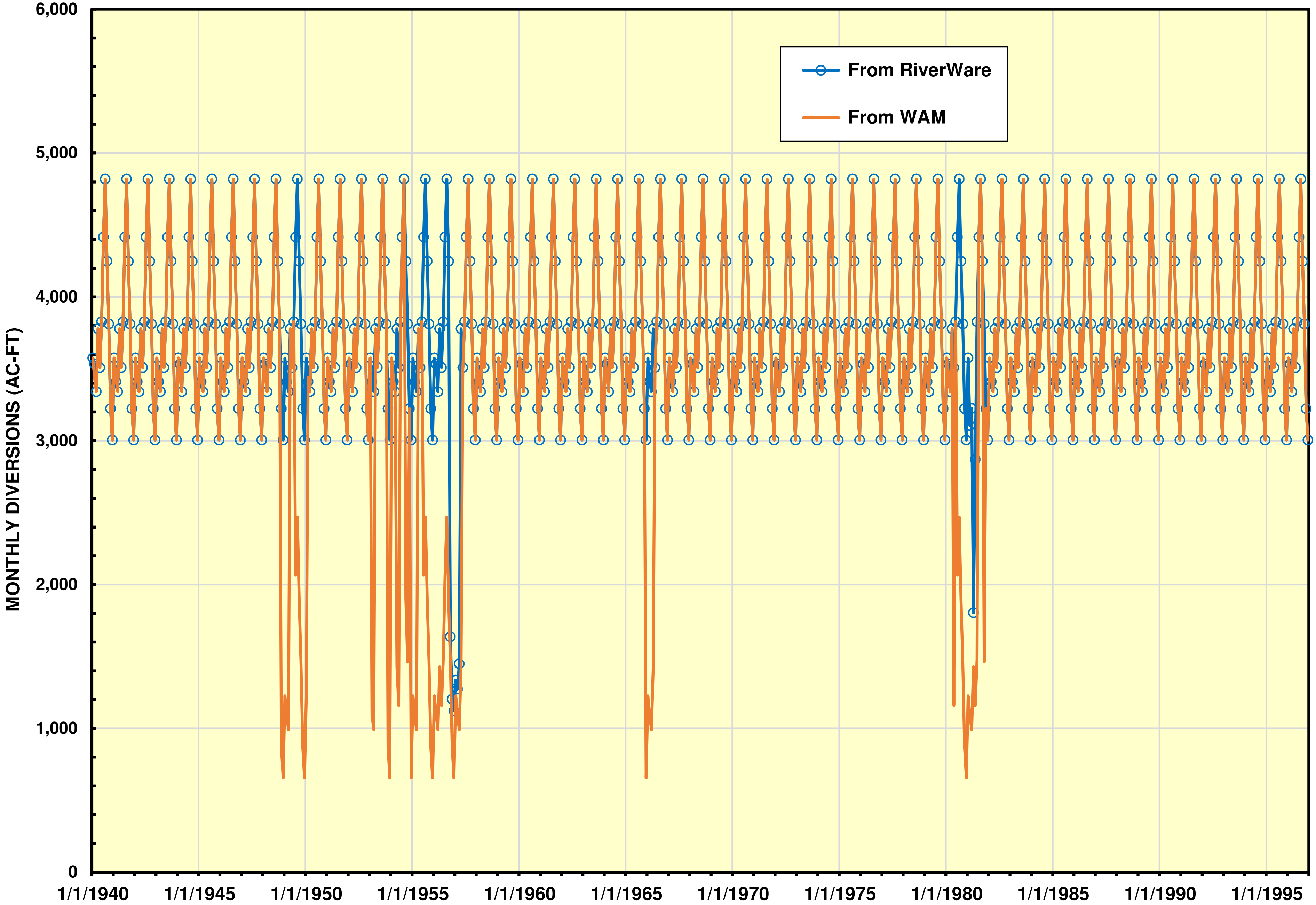
12/1/2011
1/1/2012


2011 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012

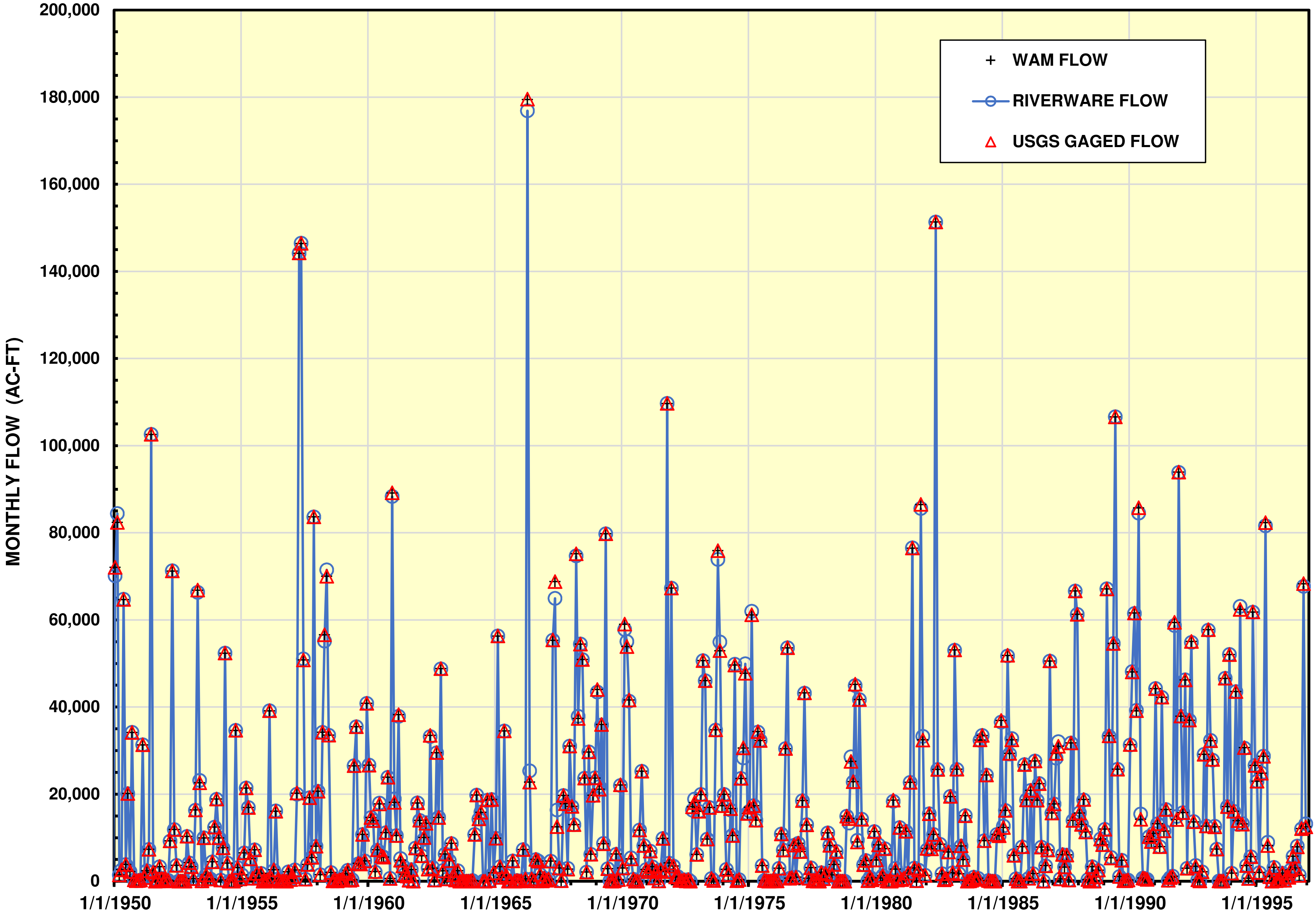
MONTHLY STORAGE IN LAKE RALPH HALL
FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



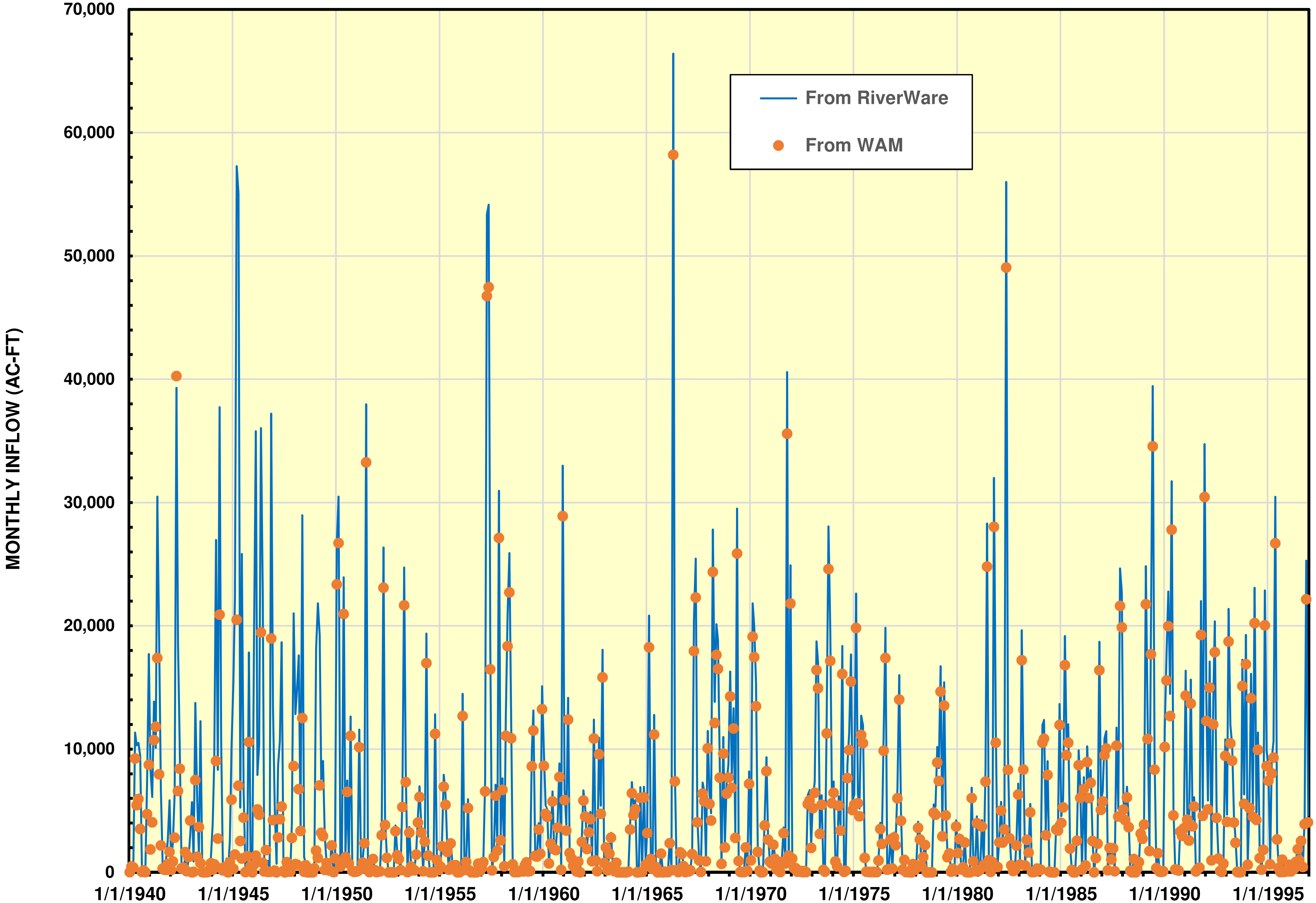
MONTHLY DIVERSIONS FROM LAKE RALPH HALL FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



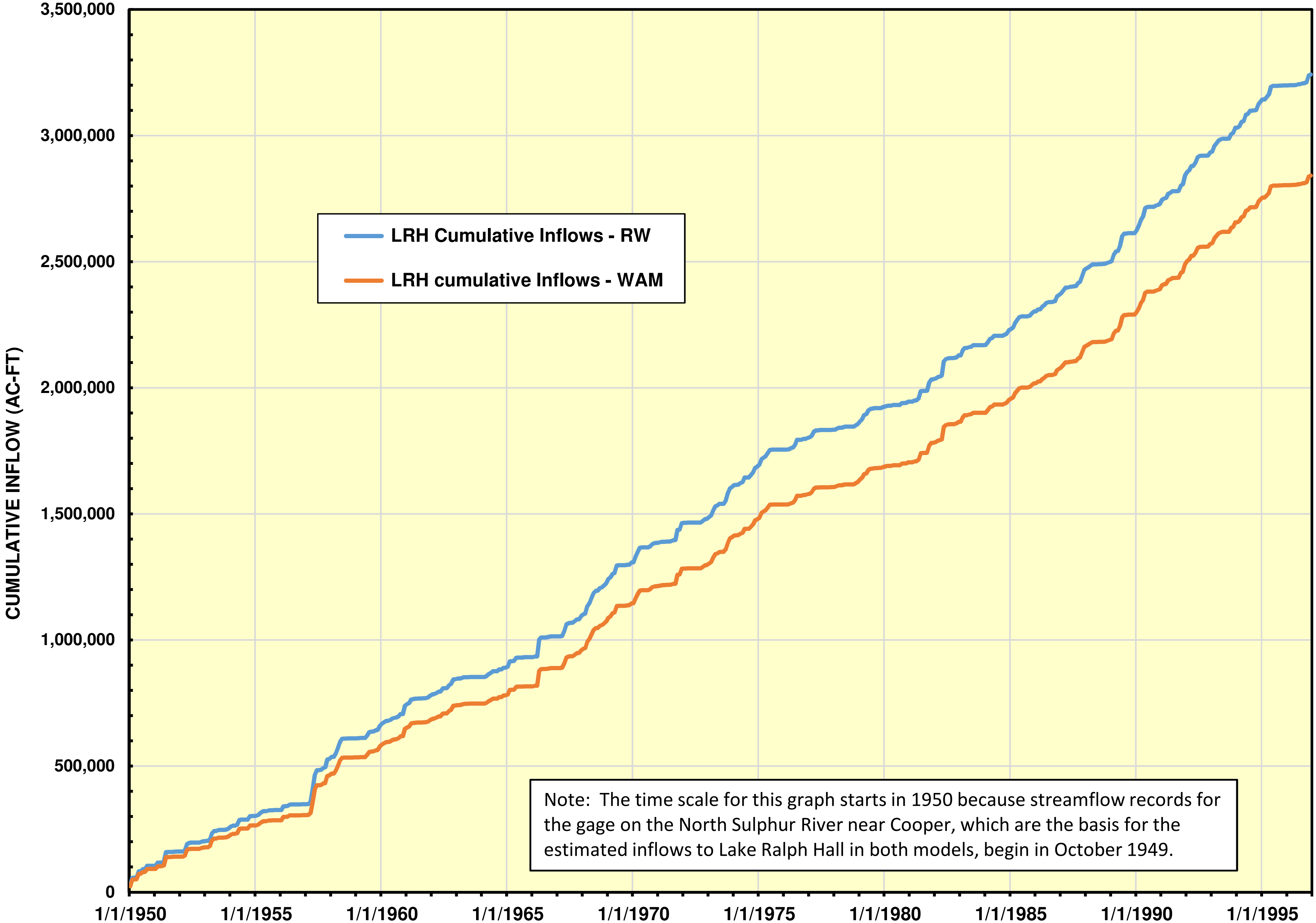
MONTHLY FLOWS AT NORTH SULPHUR RIVER GAGE NEAR COOPER FROM RIVERWARE AND WAM WITHOUT LAKE RALPH HALL AND FROM USGS GAGE



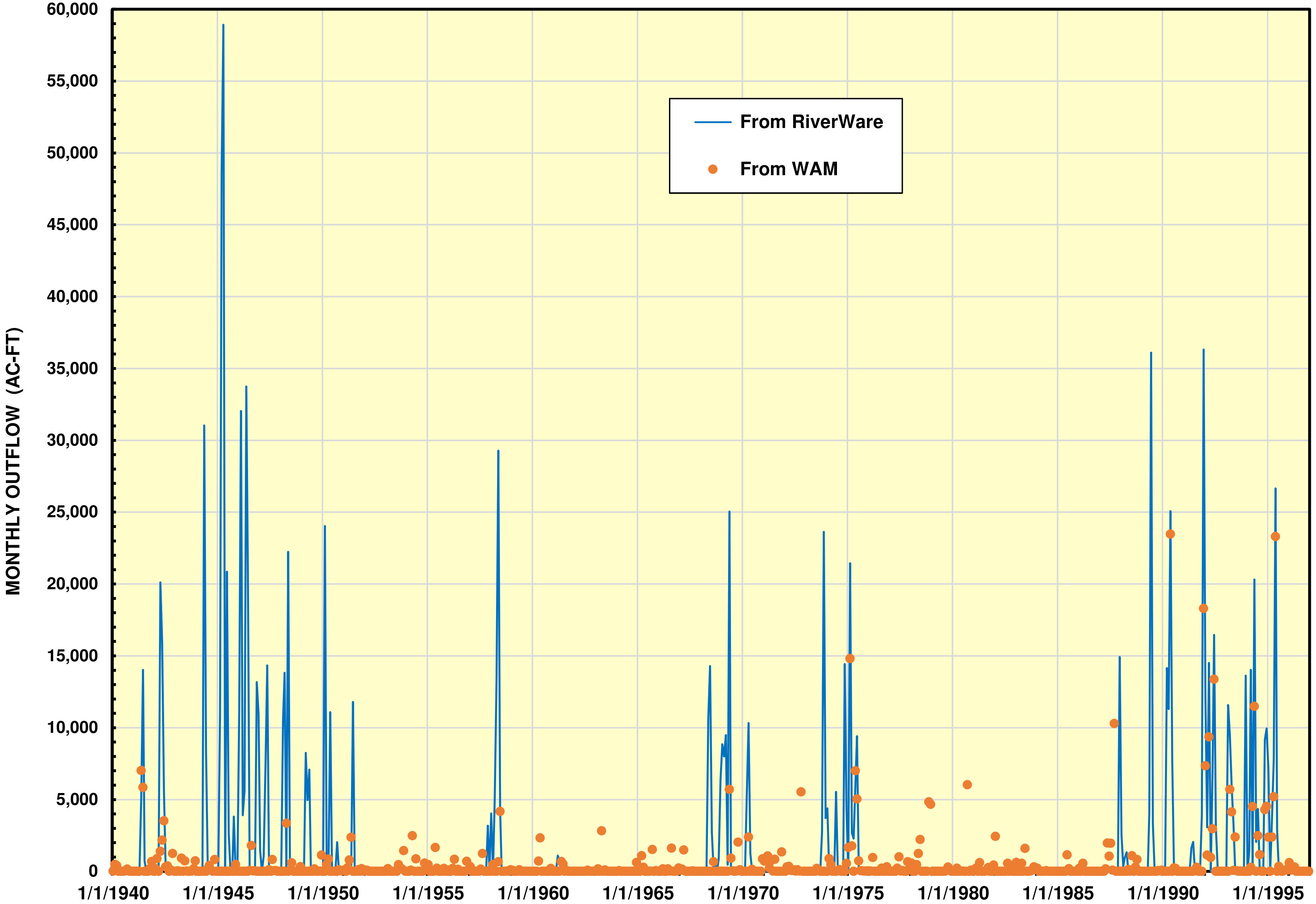
MONTHLY INFLOWS TO LAKE RALPH HALL FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



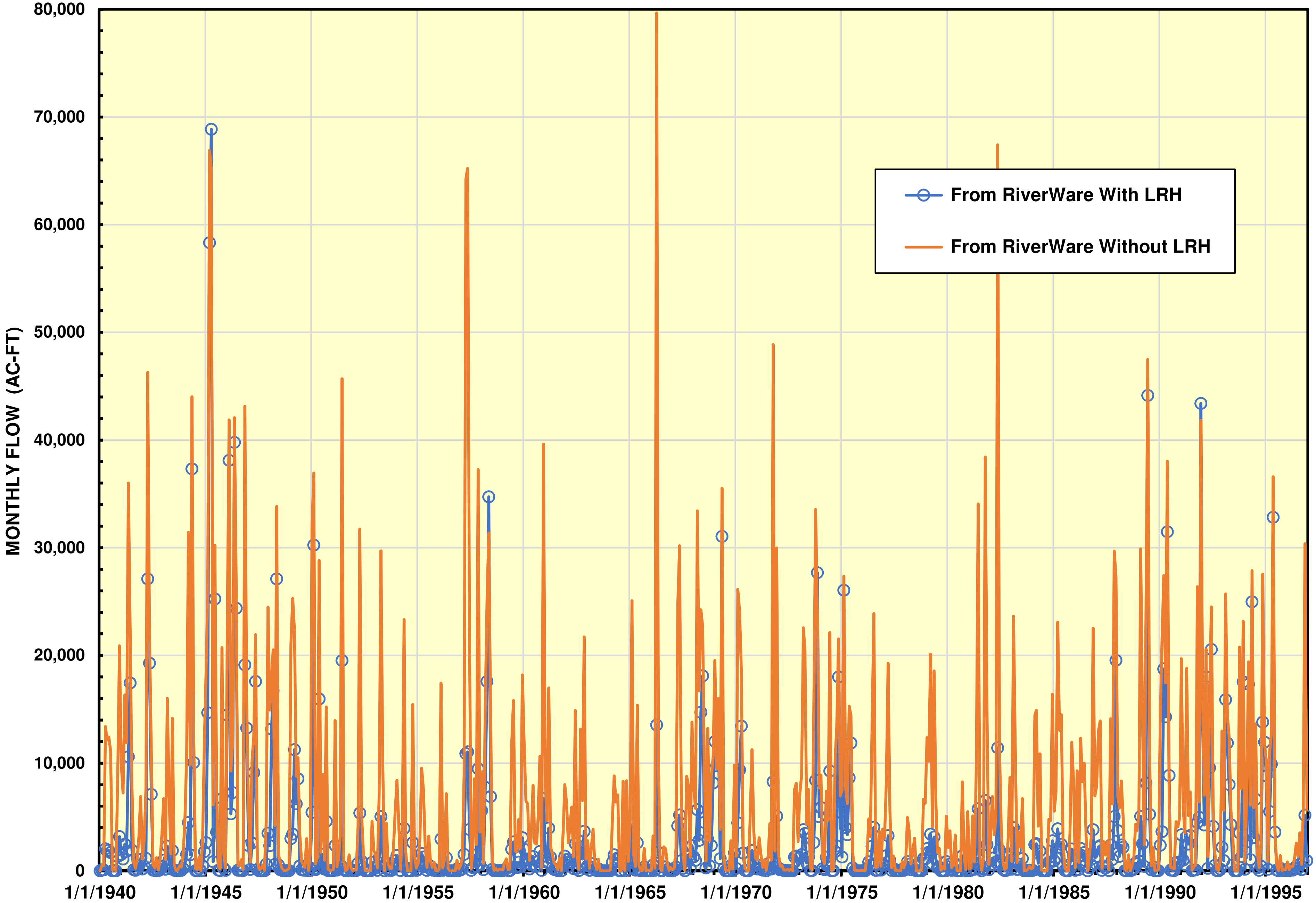
CUMULATIVE MONTHLY INFLOWS TO LAKE RALPH HALL BEGINNING IN 1950 FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



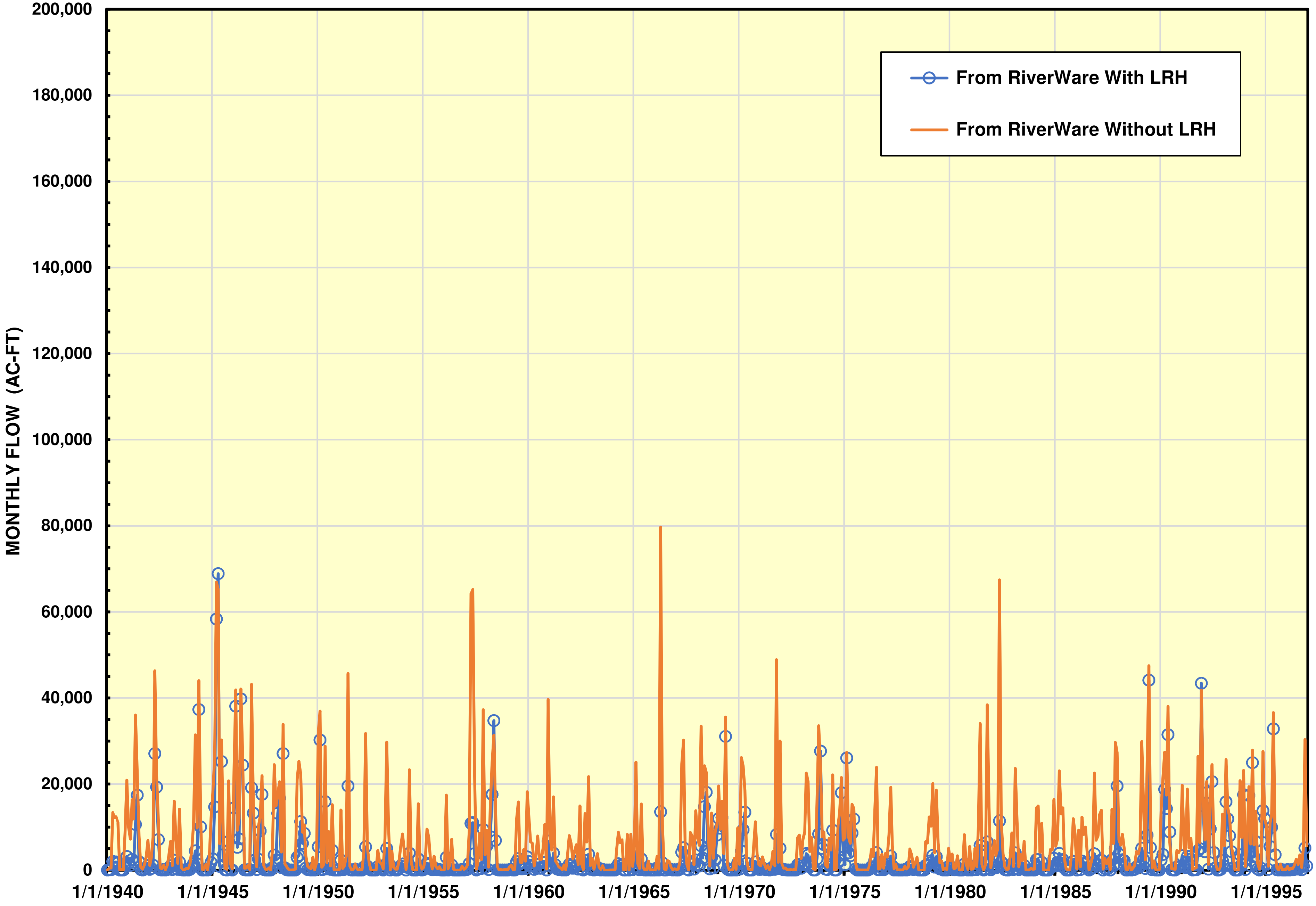
MONTHLY OUTFLOWS FROM LAKE RALPH HALL
FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL

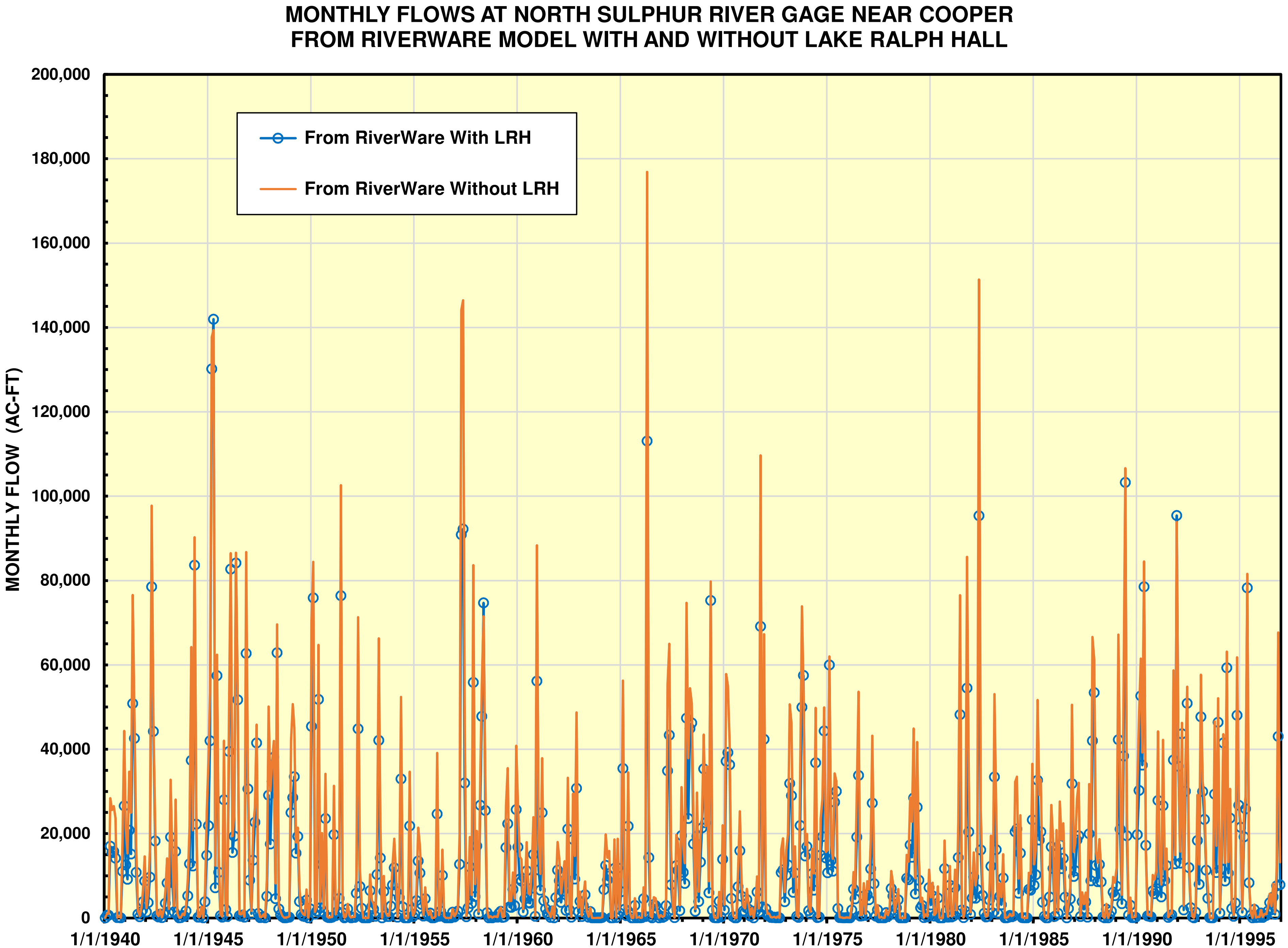


MONTHLY FLOWS BELOW LAKE RALPH HALL DAM SITE AT BAKER CREEK CONFLUENCE FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL



MONTHLY FLOWS BELOW LAKE RALPH HALL DAM SITE AT BAKER CREEK CONFLUENCE FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL




MONTHLY FLOWS AT NORTH SULPHUR RIVER GAGE NEAR COOPER
FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL
From RiverWare With LRH
From RiverWare Without LRH
MONTHLY FLOW (AC-FT)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1/1/1940
1/1/1945
1/1/1950
1/1/1955
1/1/1960
1/1/1965
1/1/1970
1/1/1975
1/1/1980
1/1/1985
1/1/1990
1/1/1995

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE AND FROM WAM WITH LAKE RALPH HALL

	RiverWare	WAM
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	62.2%	73.0%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	82.1%	83.8%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon
1.0%	99.0%	0	0	0	0	0	2	1	3	308	208	308	284
2.0%	98.0%	0	0	0	0	0	3	5	4	316	310	341	416
3.0%	97.0%	0	0	0	0	0	4	11	10	343	378	369	472
4.0%	96.0%	3	2	1	3	4	9	30	23	350	384	442	509
5.0%	95.0%	5	4	1	5	9	16	38	34	394	423	527	590
7.0%	93.0%	13	8	3	9	22	28	63	57	455	473	720	751
10.0%	90.0%	27	17	5	19	45	54	114	121	658	587	1,046	1,180
15.0%	85.0%	76	48	14	47	115	149	288	364	1,051	1,053	1,740	1,919
16.2%	83.8%	90	57	18	53	147	175	329	425	1,151	1,201	2,172	2,389
17.9%	82.1%	111	78	21	66	175	235	420	503	1,462	1,278	2,801	3,199
20.0%	80.0%	137	105	26	93	217	290	510	677	1,727	1,539	3,657	3,713
25.0%	75.0%	239	181	46	148	385	531	985	1,057	3,086	2,708	5,774	5,251
27.0%	73.0%	281	210	54	175	450	612	1,151	1,365	3,871	3,706	6,747	6,034
30.0%	70.0%	427	294	74	216	622	801	1,495	1,925	4,750	4,630	8,313	8,534
35.0%	65.0%	719	558	136	279	1,133	1,417	2,494	3,058	7,525	6,802	13,183	10,734
37.8%	62.2%	900	665	175	347	1,462	1,721	2,971	3,867	10,190	8,458	17,103	13,954
40.0%	60.0%	1,006	775	200	399	1,653	2,002	3,481	4,583	12,496	9,491	19,602	15,409
45.0%	55.0%	1,407	1,082	289	580	2,401	2,687	5,245	5,949	18,340	12,596	28,830	23,245
50.0%	50.0%	2,282	1,564	464	703	3,858	3,686	8,023	9,206	26,824	18,267	40,908	32,715
55.0%	45.0%	3,045	2,332	623	873	5,163	5,292	10,668	11,533	37,805	24,879	53,370	42,984
60.0%	40.0%	4,134	2,999	883	1,045	7,131	6,710	14,234	14,376	47,497	33,221	71,843	54,994
65.0%	35.0%	5,321	3,984	1,211	1,241	9,225	8,393	18,076	18,587	61,125	45,782	88,631	73,743
70.0%	30.0%	6,622	4,888	1,521	1,470	11,757	10,596	23,588	22,868	79,418	65,486	103,849	92,557
75.0%	25.0%	8,405	6,029	2,217	1,824	14,846	12,991	28,116	29,924	98,188	79,181	130,400	127,491
80.0%	20.0%	10,811	7,705	3,078	2,418	19,379	17,072	35,927	36,748	123,556	104,573	171,682	151,680
85.0%	15.0%	13,673	10,382	4,480	3,096	25,781	22,466	46,575	45,590	155,803	135,489	208,709	190,183
90.0%	10.0%	18,784	14,228	8,361	4,370	35,820	30,500	62,134	58,028	198,349	175,216	255,076	243,622
93.0%	7.0%	21,825	17,406	11,975	5,443	43,397	36,793	76,704	78,355	257,081	216,641	322,727	306,866
95.0%	5.0%	24,891	19,863	15,947	6,296	49,700	43,180	89,430	92,857	290,876	284,076	382,976	375,193
96.0%	4.0%	26,864	21,407	17,862	6,954	54,159	45,865	96,410	95,949	323,213	314,282	421,932	418,985
97.0%	3.0%	30,469	22,901	19,541	8,289	61,368	50,686	105,126	103,312	345,471	343,599	432,516	458,729
98.0%	2.0%	35,099	26,692	27,108	11,373	77,062	57,164	122,428	121,197	379,523	377,268	480,264	501,764
99.0%	1.0%	39,638	33,484	35,168	13,319	91,093	79,347	147,879	151,390	431,441	445,099	562,465	569,985
99.1%	0.9%	40,419	34,369	36,952	14,273	92,034	81,036	148,070	154,008	445,392	451,806	583,688	574,870
99.99%	0.01%	65,795	57,578	68,143	30,362	141,161	119,938	208,524	211,279	606,742	673,524	733,092	877,480

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE AND FROM WAM WITHOUT LAKE RALPH HALL

	RiverWare	WAM
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	79.6%	77.4%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	85.5%	83.9%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	FLOW AT LAKE RALPH HALL DAM SITE		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon
1.0%	99.0%	0	0	0	0	0	2	1	3	308	208	308	284
2.0%	98.0%	0	0	0	0	0	3	7	4	317	310	344	416
3.0%	97.0%	0	0	0	0	0	4	13	10	346	378	392	472
4.0%	96.0%	3	2	3	3	7	9	37	23	369	384	472	509
5.0%	95.0%	5	4	6	5	14	16	55	34	411	423	534	590
7.0%	93.0%	13	8	16	11	36	28	83	57	496	473	774	751
10.0%	90.0%	27	17	33	21	73	55	150	121	694	587	1,142	1,198
14.5%	85.5%	67	42	81	53	175	134	359	337	1,134	983	1,757	1,863
15.0%	85.0%	76	48	91	60	200	150	381	374	1,182	1,053	1,913	1,939
16.1%	83.9%	88	56	106	69	235	175	430	421	1,299	1,201	2,370	2,453
20.0%	80.0%	137	105	163	131	360	327	731	691	2,019	1,604	3,845	3,812
20.5%	79.6%	147	106	175	133	370	331	760	727	2,118	1,642	4,269	3,941
22.6%	77.4%	196	140	233	175	508	438	894	907	2,767	2,185	5,275	4,384
25.0%	75.0%	239	181	283	226	637	560	1,297	1,068	3,486	2,907	6,486	5,462
30.0%	70.0%	427	294	503	368	1,007	911	2,139	1,993	5,794	4,761	9,477	8,559
35.0%	65.0%	719	558	859	697	1,864	1,724	3,194	3,424	8,666	7,289	14,329	11,054
40.0%	60.0%	1,006	775	1,213	967	2,662	2,390	4,504	4,838	14,348	9,807	21,706	16,383
45.0%	55.0%	1,407	1,082	1,654	1,351	3,702	3,337	6,918	6,546	21,168	14,049	30,418	25,207
50.0%	50.0%	2,282	1,564	2,748	1,953	6,103	4,819	10,317	10,683	29,881	20,578	41,964	33,876
55.0%	45.0%	3,045	2,332	3,674	2,912	8,216	7,193	13,709	14,082	41,520	27,605	56,561	45,630
60.0%	40.0%	4,134	2,999	4,974	3,745	11,140	9,241	18,641	17,926	53,220	36,086	77,273	59,338
65.0%	35.0%	5,321	3,984	6,475	4,977	14,611	12,279	23,018	22,405	65,830	49,758	94,761	77,924
70.0%	30.0%	6,622	4,888	7,932	6,104	17,763	15,061	29,660	27,658	85,531	68,570	111,283	96,196
75.0%	25.0%	8,405	6,029	10,144	7,529	22,106	18,597	35,934	35,918	106,032	87,441	140,059	132,052
80.0%	20.0%	10,811	7,705	12,957	9,622	28,326	23,757	44,314	42,962	131,134	113,998	181,748	160,522
90.0%	10.0%	18,784	14,228	22,501	17,768	49,903	43,878	74,562	71,524	214,631	188,588	268,410	255,851
93.0%	7.0%	21,825	17,406	25,778	21,736	55,542	53,675	90,564	93,102	269,188	234,764	333,275	323,591
95.0%	5.0%	24,891	19,863	29,967	24,804	66,111	61,264	103,576	110,149	308,811	301,091	399,997	390,320
96.0%	4.0%	26,864	21,407	31,828	26,733	70,919	65,990	116,735	113,552	342,029	326,063	433,457	433,702
97.0%	3.0%	30,469	22,901	36,303	28,598	80,704	70,599	124,159	126,166	361,655	368,055	447,459	475,112
98.0%	2.0%	35,099	26,692	41,839	33,332	86,632	82,322	137,801	142,550	401,174	394,235	499,927	515,625
99.0%	1.0%	39,638	33,484	47,723	41,814	107,136	103,241	164,893	184,164	433,424	463,329	596,116	598,896
99.9%	0.1%	60,174	51,960	71,297	64,886	159,440	160,240	234,060	255,580	636,248	714,960	747,687	828,098
99.99%	0.01%	65,795	57,578	78,816	71,901	175,146	177,515	240,444	260,229	654,534	722,475	770,216	925,058

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE WITH AND WITHOUT LAKE RALPH HALL

	With LRH	Without LRH
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	62.2%	79.6%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	82.1%	85.5%

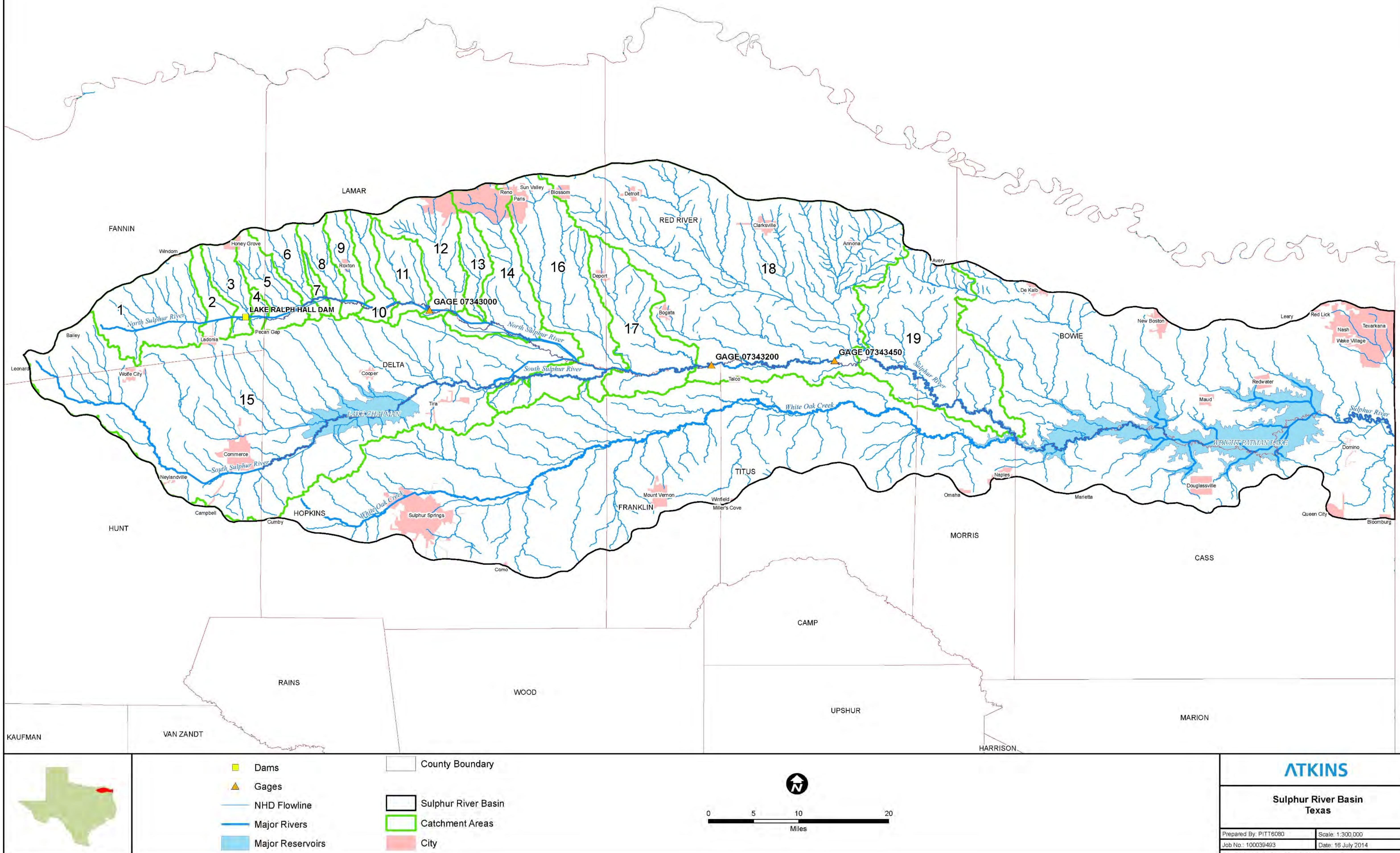
PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon
1.0%	99.0%	0	0	0	0	0	0	1	1	308	308	308	308
2.0%	98.0%	0	0	0	0	0	0	5	7	316	317	341	344
3.0%	97.0%	0	0	0	0	0	0	11	13	343	346	369	392
4.0%	96.0%	3	3	1	3	4	7	30	37	350	369	442	472
5.0%	95.0%	5	5	1	6	9	14	38	55	394	411	527	534
7.0%	93.0%	13	13	3	16	22	36	63	83	455	496	720	774
10.0%	90.0%	27	27	5	33	45	73	114	150	658	694	1,046	1,142
14.5%	85.5%	67	67	13	81	106	175	283	359	1,008	1,136	1,661	1,759
15.0%	85.0%	76	76	14	91	115	200	288	381	1,051	1,182	1,740	1,913
18.0%	82.1%	111	111	21	134	175	281	420	528	1,463	1,599	2,802	3,012
20.0%	80.0%	137	137	26	163	217	360	510	731	1,727	2,019	3,657	3,845
20.5%	79.6%	147	147	27	175	228	370	550	760	1,835	2,118	3,788	4,269
25.0%	75.0%	239	239	46	283	385	637	985	1,297	3,086	3,486	5,774	6,486
30.0%	70.0%	427	427	74	503	622	1,007	1,495	2,139	4,750	5,794	8,313	9,477
35.0%	65.0%	719	719	136	859	1,133	1,864	2,494	3,194	7,525	8,666	13,183	14,329
37.8%	62.2%	901	901	175	1,072	1,464	2,331	2,974	3,938	10,207	11,672	17,118	18,683
40.0%	60.0%	1,006	1,006	200	1,213	1,653	2,662	3,481	4,504	12,496	14,348	19,602	21,706
45.0%	55.0%	1,407	1,407	289	1,654	2,401	3,702	5,245	6,918	18,340	21,168	28,830	30,418
50.0%	50.0%	2,282	2,282	464	2,748	3,858	6,103	8,023	10,317	26,824	29,881	40,908	41,964
55.0%	45.0%	3,045	3,045	623	3,674	5,163	8,216	10,668	13,709	37,805	41,520	53,370	56,561
60.0%	40.0%	4,134	4,134	883	4,974	7,131	11,140	14,234	18,641	47,497	53,220	71,843	77,273
65.0%	35.0%	5,321	5,321	1,211	6,475	9,225	14,611	18,076	23,018	61,125	65,830	88,631	94,761
70.0%	30.0%	6,622	6,622	1,521	7,932	11,757	17,763	23,588	29,660	79,418	85,531	103,849	111,283
75.0%	25.0%	8,405	8,405	2,217	10,144	14,846	22,106	28,116	35,934	98,188	106,032	130,400	140,059
80.0%	20.0%	10,811	10,811	3,078	12,957	19,379	28,326	35,927	44,314	123,556	131,134	171,682	181,748
85.0%	15.0%	13,673	13,673	4,480	16,198	25,781	35,713	46,575	58,546	155,803	163,200	208,709	218,084
90.0%	10.0%	18,784	18,784	8,361	22,501	35,820	49,903	62,134	74,562	198,349	214,631	255,076	268,410
93.0%	7.0%	21,825	21,825	11,975	25,778	43,397	55,542	76,704	90,564	257,081	269,188	322,727	333,275
95.0%	5.0%	24,891	24,891	15,947	29,967	49,700	66,111	89,430	103,576	290,876	308,811	382,976	399,997
96.0%	4.0%	26,864	26,864	17,862	31,828	54,159	70,919	96,410	116,735	323,213	342,029	421,932	433,457
97.0%	3.0%	30,469	30,469	19,541	36,303	61,368	80,704	105,126	124,159	345,471	361,655	432,516	447,459
98.0%	2.0%	35,099	35,099	27,108	41,839	77,062	86,632	122,428	137,801	379,523	401,174	480,264	499,927
99.0%	1.0%	39,638	39,638	35,168	47,723	91,093	107,136	147,879	164,893	431,441	433,424	562,465	596,116
99.9%	0.1%	60,174	60,174	61,662	71,297	133,926	159,440	194,211	234,060	597,068	636,248	725,870	747,687
99.99%	0.01%	65,795	65,795	68,143	78,816	141,161	175,146	208,524	240,444	606,742	654,534	733,092	770,216

STATISTICAL ANALYSIS OF FLOWS FROM WAM WITH AND WITHOUT LAKE RALPH HALL

	With LRH	Without LRH
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	73.0%	77.4%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	83.8%	83.9%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
		With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH
%	%	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon
1.0%	99.0%	0	0	0	0	2	2	3	3	208	208	284	284
2.0%	98.0%	0	0	0	0	3	3	4	4	310	310	416	416
3.0%	97.0%	0	0	0	0	4	4	10	10	378	378	472	472
4.0%	96.0%	2	2	3	3	9	9	23	23	384	384	509	509
5.0%	95.0%	4	4	5	5	16	16	34	34	423	423	590	590
7.0%	93.0%	8	8	9	11	28	28	57	57	473	473	751	751
10.0%	90.0%	17	17	19	21	54	55	121	121	587	587	1,180	1,198
15.0%	85.0%	48	48	47	60	149	150	364	374	1,053	1,053	1,919	1,939
16.1%	83.9%	56	56	53	69	167	175	421	421	1,190	1,201	2,329	2,453
16.2%	83.8%	57	57	53	72	175	180	425	425	1,201	1,206	2,389	2,506
20.0%	80.0%	105	105	93	131	290	327	677	691	1,539	1,604	3,713	3,812
22.6%	77.4%	140	140	113	175	381	437	874	906	2,070	2,182	4,275	4,377
25.0%	75.0%	181	181	148	226	531	560	1,057	1,068	2,708	2,907	5,251	5,462
27.0%	73.0%	210	210	175	262	612	651	1,365	1,393	3,706	4,016	6,034	6,184
30.0%	70.0%	294	294	216	368	801	911	1,925	1,993	4,630	4,761	8,534	8,559
35.0%	65.0%	558	558	279	697	1,417	1,724	3,058	3,424	6,802	7,289	10,734	11,054
40.0%	60.0%	775	775	399	967	2,002	2,390	4,583	4,838	9,491	9,807	15,409	16,383
45.0%	55.0%	1,082	1,082	580	1,351	2,687	3,337	5,949	6,546	12,596	14,049	23,245	25,207
50.0%	50.0%	1,564	1,564	703	1,953	3,686	4,819	9,206	10,683	18,267	20,578	32,715	33,876
55.0%	45.0%	2,332	2,332	873	2,912	5,292	7,193	11,533	14,082	24,879	27,605	42,984	45,630
60.0%	40.0%	2,999	2,999	1,045	3,745	6,710	9,241	14,376	17,926	33,221	36,086	54,994	59,338
65.0%	35.0%	3,984	3,984	1,241	4,977	8,393	12,279	18,587	22,405	45,782	49,758	73,743	77,924
70.0%	30.0%	4,888	4,888	1,470	6,104	10,596	15,061	22,868	27,658	65,486	68,570	92,557	96,196
75.0%	25.0%	6,029	6,029	1,824	7,529	12,991	18,597	29,924	35,918	79,181	87,441	127,491	132,052
80.0%	20.0%	7,705	7,705	2,418	9,622	17,072	23,757	36,748	42,962	104,573	113,998	151,680	160,522
90.0%	10.0%	14,228	14,228	4,370	17,768	30,500	43,878	58,028	71,524	175,216	188,588	243,622	255,851
93.0%	7.0%	17,406	17,406	5,443	21,736	36,793	53,675	78,355	93,102	216,641	234,764	306,866	323,591
95.0%	5.0%	19,863	19,863	6,296	24,804	43,180	61,264	92,857	110,149	284,076	301,091	375,193	390,320
96.0%	4.0%	21,407	21,407	6,954	26,733	45,865	65,990	95,949	113,552	314,282	326,063	418,985	433,702
97.0%	3.0%	22,901	22,901	8,289	28,598	50,686	70,599	103,312	126,166	343,599	368,055	458,729	475,112
98.0%	2.0%	26,692	26,692	11,373	33,332	57,164	82,322	121,197	142,550	377,268	394,235	501,764	515,625
99.0%	1.0%	33,484	33,484	13,319	41,814	79,347	103,241	151,390	184,164	445,099	463,329	569,985	598,896
99.9%	0.1%	51,960	51,960	30,086	64,886	108,282	160,240	207,607	255,580	666,987	714,960	779,543	828,098
99.99%	0.01%	57,578	57,578	30,362	71,901	119,938	177,515	211,279	260,229	673,524	722,475	877,480	925,058

ATTACHMENT D



ATTACHMENT E

SUMMARY OF ANALYSIS OF FILLING RIVER CHANNEL POOLS DOWNSTREAM OF LAKE RALPH HALL WITH NORTH SULPHUR RIVER FLOWS SIMULATED WITH RIVERWARE MODEL AND WITH WAM FOR CONDITIONS WITHOUT AND WITH LAKE RALPH HALL PROJECT

STATION NO.	WATER COURSE	LOCATION DESCRIPTION	DRAINAGE AREA sq. mi.	DISTANCE ABOVE N SULPHUR GAGE miles	VOLUME REQUIRED TO FILL ALL D/S POOLS ac-ft	POOL VOLUME IN EACH D/S REACH ac-ft	% OF TIME POOLS ARE FILLED		
							Without Lake Ralph Hall	With Lake Ralph Hall	Deviation From Without LRH Case
FROM RIVERWARE MODEL (06-26-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	- -	- -	- -	- -
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	92.7%	83.6%	-9.1%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	86.7%	73.2%	-13.5%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	85.8%	82.0%	-3.8%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	86.7%	86.3%	-0.4%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	85.8%	85.4%	-0.4%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	85.4%	83.6%	-1.8%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	89.8%	89.6%	-0.1%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	85.1%	82.7%	-2.3%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	- -	- -	- -	- -
FROM WAM (04-06-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	- -	- -	- -	- -
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	90.8%	90.2%	-0.6%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	84.8%	83.5%	-1.3%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	83.9%	83.8%	-0.1%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	85.4%	85.4%	0.0%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	83.9%	83.9%	0.0%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	83.3%	83.2%	-0.1%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	88.6%	88.6%	0.0%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	83.2%	83.0%	-0.1%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	- -	- -	- -	- -

Robert J. Brandes Consulting

MEMORANDUM

To: Ed Motley
CH2M-Hill

From: Bob Brandes
Kirk Kennedy

Subject: Lake Ralph Hall
RiverWare Modeling

Date: June 29, 2015

As directed by the Upper Trinity Regional Water District (UTRWD), we have responded to the request from Corps of Engineers Fort Worth Office (Corps) to operate the Corps' daily RiverWare model of the Sulphur, Cypress and Red River Basins under conditions without and with the Lake Ralph Hall Project. From the modeling results, we have extracted daily river flows at locations along the North Sulphur and Sulphur Rivers where computational nodes exist in the model, and we have analyzed these flows with regard to frequency of occurrence and the frequency of filling river channel pools along the segment of the North Sulphur River from the proposed Lake Ralph Hall dam site downstream to the USGS streamflow gage near Cooper (Gage No. 07343000). We also have extracted and analyzed the daily storage and diversions for Lake Ralph Hall as simulated with the RiverWare model.

The version of the RiverWare model provided by the Corps included the physical representation of Lake Ralph Hall, but it did not have any diversions specified for withdrawing water from the reservoir as proposed by the UTRWD. We incorporated the same diversion routine that was used in the WAM for the previous analyses of the impacts of Lake Ralph Hall on monthly river flows that were conducted in July of 2014. This routine allows monthly diversions equivalent to 45,000 acre-feet per year to be made from Lake Ralph Hall provided the beginning-of-month storage in the reservoir exceeds 27,500 acre-feet, with the monthly diversions reduced to the equivalent of 16,800 acre-feet per year when the storage falls below 27,500 acre-feet. As originally modeled with the WAM, this operating procedure was designed to protect a firm annual yield of 16,800 acre-feet for Lake Ralph Hall while allowing overdrafting of the reservoir up to the full authorized diversion amount of 45,000 acre-feet per year when adequate stored water is available in the reservoir.

The period of record for the hydrologic conditions simulated with the daily RiverWare model is 1938 through 2014, which encompasses the monthly hydrologic conditions simulated with the WAM that extend from 1940 through 1996. While the source and derivation of the monthly naturalized flows used in the WAM are well documented, we do not have information regarding the procedures used to develop the daily flows that are input into the RiverWare model; however, as will be demonstrated, it is apparent that historical flow data for the North Sulphur River from the USGS streamflow gage near Cooper, to the extent they are available, have been used for representing flow conditions in the RiverWare model for at least the upper segment of the North

6000 Maurys Trail
Austin, Texas 78730
robert.brandes@atkinsglobal.com
Office Phone: 512/342-3233
Mobile Phone: 512/461-1477

Sulphur River. As we have discussed before, the RiverWare model does not apply the prior appropriation doctrine for allocating available streamflows among existing water rights in the Sulphur Basin, so in the model no streamflows are ever required to be passed downstream during water shortage periods by the more junior water rights to satisfy the demands of the more senior water rights. Furthermore, it appears that the only demands associated with existing water rights in the entire Sulphur Basin that are included in the RiverWare model are those for Lake Chapman and Lake Wright Patman; all other water rights are not represented. The WAM includes all existing water rights in the Sulphur Basin, with total authorized diversions of about 500,000 acre-feet per year, and allocates water to these water rights in order of seniority as required under Texas state law; so in the WAM, Lake Ralph Hall, with its relatively junior priority, must pass inflows downstream whenever senior water rights are not fully satisfied. These differences in the models regarding how streamflow allocations are made to existing water rights are reflected in their respective simulated river flows.

Since the WAM uses a monthly time step for performing water availability simulations, the underlying purpose for applying the daily RiverWare model was to be able to evaluate daily flow variations under conditions without and with Lake Ralph Hall. Therefore, the first set of results presented herein consists of plots of simulated daily flows, expressed in cubic feet per second (cfs), at USGS Gage No. 07343000 on the North Sulphur River near Cooper (see Attachment A) and at Gage No. 07343200 on the Sulphur River near Talco (see Attachment B). These depictions of daily flows illustrate conditions on the eroded and degraded segment of the North Sulphur River, as well as on the more natural segment of the Sulphur River below the confluence with the South Sulphur River and also below the infamous log jam. Graphs of daily flows covering one calendar year each are presented for 1956, 1980, 1992 and 2011, with two graphs with maximum flow scales of 500 cfs and 5,000 cfs provided for each year. The selected years are characterized by periods of extremely low flows (1956 and 2011), varying flows (1980), and very high flows (1992). As expected, these plots of daily flows without and with Lake Ralph Hall indicate some reduction in peak flows for individual flood events as a result of the reservoir, with these reductions more pronounced at the upper gage on the North Sulphur River. The peak flow reductions are less pronounced at the lower gage on the Sulphur River, as would be expected with the increased tributary inflows from the intervening watershed. Since the major reductions in peak flows are limited to the eroded and degraded channel of the North Sulphur River where overbanking of adjacent floodplain areas typically does not occur, the impacts of these reduced peak flows are not likely to be significant.

We have also compiled the daily simulated flows from the RiverWare model into monthly values to better provide meaningful comparisons of conditions without and with Lake Ralph Hall and to facilitate comparisons with the results from the WAM. Attachment C contains a group of plots and tables illustrating these comparisons for locations along the North Sulphur and Sulphur Rivers where the RiverWare model has computational nodes.

The first two plots on pages 1 and 2 of Attachment C show the storage in Lake Ralph Hall and the diversions from the reservoir as simulated with the RiverWare model and with the WAM. As illustrated, the simulated storage in the reservoir is considerably greater for the RiverWare model, with substantially more spills from the reservoir downstream into the North Sulphur River. As shown on the graph on page 2, during these higher storage periods, more water is able to be diverted from the reservoir since the criterion for making diversions up to the fully authorized amount of 45,000 acre-feet/year is satisfied more often.

The disparity between the storage results for Lake Ralph Hall from the RiverWare model and the WAM leads to questions as to the source and magnitude of the inflows to the reservoir as simulated with the two models, notwithstanding the fact that the RiverWare model ignores water rights and does not require junior water rights to pass flows to downstream senior water rights during times of water shortage. It is assumed that both models utilize historical flow data from the gage on the North Sulphur River near Cooper as the underlying basis for their specified river flow inputs for this segment of the overall river system network. This has been confirmed by comparing the simulated flows in the river at this gage location without Lake Ralph Hall in operation. As shown on the graph on page 3 of Attachment C, the monthly flow values from the two models at the gage location and the corresponding measured monthly flows at the gage are essentially the same over the common period of the model simulations when the gage was in operation (which began in October 1949). This analysis rules out the possibility that different sources of flow data were used for the upper segment of the North Sulphur River in the two models. However, when this same comparison is made of the simulated inflows to Lake Ralph Hall approximately 20 miles upstream from the gage, differences are noted between the two models. The graph on page 4 of Attachment C indicates that the simulated inflows to Lake Ralph Hall for the RiverWare model generally are higher than those for the WAM. This graph also indicates that apparently different base flows were used in the models prior to the existence of the gage in 1949, possibly due to the application of different data fill-in techniques. The graph on page 5 of Attachment C presents a time-series plot of the cumulative inflows to Lake Ralph Hall as simulated with the two models for the common period when the gage was in operation beginning in 1950, and it further illustrates the differences in these two sets of inflows, with the total cumulative deviation over 50 years approaching about 500,000 acre-feet. The differences in the inflows to Lake Ralph Hall during the period when gage flow records are available may be due to the fact that the RiverWare model uses a daily time step, with various flow routing parameters and lag coefficients to account for the movement of water downstream, whereas the WAM uses a monthly time step with no time adjustments other than those reflected in the flow data themselves. In any event, these differences in the inflows to Lake Ralph Hall between the two models are worthy of note, and they are likely reflected in the simulated flows downstream and must be considered when evaluating results.

A plot of the monthly simulated outflows from Lake Ralph Hall for the two models is presented on the graph on page 6 of Attachment C, again illustrating the significant spills from the reservoir as simulated with the RiverWare model. Inflows periodically passed downstream for satisfying the demands of senior water rights also are indicated on this plot by the WAM flows during dry periods. Monthly flows from the RiverWare model at the location of the first tributary downstream of Lake Ralph Hall (Baker Creek), which enters the North Sulphur River approximately one mile below the dam, are plotted with two different scales on the graphs on pages 7 and 8 of Attachment C for conditions without and with Lake Ralph Hall. Both plots illustrate the obvious; more flow is in the river downstream without Lake Ralph Hall than with it. The graph on page 9 of Attachment C depicts similar results at the location of the gage on the North Sulphur River near Cooper, but it is interesting to compare the flow magnitudes in this graph with those in the graph on page 8, both of which are plotted at the same flow scale. This comparison clearly illustrates the significant effect of flows that enter the river downstream of Lake Ralph Hall from tributaries, even with the reservoir in operation.

Finally, the tables on pages 10 through 13 present statistical results for the simulated monthly flows from the RiverWare model and from the WAM. Flows corresponding to specific percentiles and exceedance frequencies are indicated for the RiverWare model and the WAM and for conditions without and with Lake Ralph Hall in operation. These values are presented at locations where the RiverWare model has computational nodes, plus one additional location at the confluence of Baker Creek with the North Sulphur River. These locations can be identified on the map of the Sulphur River Basin in Attachment D, and they include upstream of Lake Ralph Hall for the inflow to the reservoir, below Lake Ralph Hall immediately downstream of Baker Creek (Catchment 3 on the map), at the North Sulphur River gage near Cooper (Gage No. 07343000 on the map), at the proposed site for the Parkhouse 2 Reservoir on the North Sulphur River (immediately below Catchment 14 on the map), at the Sulphur River gage near Talco (Gage No. 07343200 on the map), and at the proposed site of the Marvin Nichols Reservoir on the Sulphur River (immediately below Catchment 18 on the map). Flows from the RiverWare model at the Baker Creek location have been derived by adding to the simulated outflows from Lake Ralph Hall the incremental inflow from the watershed between the reservoir and Baker Creek, including Baker Creek. This incremental inflow was calculated by applying a drainage area ratio to the total simulated incremental inflow from the watershed between the reservoir and the North Sulphur River gage near Cooper. Comparisons of statistical results are presented for flows from the RiverWare model and from the WAM with Lake Ralph Hall (page 10) and without Lake Ralph Hall (page 11), for flows from the RiverWare model with and without Lake Ralph Hall (page 12), and for flows from the WAM with and without Lake Ralph Hall (page 13). As shown on each table, for flows at the Baker Creek location and at the North Sulphur River gage near Cooper, the exceedance frequencies have been determined for a flow of 175 acre-feet/month, which is the flow volume determined by Dr. Norman Johns of the National Wildlife Foundation as that needed to completely fill all of the downstream pools in the channel of the North Sulphur River from Baker Creek to the gage on the river near Cooper. While these exceedance frequencies provide some insight as to the effects of using the different models and the impacts of Lake Ralph Hall itself, a more in-depth analysis of downstream pool filling is discussed below.

Attachment E presents a summary of the results from the downstream pool filling analyses performed using monthly flows simulated with the RiverWare model by applying the same procedures previously employed (April 2015) for analyzing pool filling with WAM flows at the same locations. These previous results from analyzing the WAM flows also are included at the bottom of this table for reference purposes. This table presents the % of Time Pools Are Filled, on a monthly basis, under conditions without and with Lake Ralph Hall in operation for each of the reaches between tributaries for the segment of the North Sulphur River from the Lake Ralph Hall dam down to the North Sulphur River streamflow gage near Cooper. These values were derived by analyzing the monthly flows as simulated with the RiverWare model and the WAM at each of these locations to determine if they are sufficient to fill the pools in each of the downstream reaches based on Dr. Johns' pool volume estimate of 175 acre-feet for the total dam-to-gage reach. The intervening values of the flow volume required for filling the pools in each of the reaches were derived by making proportional adjustments of the 175 acre-foot value based on river channel distance below the dam. This assumes that the total pool volume is linearly distributed along this segment of the river channel. As shown in the table, and as expected, the values of Volume Required to Fill All Downstream Pools decrease with distance below the Lake Ralph Hall dam since the volume of pools decreases. The value of the % of Time Pools Are Filled at a particular location reflects the use of river flows to fill upstream pools, increases in river flows in the downstream direction with added tributary inflows, and the different pool volumes as they vary by reach. The monthly river flows from the RiverWare model at each of these locations were derived using the same approach described above for determining the river flows at the Baker

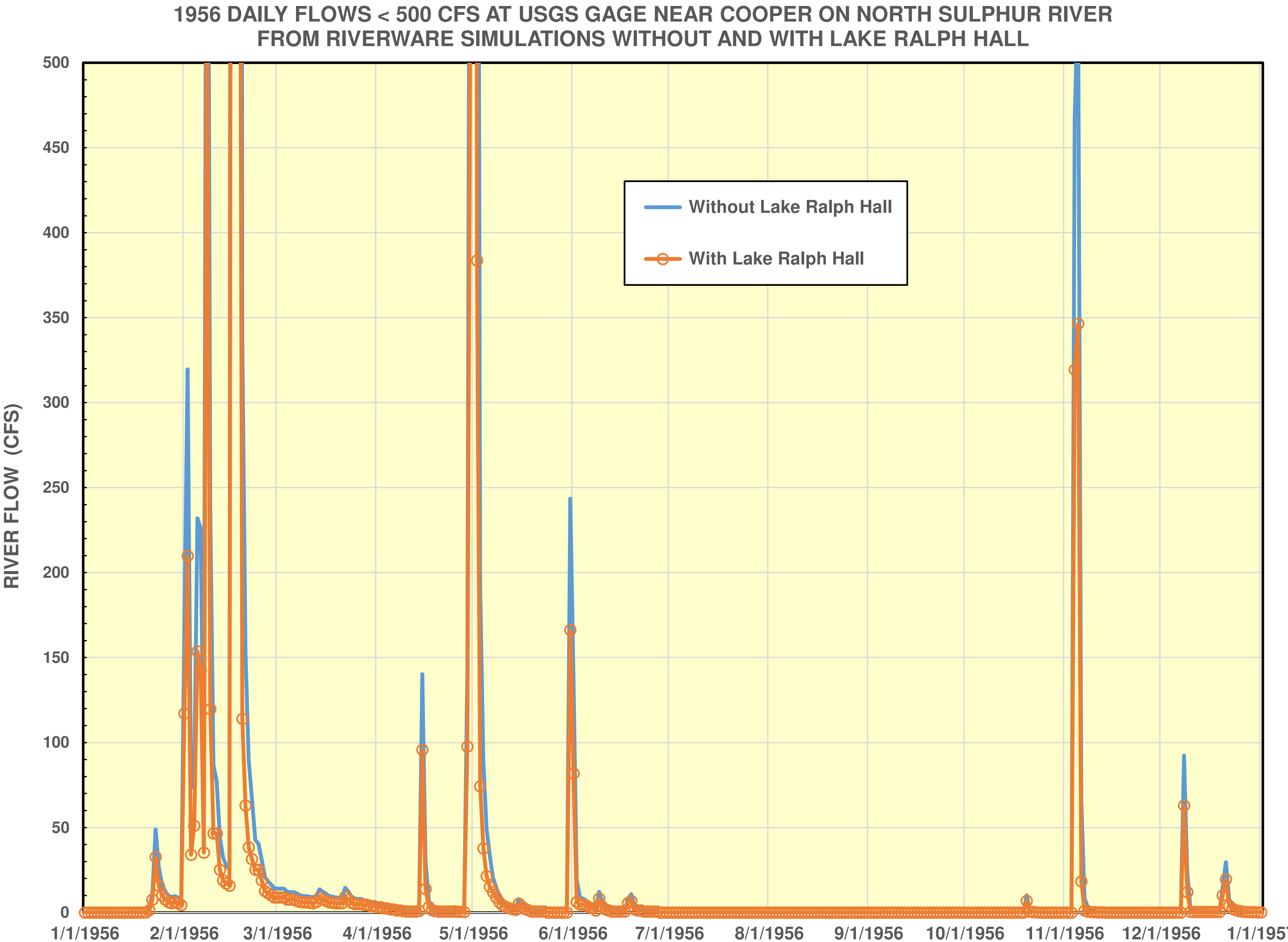
Creek location based on the simulated RiverWare flows at the dam and at the downstream gage near Cooper. As noted, the maximum reduction in the % of Time Pools Are Filled from the Without Lake Ralph Hall case to the With Lake Ralph Hall case for the RiverWare results is 13.5%, with the second largest reduction equal to 9.7%. For the WAM flows, these maximum reductions are 0.6% and 1.3%, respectively. As expected, both of these sets of higher reductions occur in reaches of the river closest to Lake Ralph Hall. Beginning at a point about half way down the river between Lake Ralph Hall and the gage, the reductions are substantially less, generally at levels considered to be within the simulation accuracy of the models considering the sources and accuracy of data and the simulation procedures used in the models. Over the entire segment of the North Sulphur River from Lake Ralph Hall down to the gage, the reach length-weighted average reduction in the % of Time Pools Are Filled from the Without Lake Ralph Hall case to the With Lake Ralph Hall case is -5.9% for the RiverWare flows and -0.5% for WAM flows.

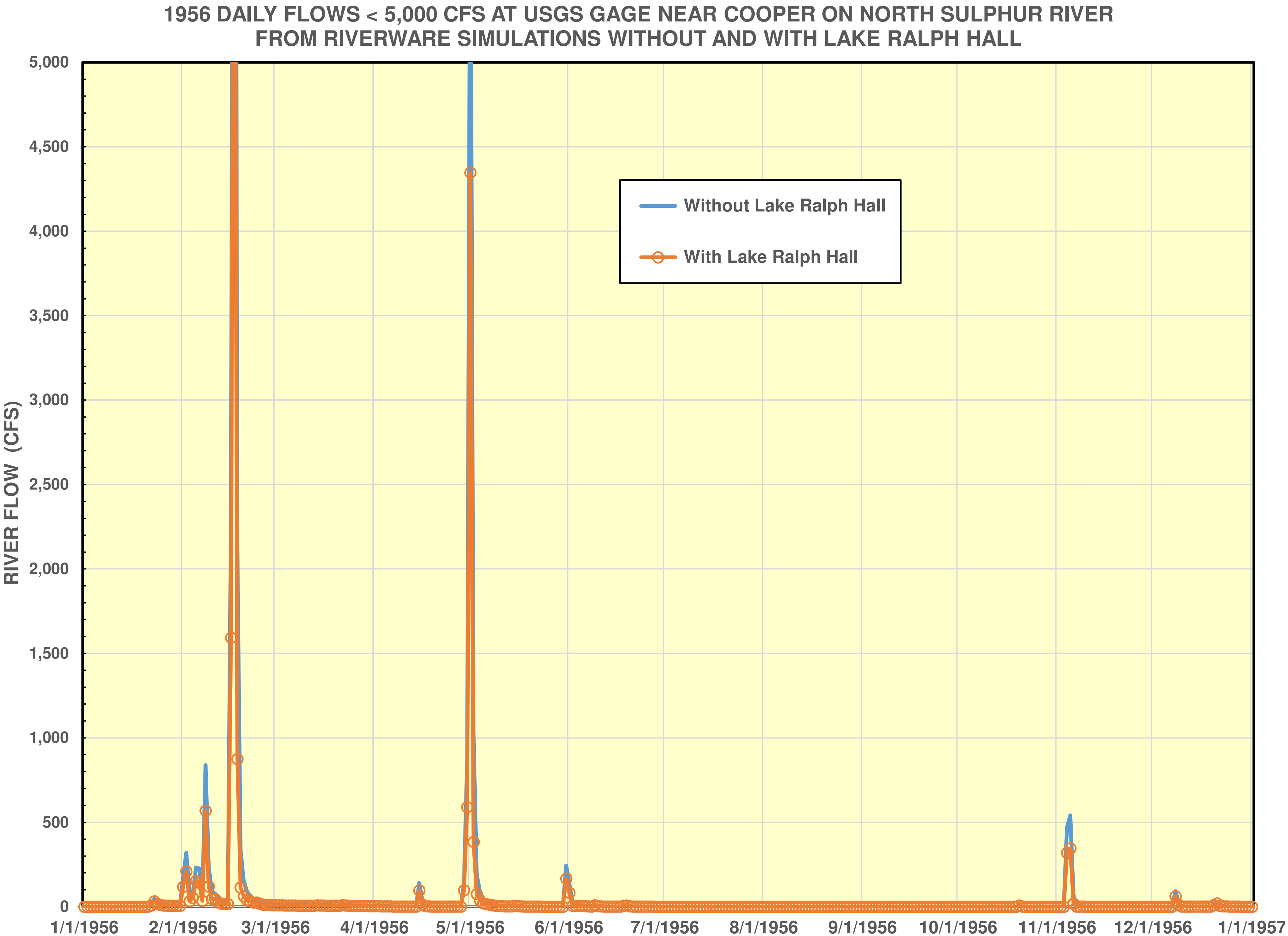
While the RiverWare model does provide daily simulations of flows in the North Sulphur and Sulphur Rivers, it is apparent from comparisons of these flows under conditions without and with Lake Ralph Hall that the daily variations themselves really do not tell us much more, if anything, about the effects of Lake Ralph Hall than monthly flow values. From the graphs of daily flows in Attachments A and B, it is shown that flood hydrographs occur at generally the same frequency and duration without or with Lake Ralph Hall. It is only the peaks of these hydrographs that are somewhat reduced due to the effects of Lake Ralph Hall, and peak flood flows in the North Sulphur River, unless they are associated with significant flood events on the order of the 25-year flood or greater, do not produce overbanking conditions that normally might be considered important from an aquatic ecological perspective. The incised channel of the North Sulphur River upstream of and for some distance downstream of the gage near Cooper simply is too deep to allow overtopping by the vast majority of flood events and too steep-walled to support and maintain typical lower floodplain conditions. Farther downstream, as inflows continue to enter the North Sulphur River and the Sulphur River below the confluence with the South Sulphur River, the reduction of river flows caused by Lake Ralph Hall becomes relatively less significant, to the point that the reservoir likely has minimal impact on instream and floodplain conditions.

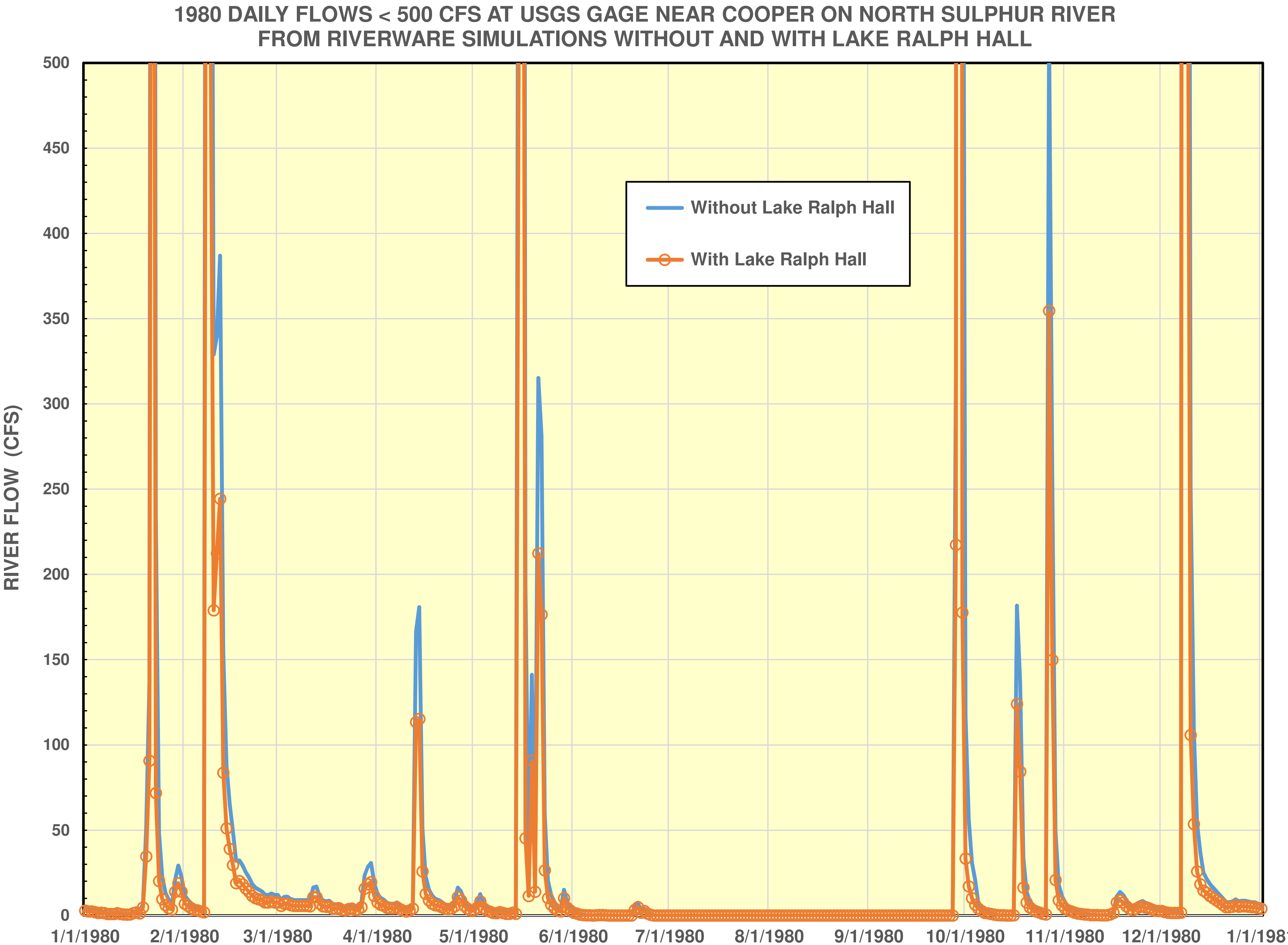
When considering the results from the RiverWare model of the Sulphur, Cypress and Red River Basins, it also is important to note that some of the deficiencies of the model could be relevant with respect to evaluating the impacts of Lake Ralph Hall. The exclusion of existing water rights from the model and the prior appropriation doctrine precludes any passing of inflows through the reservoir to satisfy the demands of downstream senior water rights. These additional flows in the river, which the WAM does model, could serve to supplement tributary inflows for filling channel pools and supporting aquatic life downstream of the reservoir. While typically the passing of flows for satisfying senior water rights only occurs during extremely dry periods when a "call" is made by the downstream senior water rights, it is not something that would never occur as the RiverWare model assumes. With the construction and operation of Lake Ralph Hall, it is very likely that owners of existing downstream water rights, especially those with large irrigation rights located near or below the confluence of the North and South Sulphur Rivers, as well as Lake Wright Patman located farther downstream on the Sulphur River, will closely monitor their available water supplies from the river and will certainly issue a call for Lake Ralph Hall to pass inflows to meet their needs if they believe Lake Ralph Hall is depriving them of flows to which they are entitled. In this regard, the WAM probably provides a better estimate of low flow conditions in the North Sulphur River with Lake Ralph Hall in operation than the daily RiverWare model does. Another point to note relates to the higher level of inflows to Lake Ralph Hall that the RiverWare model produces. It is not clear as to why this occurs, but it definitely affects the operation of the reservoir and may artificially increase the frequency of flood spills from the reservoir that flow into the river downstream.

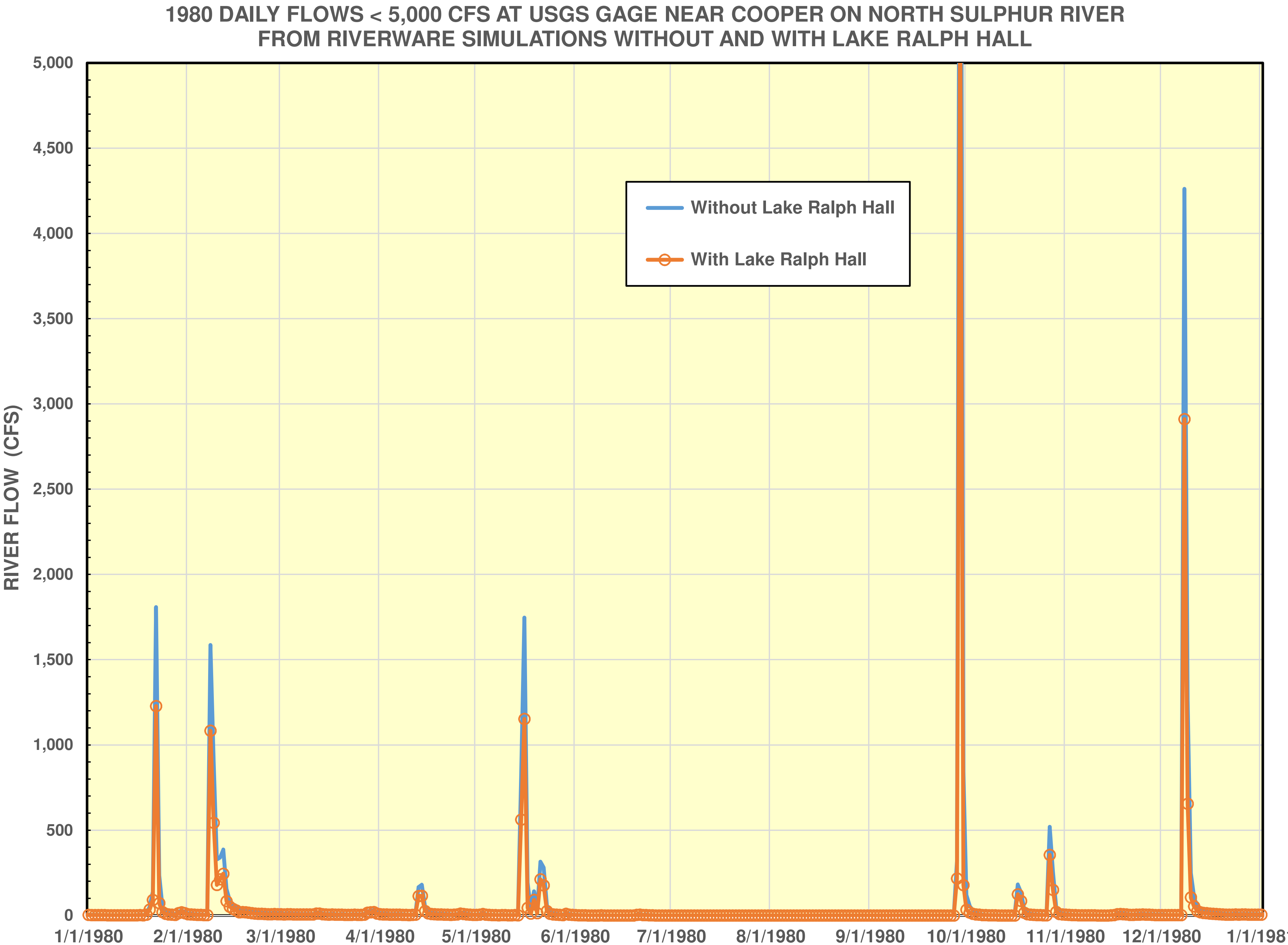
In summary, the application of the daily RiverWare model for analyzing the effects of Lake Ralph Hall on downstream river flows is considered to have been a worthwhile effort. It has provided a better understanding of the significance of daily variations in river flows and how Lake Ralph Hall might affect those flow variations and flood hydrographs, information that may be useful for further evaluating the impacts of Lake Ralph Hall. In the end, however, it remains that the place where Lake Ralph Hall will likely have its most significant effect on the flow regime of the North Sulphur and Sulphur Rivers is still the segment immediately downstream of the reservoir that is characterized by an eroded and degraded channel devoid of significant aquatic life such that reductions in river flows caused by the reservoir are not likely to result in noticeable environmental impacts. Even then, the UTRWD is proposing to develop and construct the mitigation area on the south floodplain of the North Sulphur River below the reservoir by restoring the configuration of approximately 14,000 feet of the abandoned river channel, planting native vegetation and trees, and stocking the restored pools and channel with fish and aquatic species that typically inhabited the historical river system.

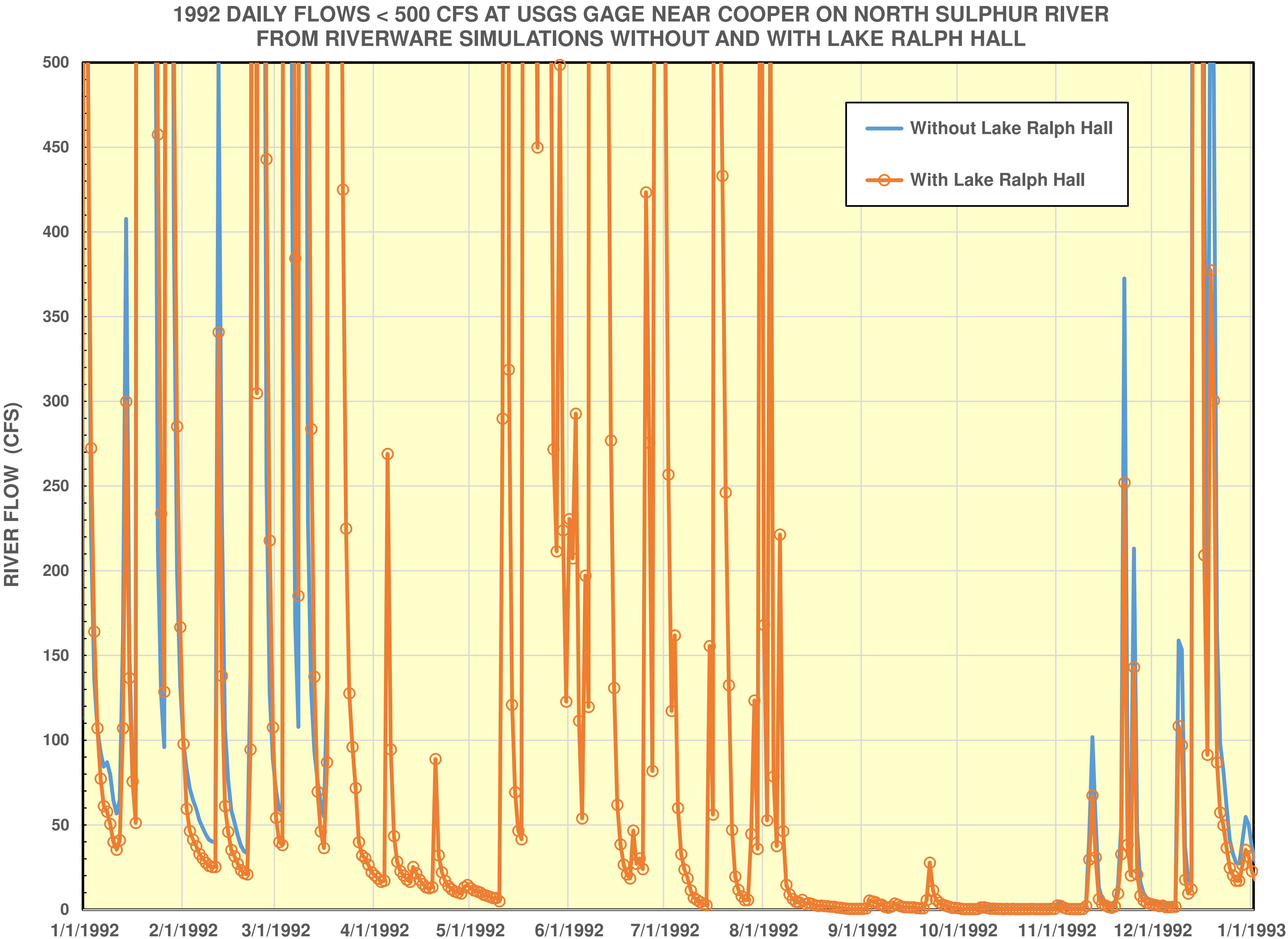
If you have any questions regarding the material presented herein or if you want to discuss these results further, please contact us at your convenience. Also, we are in the process of assembling the RiverWare results files and the various spreadsheets used in analyzing and presenting the results for delivery to the Corps.

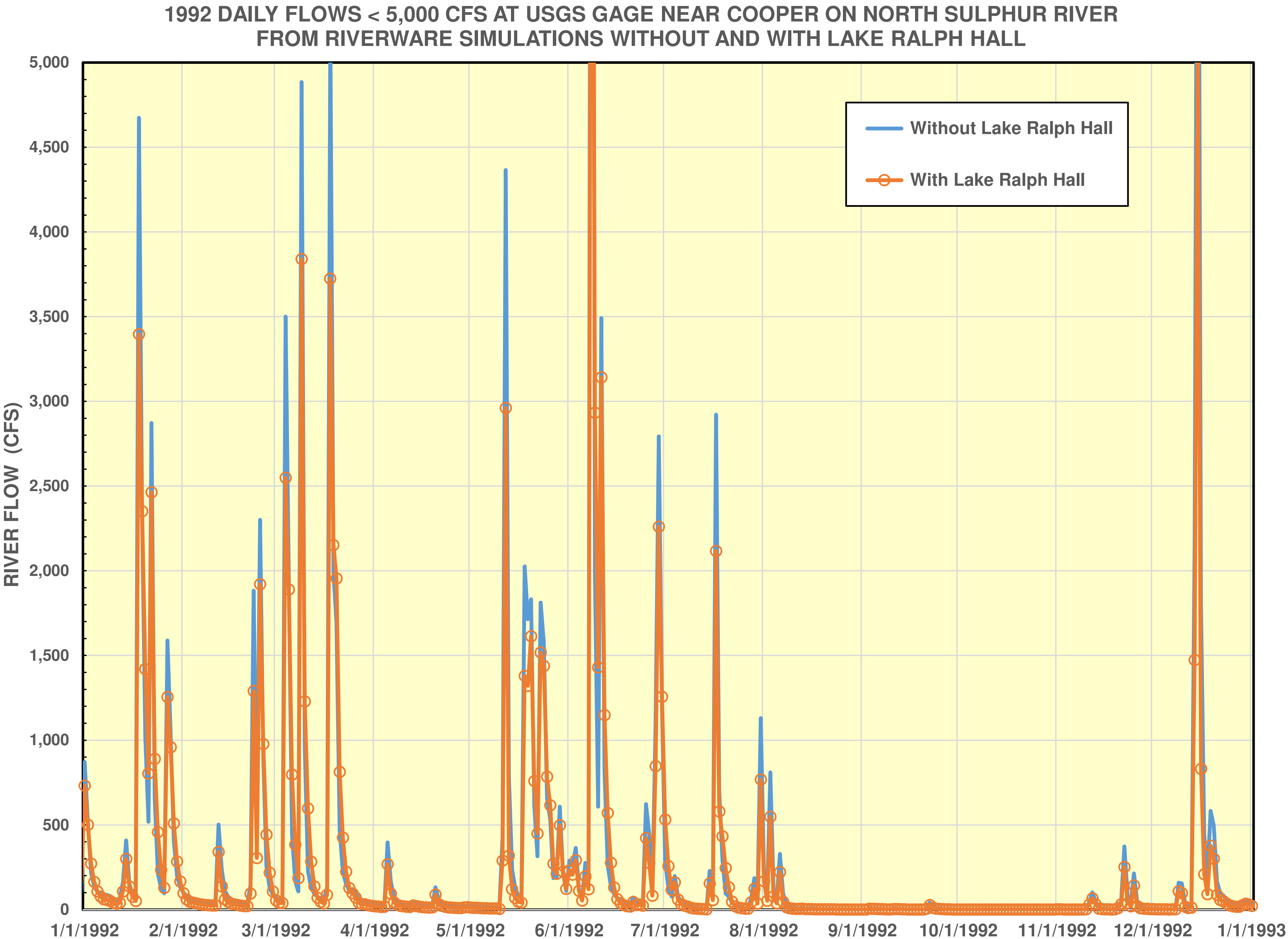

1956 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957

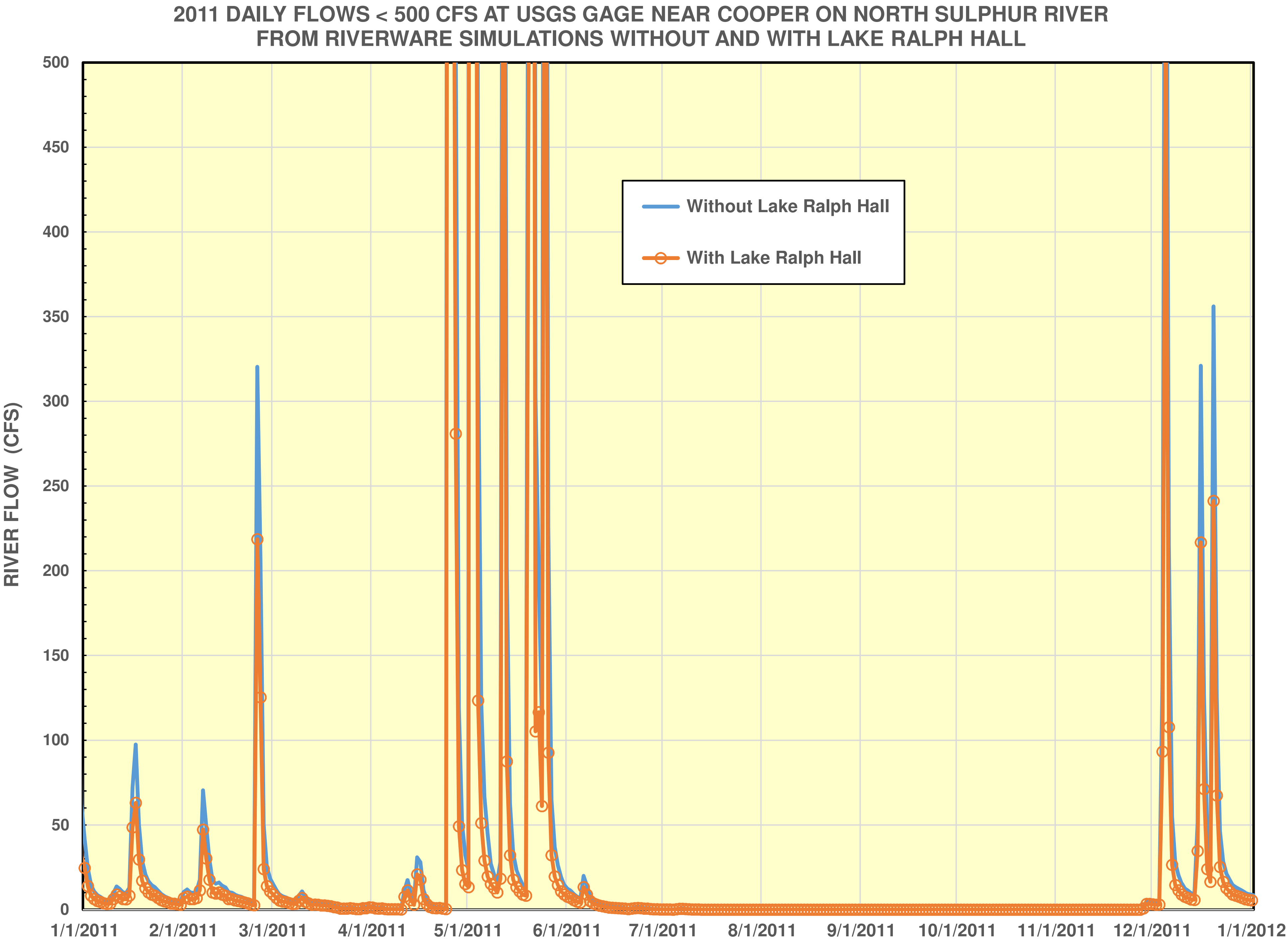

1956 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957
Without Lake Ralph Hall
With Lake Ralph Hall

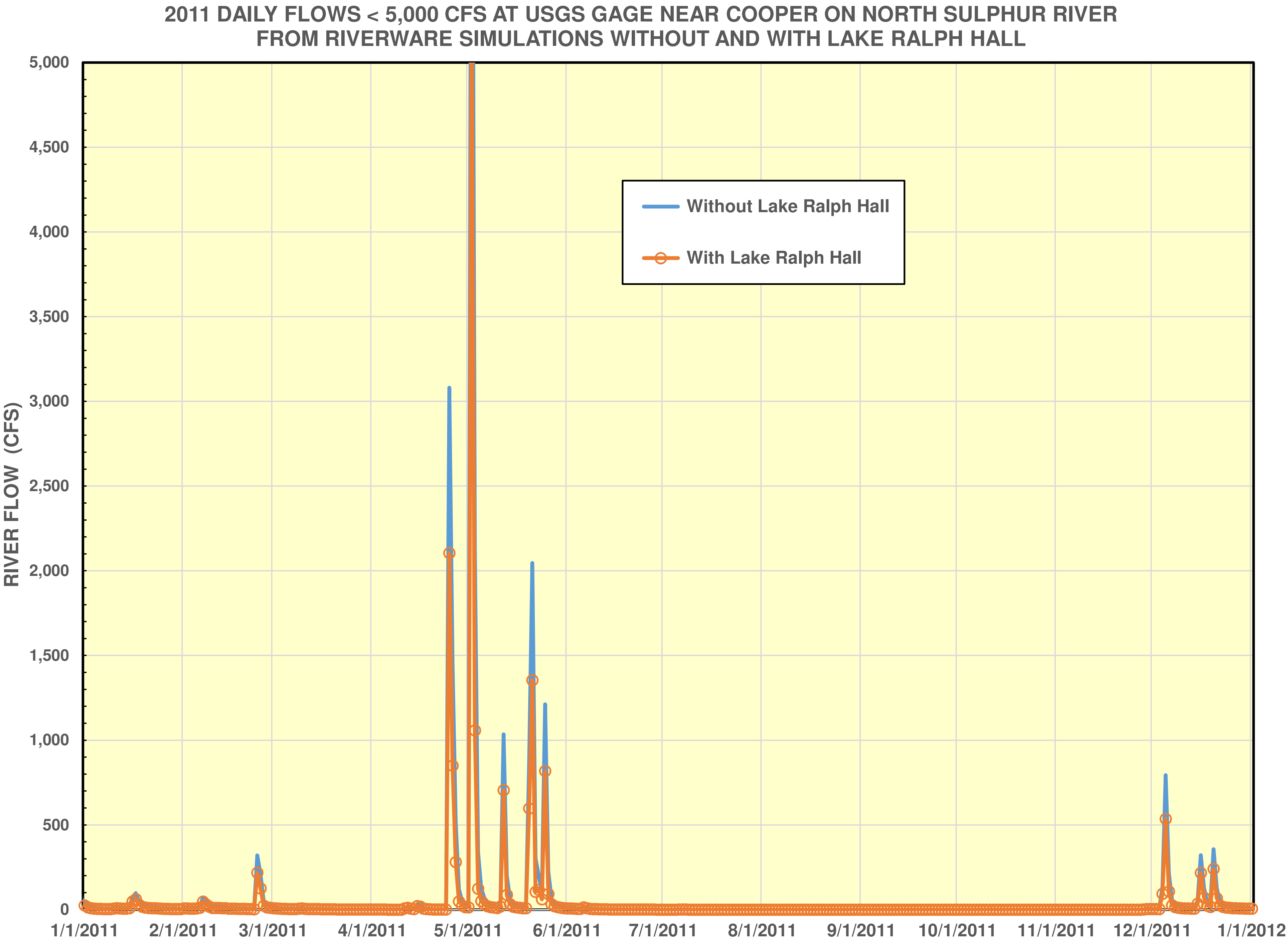

1980 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981

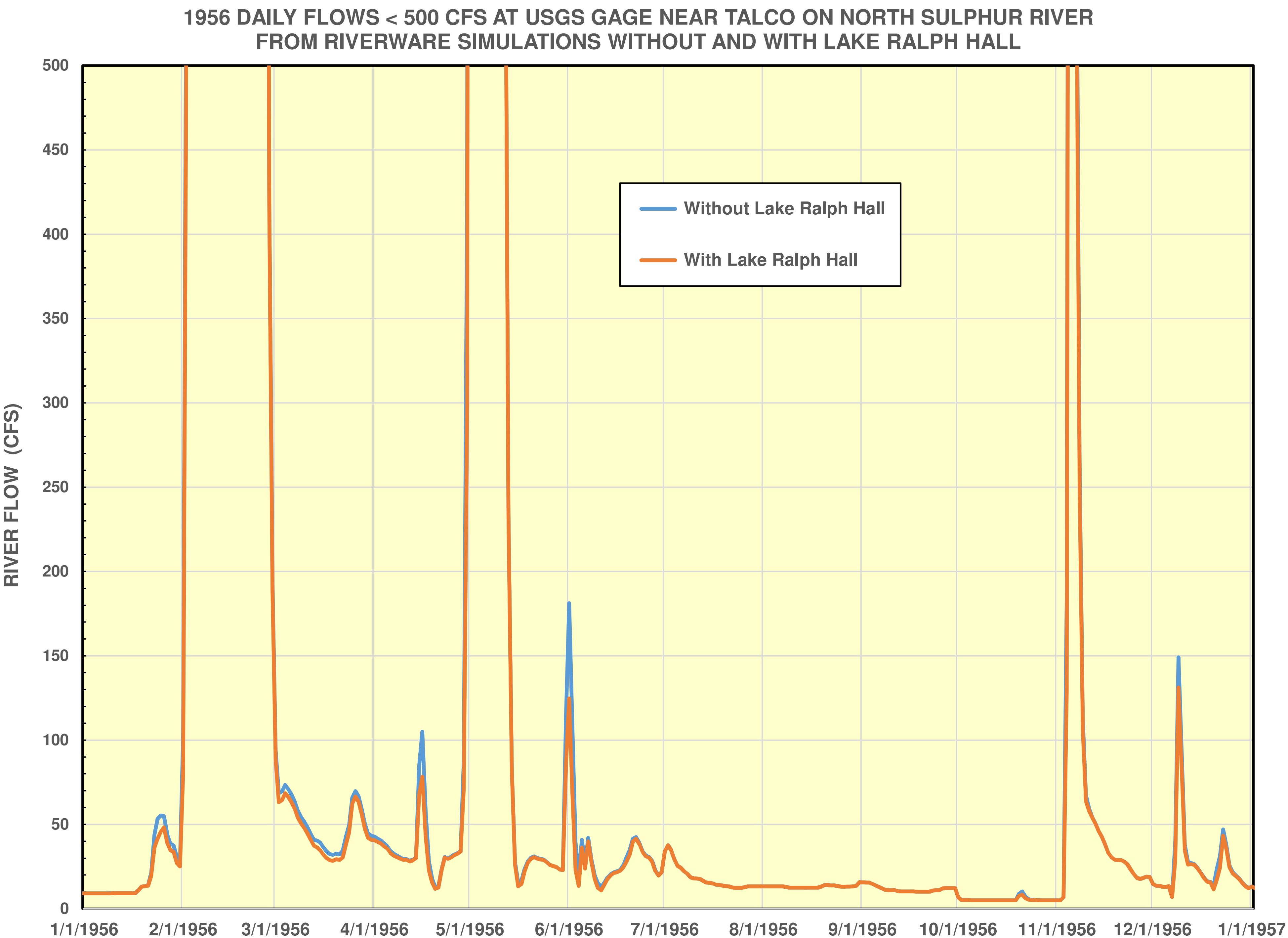

1980 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981
Without Lake Ralph Hall
With Lake Ralph Hall

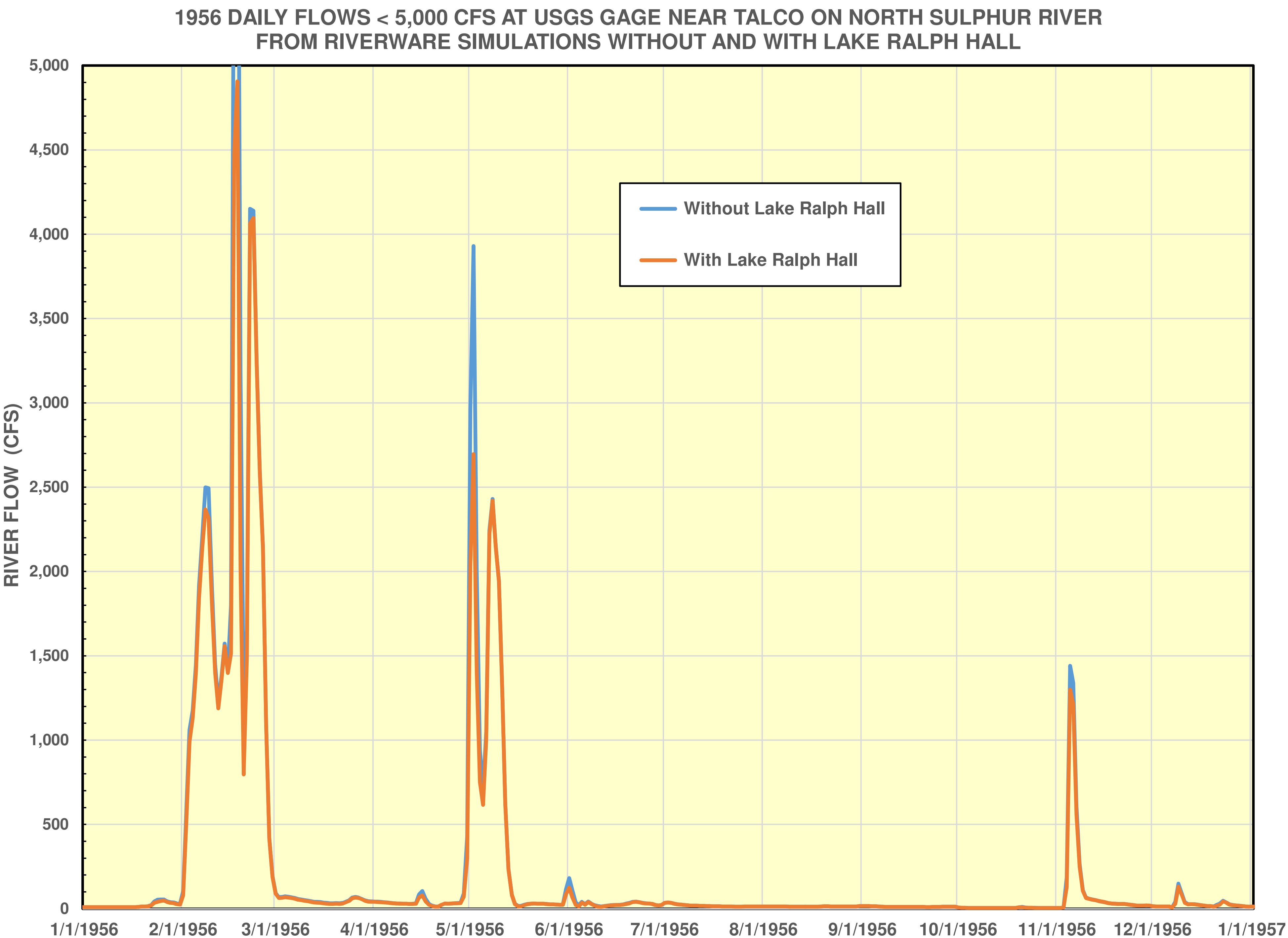

1992 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall

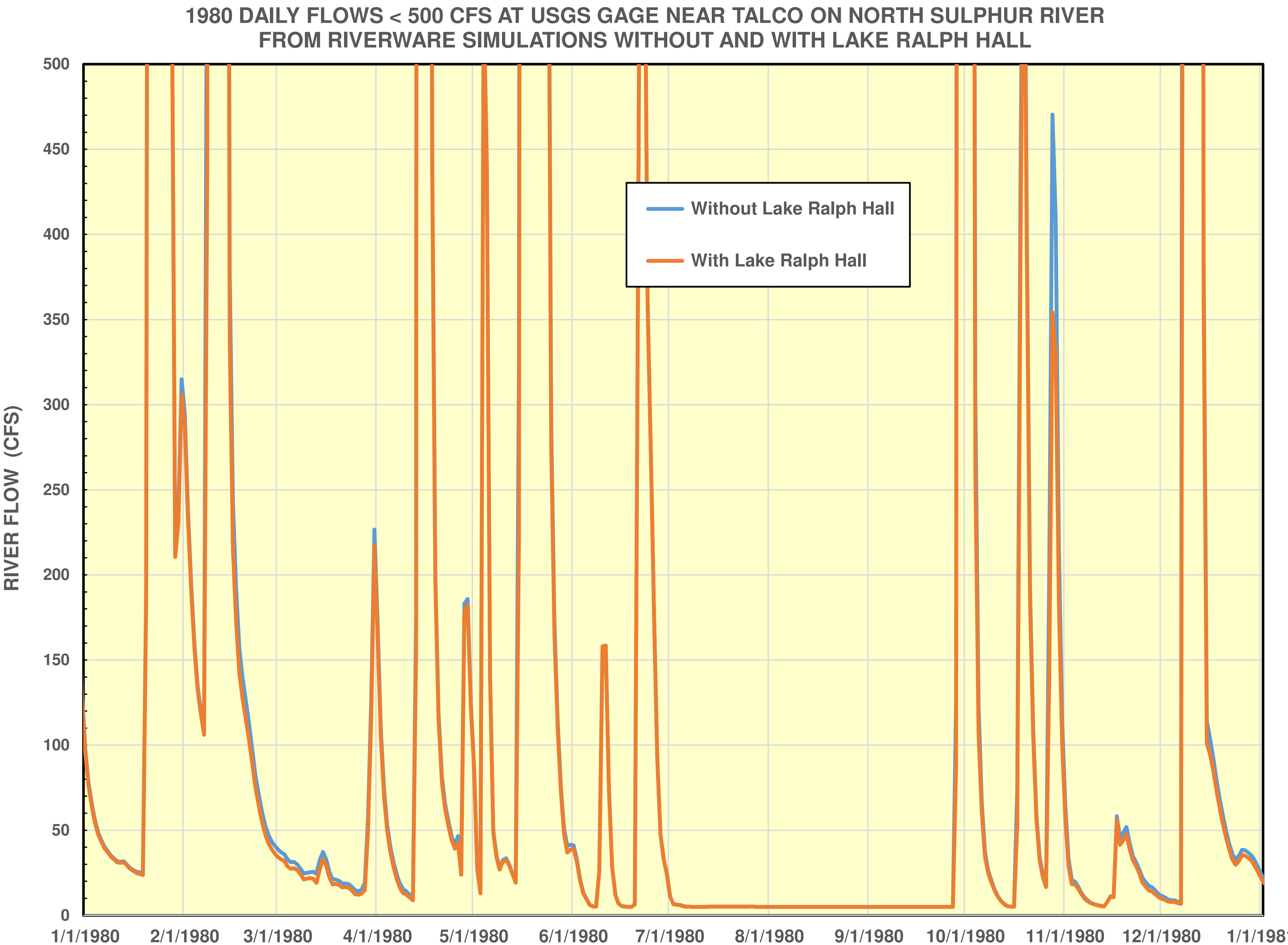

1992 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall

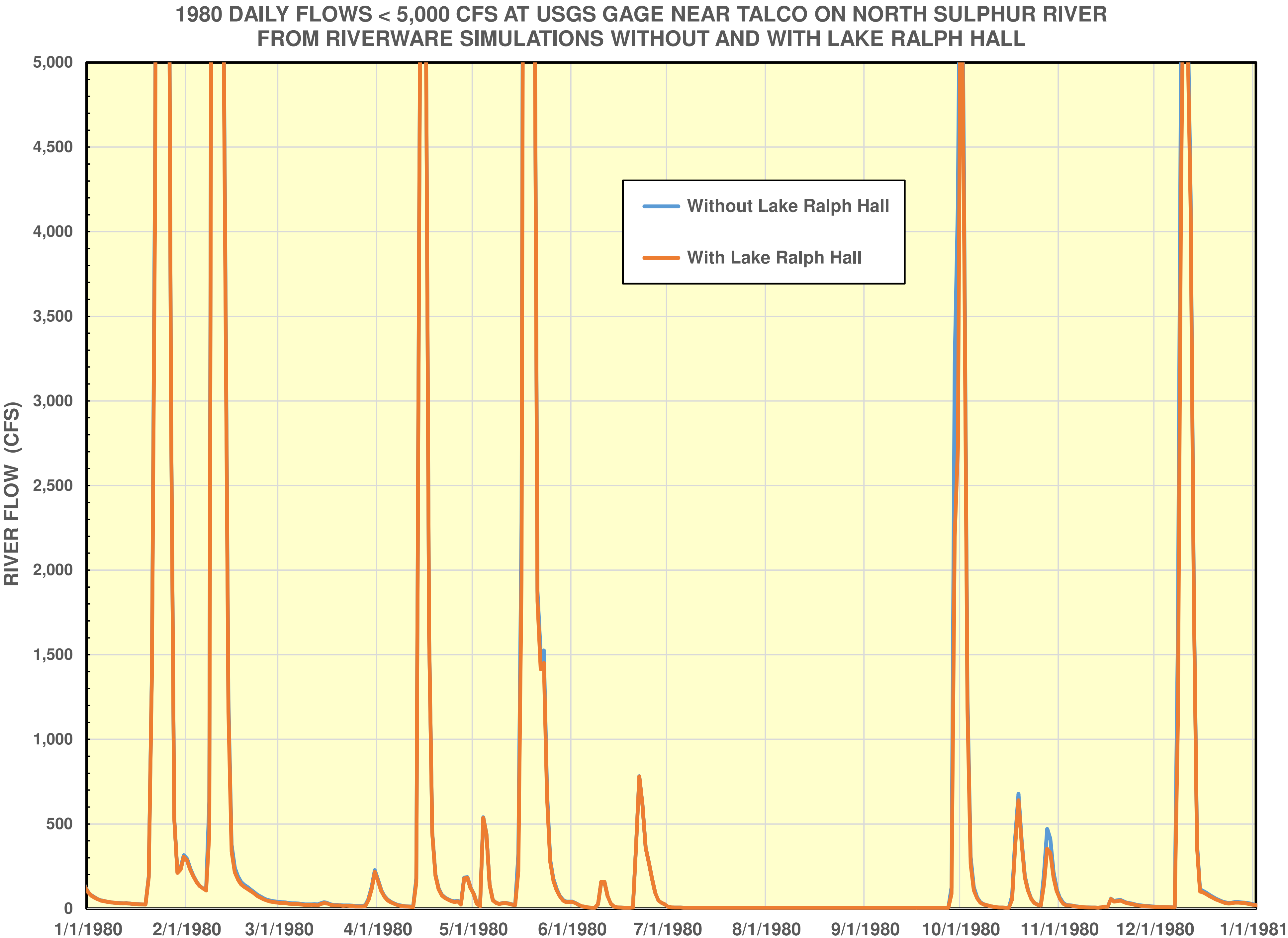

2011 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012
Without Lake Ralph Hall
With Lake Ralph Hall

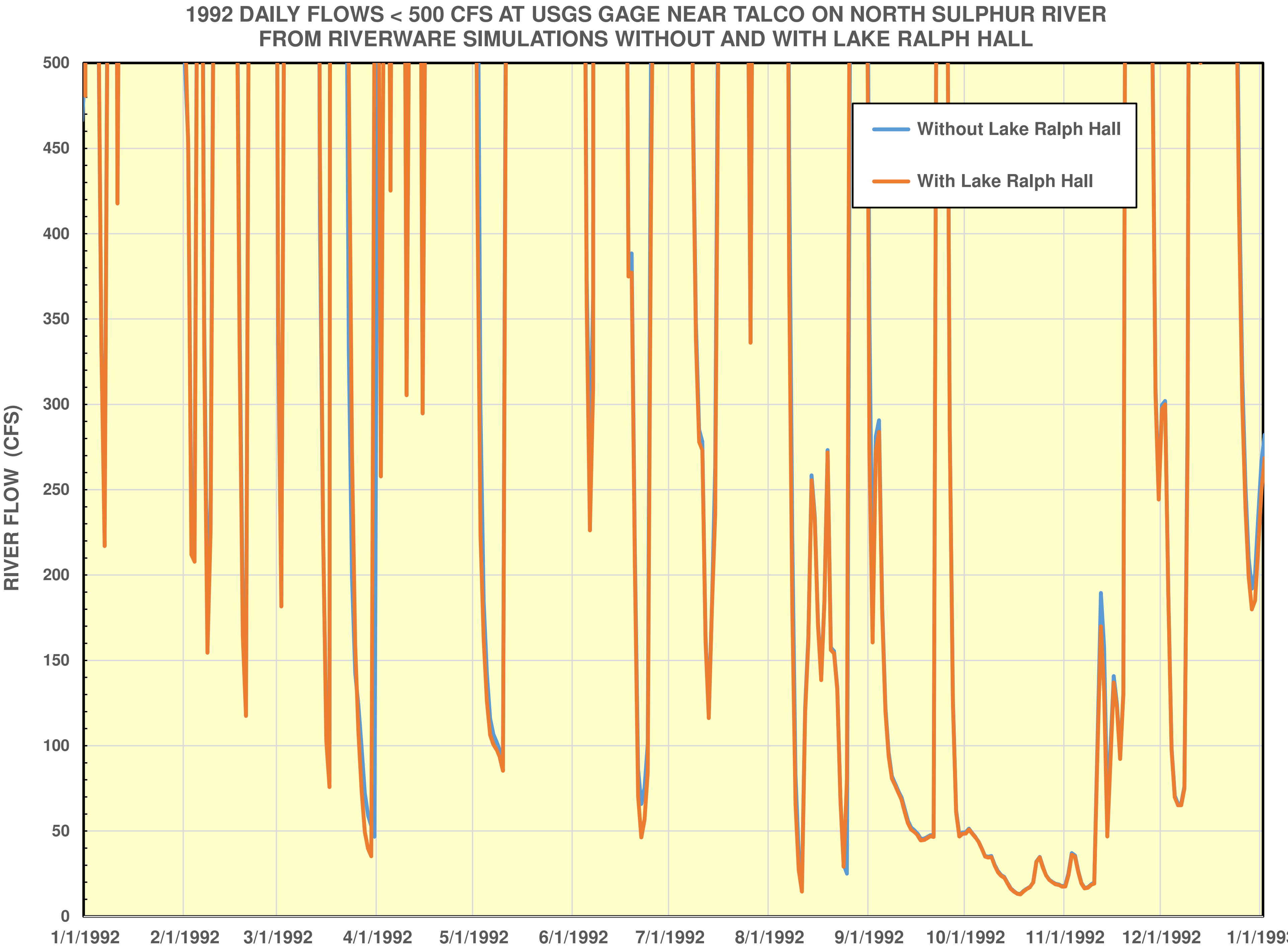

2011 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR COOPER ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012

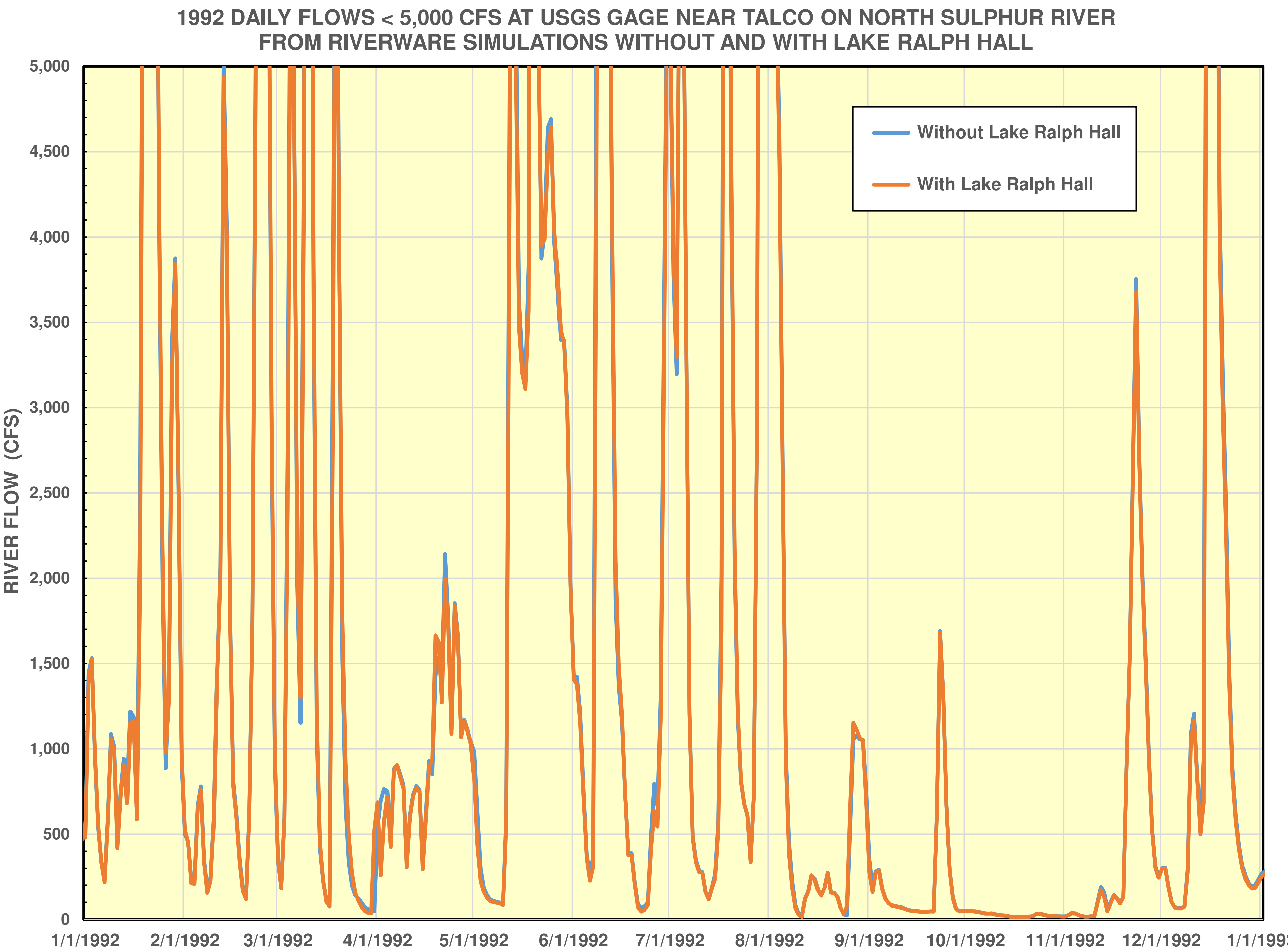

1956 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
0
50
100
150
200
250
300
350
400
450
500
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957

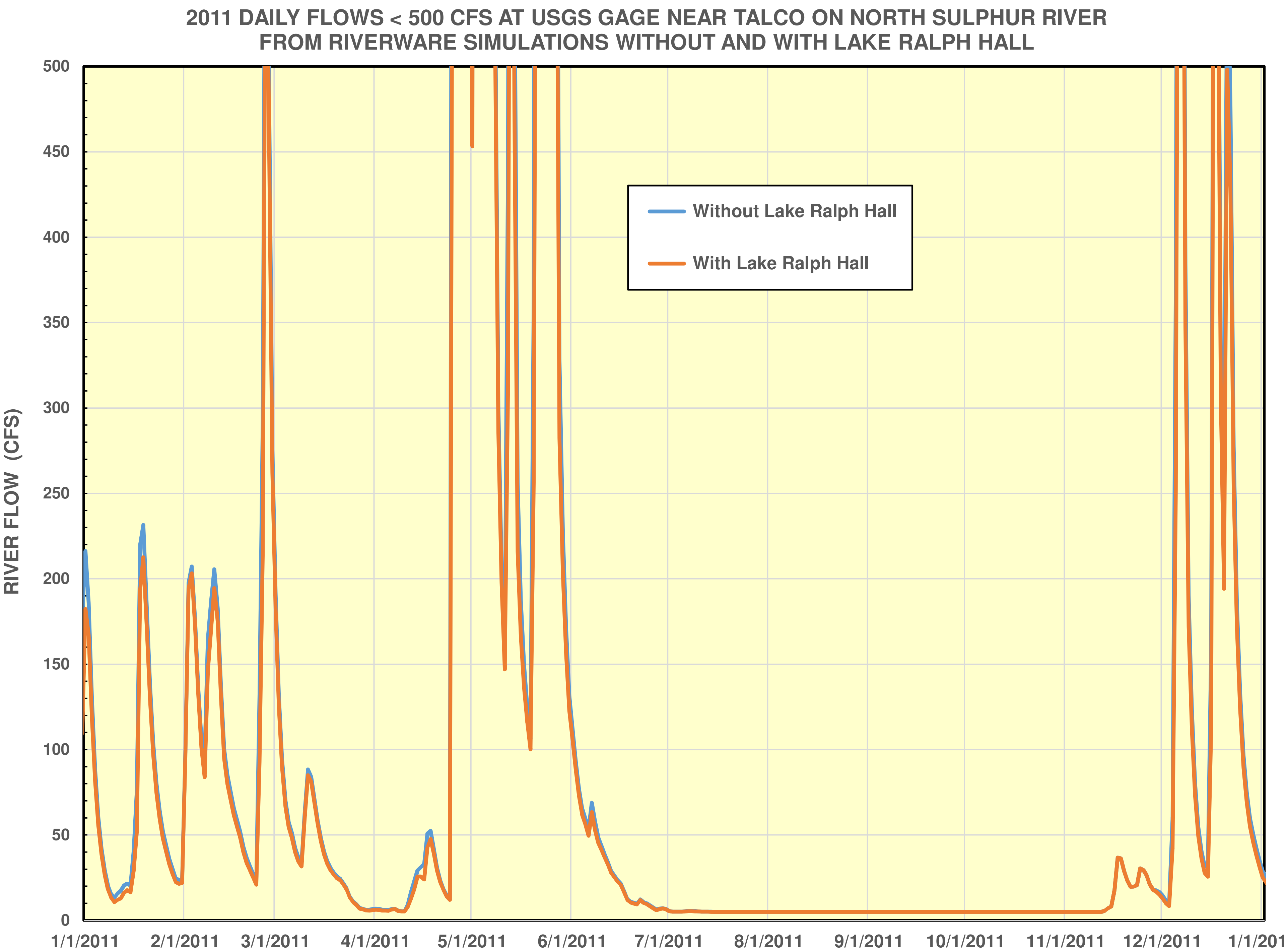

1956 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1956
2/1/1956
3/1/1956
4/1/1956
5/1/1956
6/1/1956
7/1/1956
8/1/1956
9/1/1956
10/1/1956
11/1/1956
12/1/1956
1/1/1957
Without Lake Ralph Hall
With Lake Ralph Hall

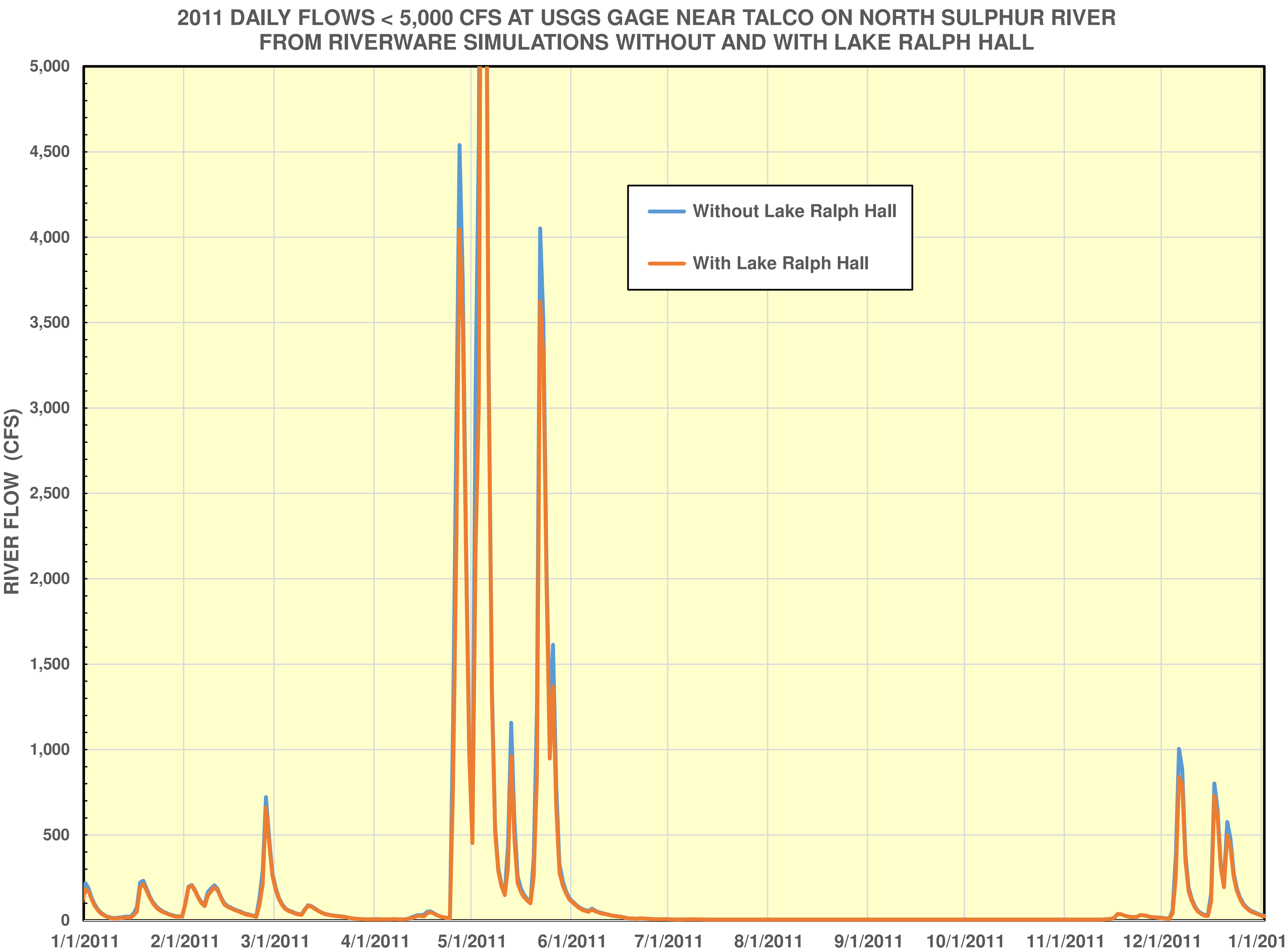

1980 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981
Without Lake Ralph Hall
With Lake Ralph Hall


1980 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1980
2/1/1980
3/1/1980
4/1/1980
5/1/1980
6/1/1980
7/1/1980
8/1/1980
9/1/1980
10/1/1980
11/1/1980
12/1/1980
1/1/1981
Without Lake Ralph Hall
With Lake Ralph Hall

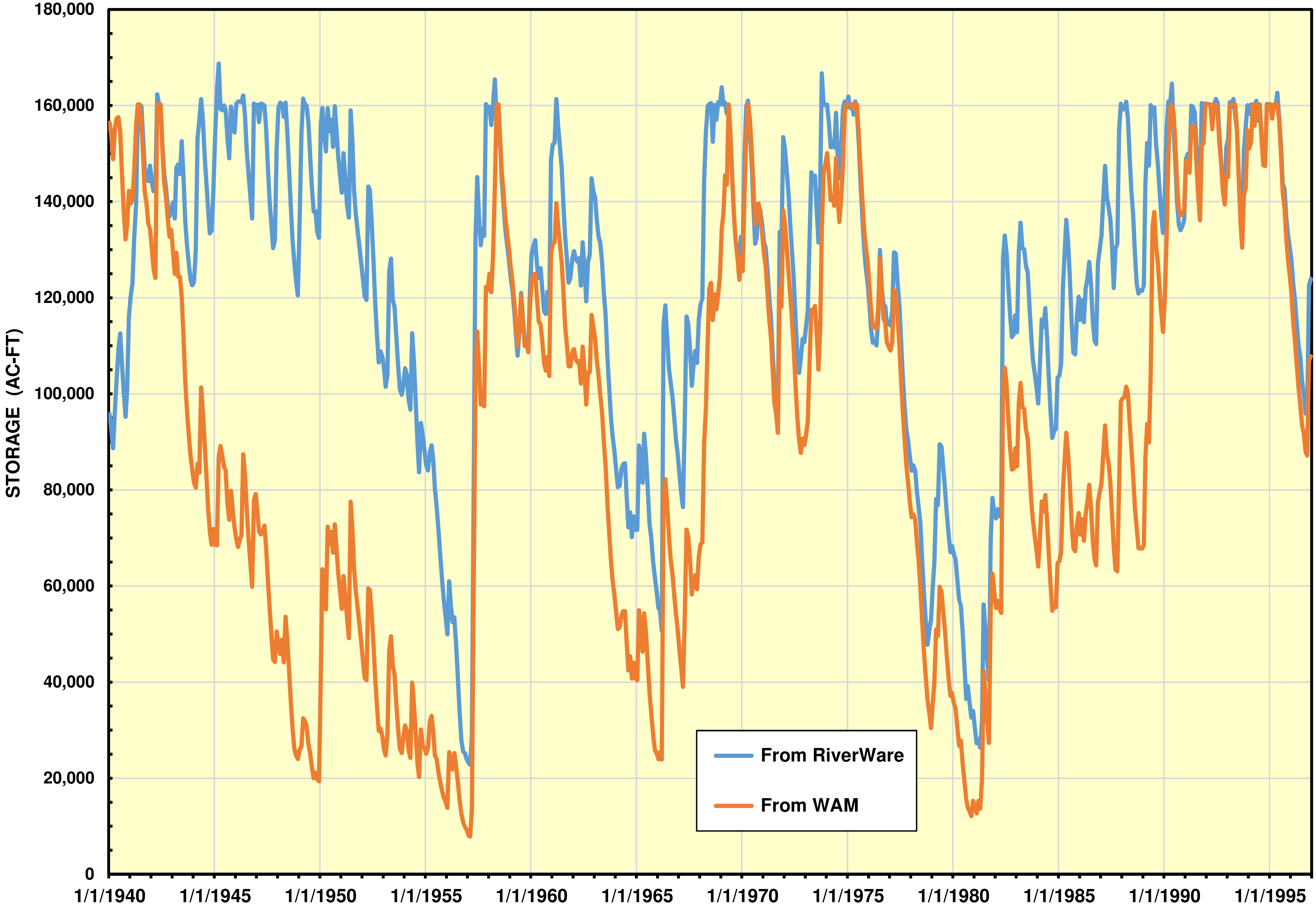

1992 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
Without Lake Ralph Hall
With Lake Ralph Hall
RIVER FLOW (CFS)
0
50
100
150
200
250
300
350
400
450
500
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993


1992 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/1992
2/1/1992
3/1/1992
4/1/1992
5/1/1992
6/1/1992
7/1/1992
8/1/1992
9/1/1992
10/1/1992
11/1/1992
12/1/1992
1/1/1993
Without Lake Ralph Hall
With Lake Ralph Hall

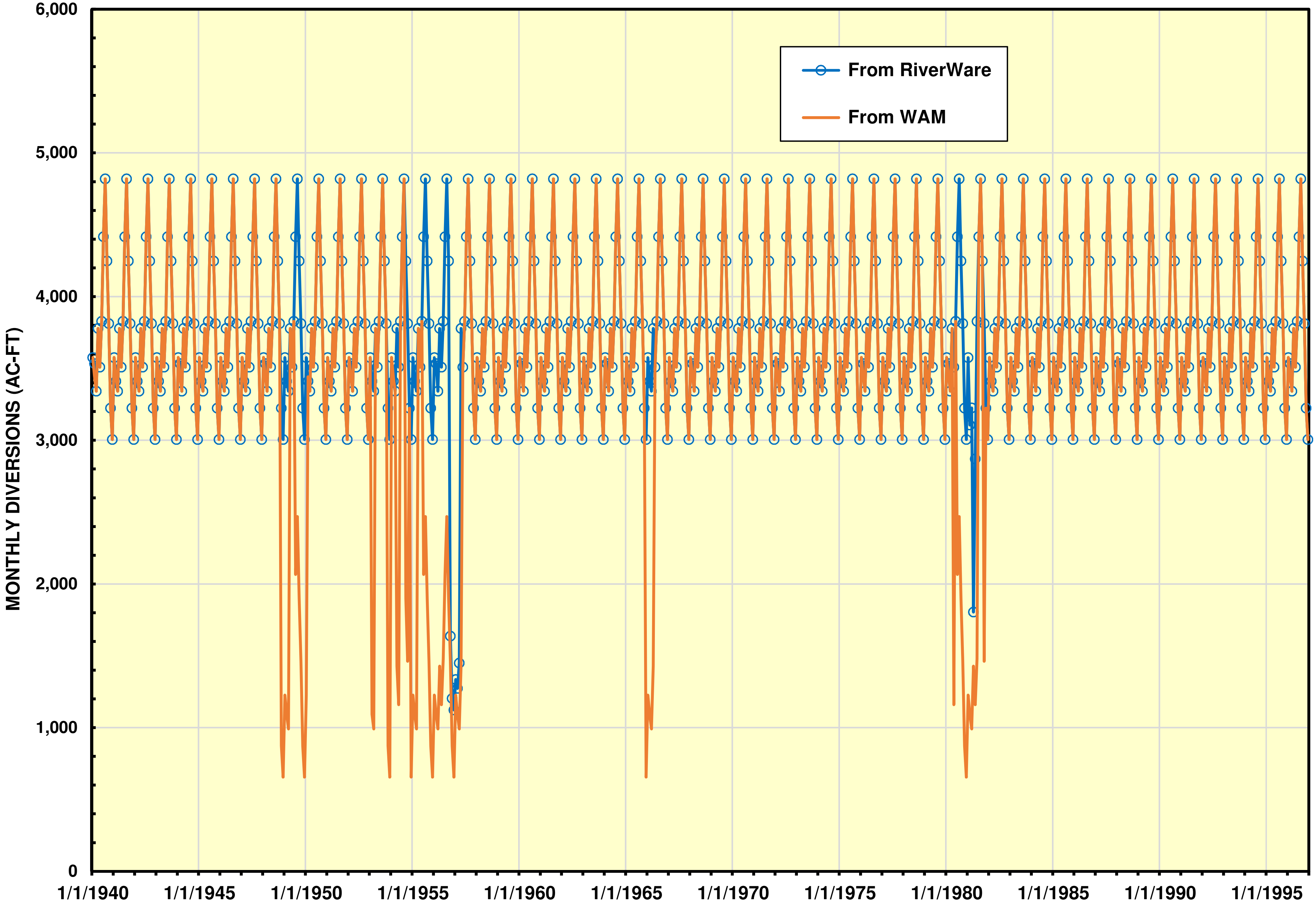

2011 DAILY FLOWS < 500 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
500
450
400
350
300
250
200
150
100
50
0
Without Lake Ralph Hall
With Lake Ralph Hall
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012

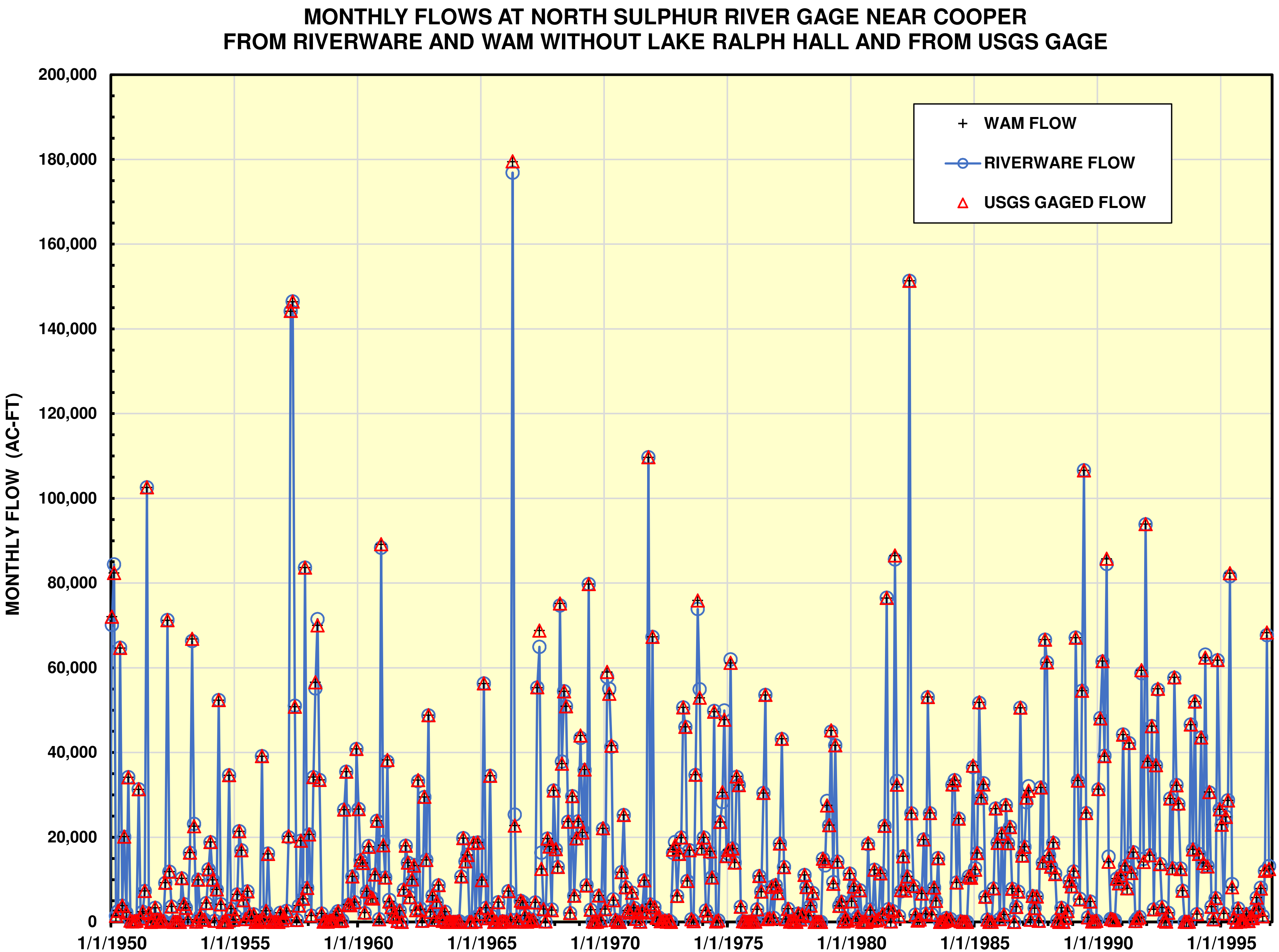

2011 DAILY FLOWS < 5,000 CFS AT USGS GAGE NEAR TALCO ON NORTH SULPHUR RIVER
FROM RIVERWARE SIMULATIONS WITHOUT AND WITH LAKE RALPH HALL
RIVER FLOW (CFS)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1/1/2011
2/1/2011
3/1/2011
4/1/2011
5/1/2011
6/1/2011
7/1/2011
8/1/2011
9/1/2011
10/1/2011
11/1/2011
12/1/2011
1/1/2012
Without Lake Ralph Hall
With Lake Ralph Hall

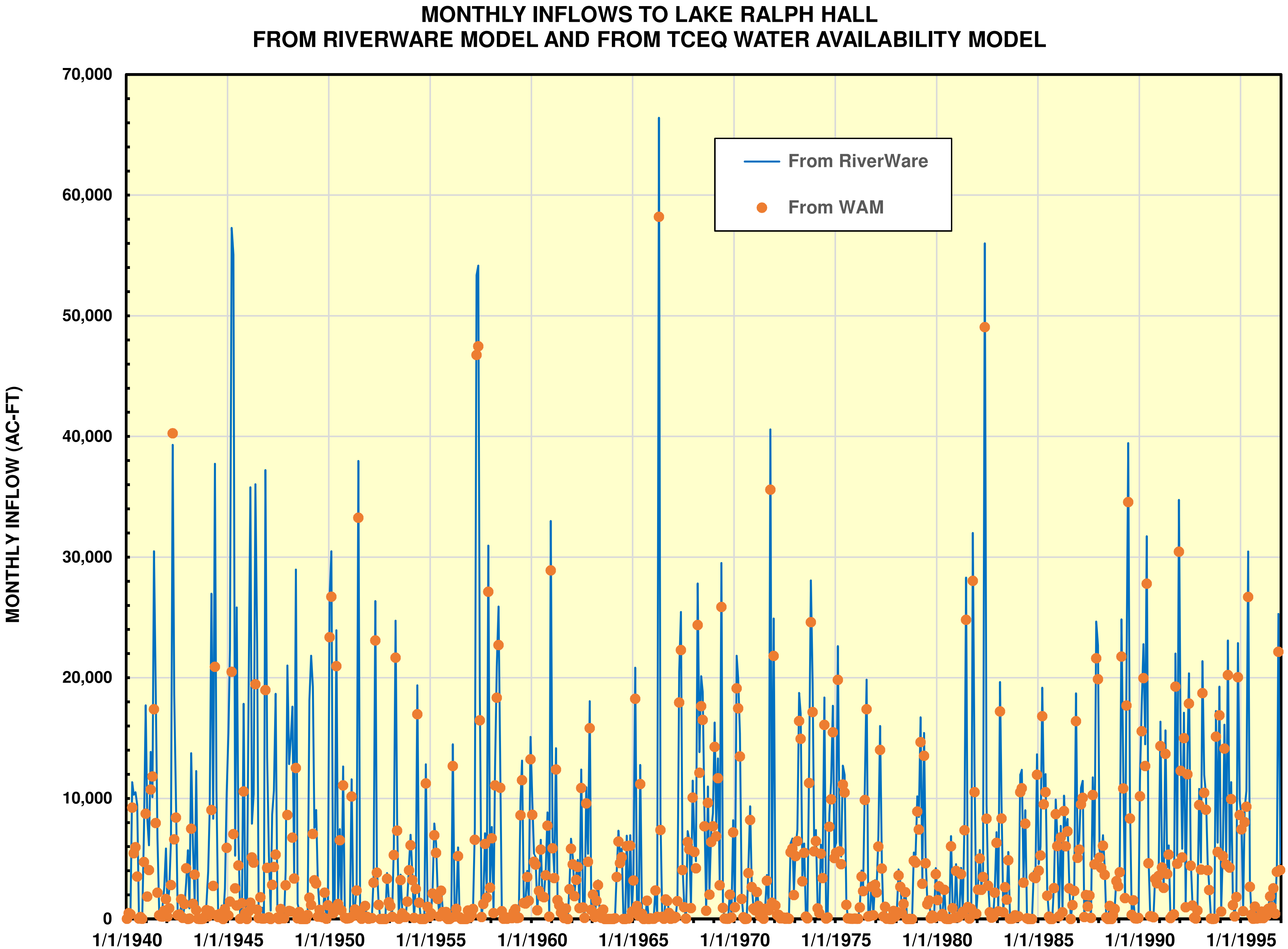
MONTHLY STORAGE IN LAKE RALPH HALL FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



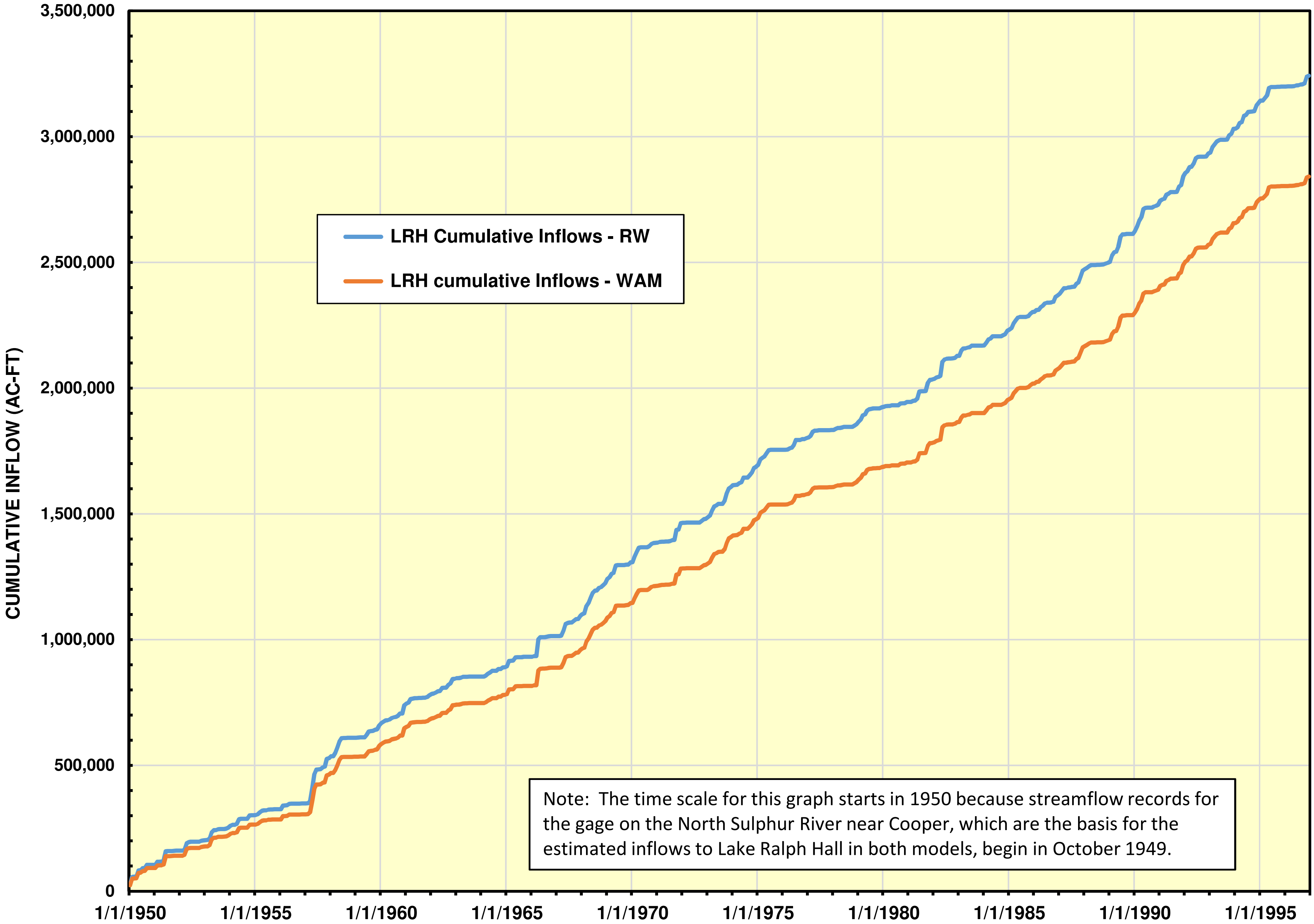
MONTHLY DIVERSIONS FROM LAKE RALPH HALL
FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



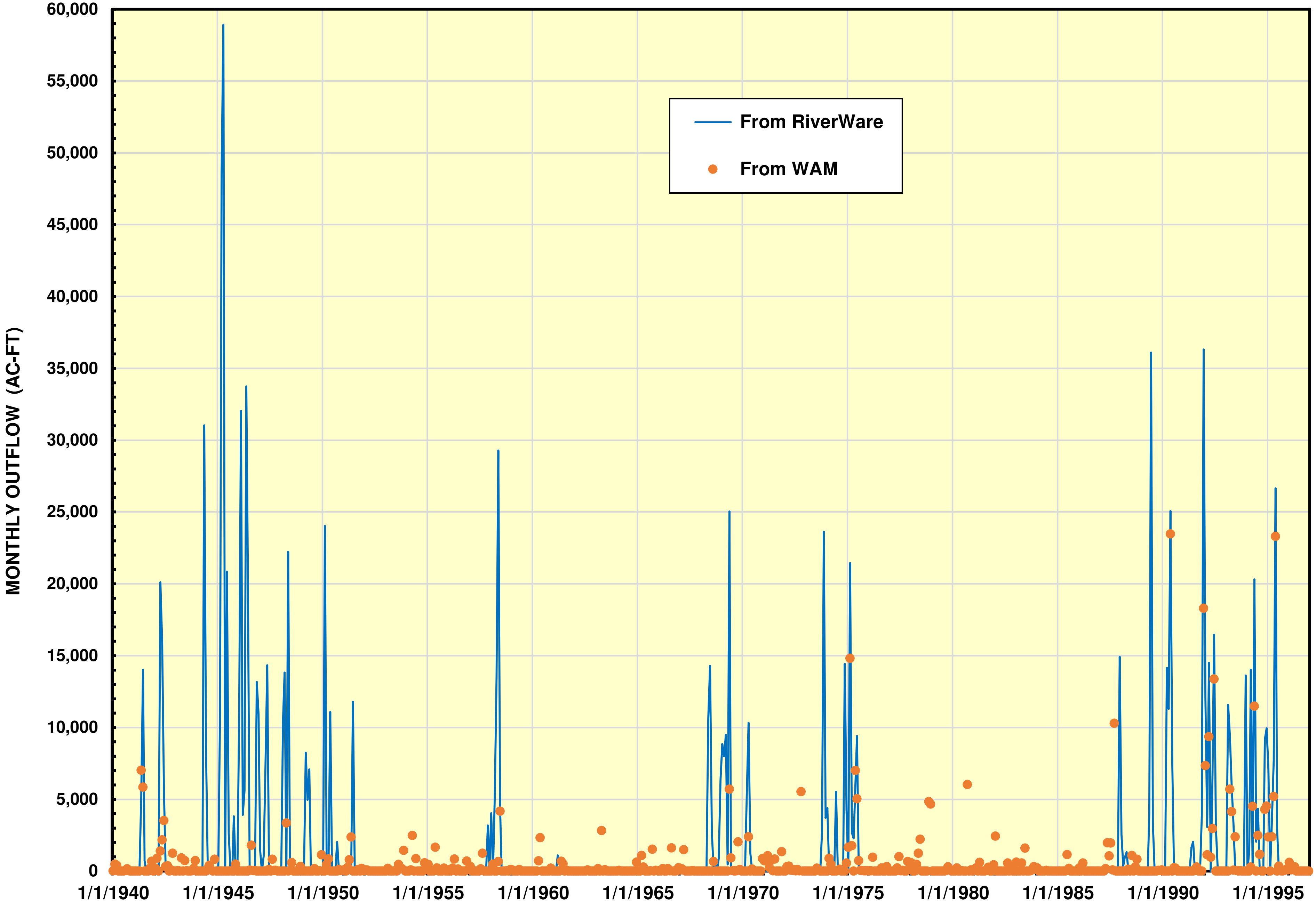

MONTHLY FLOWS AT NORTH SULPHUR RIVER GAGE NEAR COOPER
FROM RIVERWARE AND WAM WITHOUT LAKE RALPH HALL AND FROM USGS GAGE
MONTHLY FLOW (AC-FT)
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000
1/1/1950
1/1/1955
1/1/1960
1/1/1965
1/1/1970
1/1/1975
1/1/1980
1/1/1985
1/1/1990
1/1/1995
WAM FLOW
RIVERWARE FLOW
USGS GAGED FLOW


MONTHLY INFLOWS TO LAKE RALPH HALL
FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL
MONTHLY INFLOW (AC-FT)
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
1/1/1940
1/1/1945
1/1/1950
1/1/1955
1/1/1960
1/1/1965
1/1/1970
1/1/1975
1/1/1980
1/1/1985
1/1/1990
1/1/1995
From RiverWare
From WAM

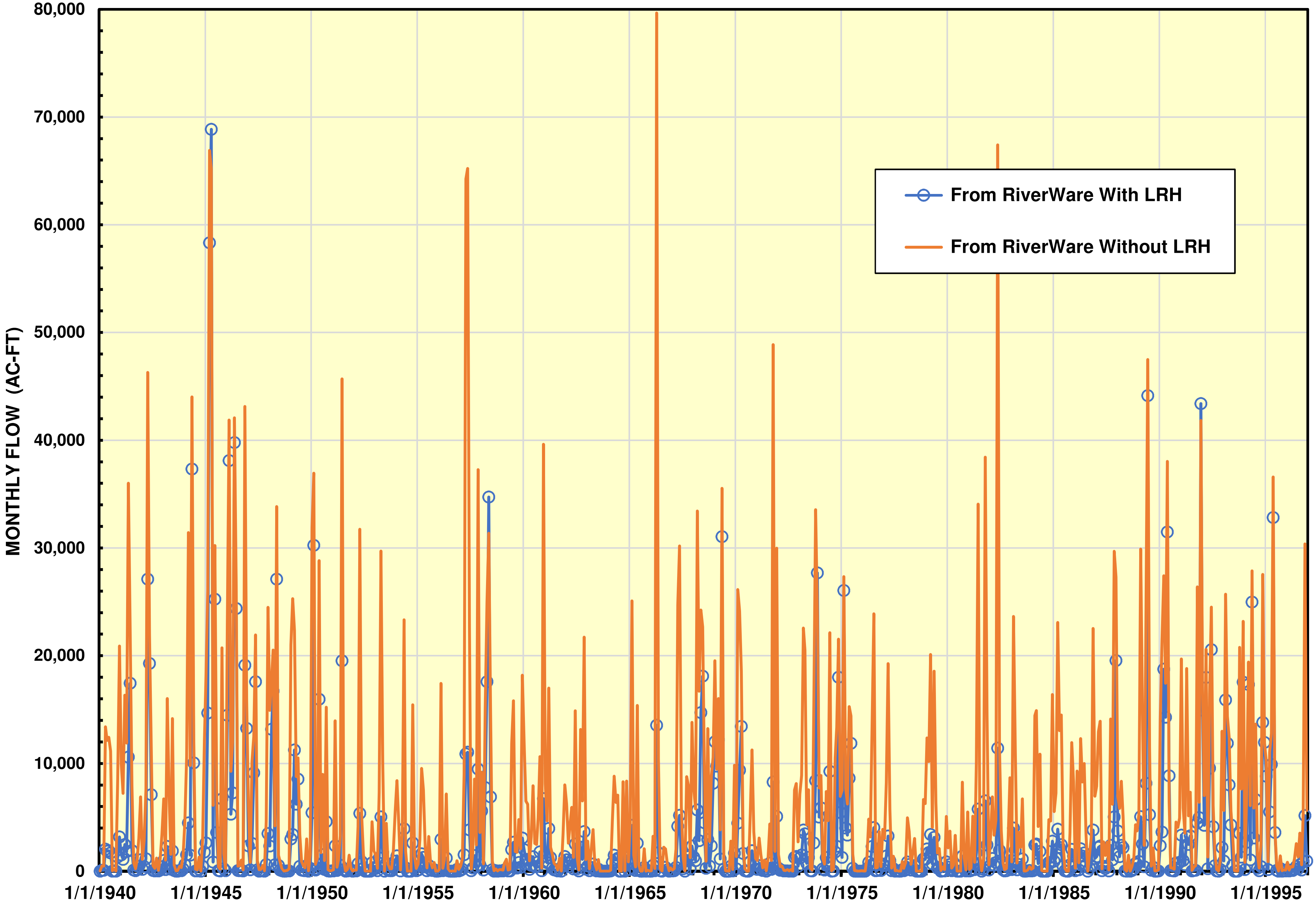
CUMULATIVE MONTHLY INFLOWS TO LAKE RALPH HALL BEGINNING IN 1950 FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL



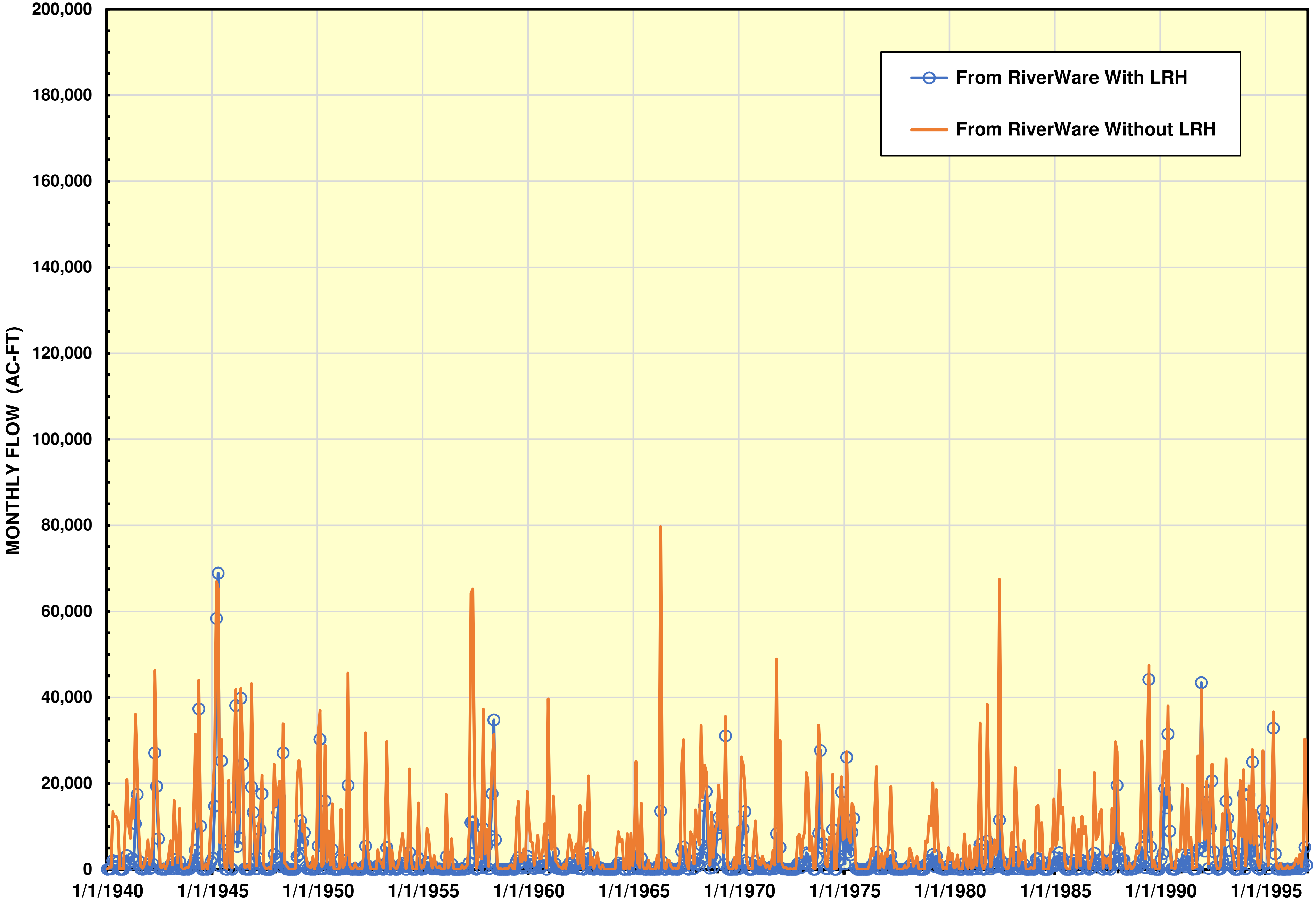
MONTHLY OUTFLOWS FROM LAKE RALPH HALL FROM RIVERWARE MODEL AND FROM TCEQ WATER AVAILABILITY MODEL

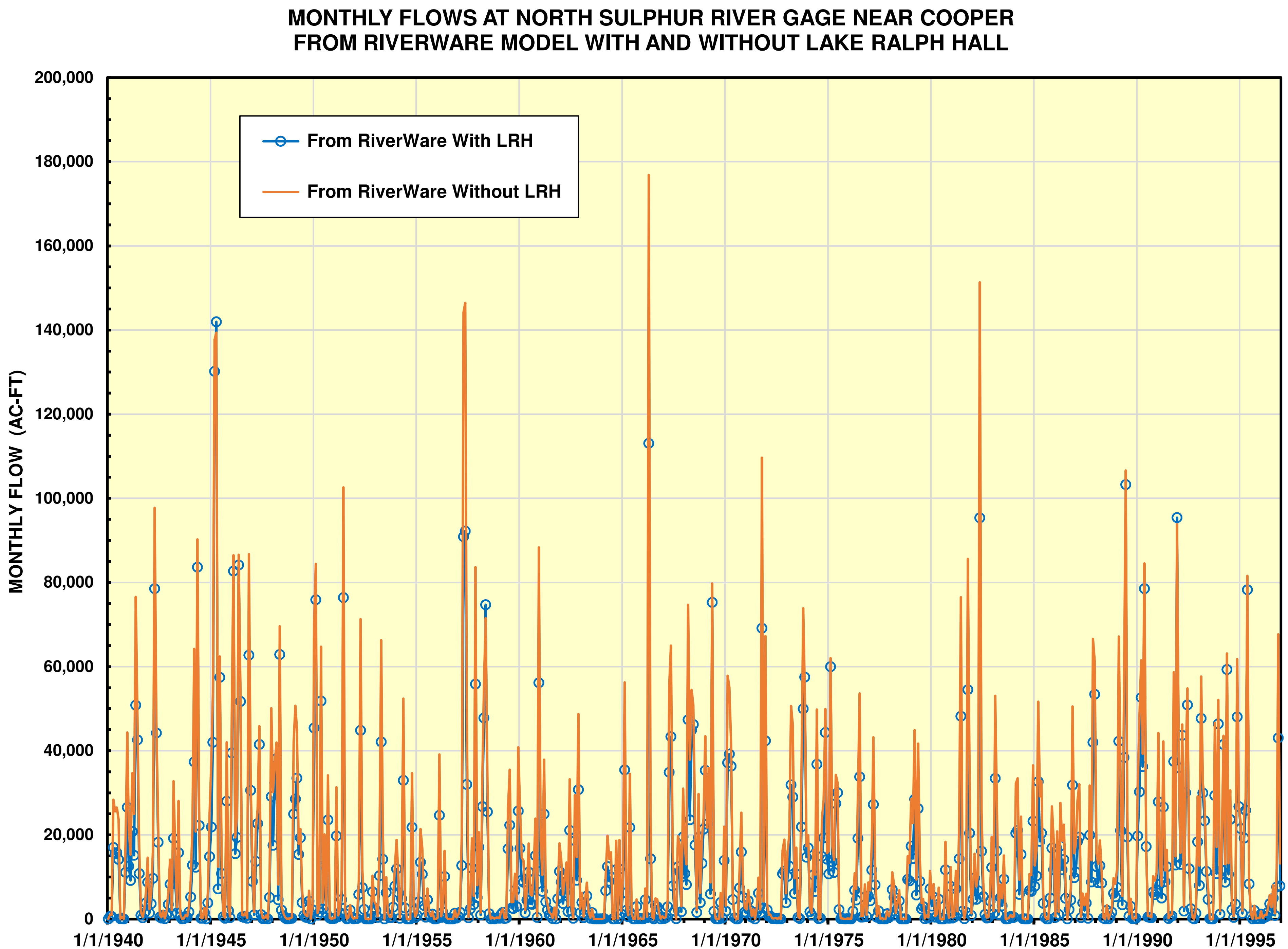


MONTHLY FLOWS BELOW LAKE RALPH HALL DAM SITE AT BAKER CREEK CONFLUENCE FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL



MONTHLY FLOWS BELOW LAKE RALPH HALL DAM SITE AT BAKER CREEK CONFLUENCE FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL




MONTHLY FLOWS AT NORTH SULPHUR RIVER GAGE NEAR COOPER
FROM RIVERWARE MODEL WITH AND WITHOUT LAKE RALPH HALL
MONTHLY FLOW (AC-FT)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1/1/1940
1/1/1945
1/1/1950
1/1/1955
1/1/1960
1/1/1965
1/1/1970
1/1/1975
1/1/1980
1/1/1985
1/1/1990
1/1/1995
From RiverWare With LRH
From RiverWare Without LRH

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE AND FROM WAM WITH LAKE RALPH HALL

	RiverWare	WAM
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	62.2%	73.0%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	82.1%	83.8%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon
1.0%	99.0%	0	0	0	0	0	2	1	3	308	208	308	284
2.0%	98.0%	0	0	0	0	0	3	5	4	316	310	341	416
3.0%	97.0%	0	0	0	0	0	4	11	10	343	378	369	472
4.0%	96.0%	3	2	1	3	4	9	30	23	350	384	442	509
5.0%	95.0%	5	4	1	5	9	16	38	34	394	423	527	590
7.0%	93.0%	13	8	3	9	22	28	63	57	455	473	720	751
10.0%	90.0%	27	17	5	19	45	54	114	121	658	587	1,046	1,180
15.0%	85.0%	76	48	14	47	115	149	288	364	1,051	1,053	1,740	1,919
16.2%	83.8%	90	57	18	53	147	175	329	425	1,151	1,201	2,172	2,389
17.9%	82.1%	111	78	21	66	175	235	420	503	1,462	1,278	2,801	3,199
20.0%	80.0%	137	105	26	93	217	290	510	677	1,727	1,539	3,657	3,713
25.0%	75.0%	239	181	46	148	385	531	985	1,057	3,086	2,708	5,774	5,251
27.0%	73.0%	281	210	54	175	450	612	1,151	1,365	3,871	3,706	6,747	6,034
30.0%	70.0%	427	294	74	216	622	801	1,495	1,925	4,750	4,630	8,313	8,534
35.0%	65.0%	719	558	136	279	1,133	1,417	2,494	3,058	7,525	6,802	13,183	10,734
37.8%	62.2%	900	665	175	347	1,462	1,721	2,971	3,867	10,190	8,458	17,103	13,954
40.0%	60.0%	1,006	775	200	399	1,653	2,002	3,481	4,583	12,496	9,491	19,602	15,409
45.0%	55.0%	1,407	1,082	289	580	2,401	2,687	5,245	5,949	18,340	12,596	28,830	23,245
50.0%	50.0%	2,282	1,564	464	703	3,858	3,686	8,023	9,206	26,824	18,267	40,908	32,715
55.0%	45.0%	3,045	2,332	623	873	5,163	5,292	10,668	11,533	37,805	24,879	53,370	42,984
60.0%	40.0%	4,134	2,999	883	1,045	7,131	6,710	14,234	14,376	47,497	33,221	71,843	54,994
65.0%	35.0%	5,321	3,984	1,211	1,241	9,225	8,393	18,076	18,587	61,125	45,782	88,631	73,743
70.0%	30.0%	6,622	4,888	1,521	1,470	11,757	10,596	23,588	22,868	79,418	65,486	103,849	92,557
75.0%	25.0%	8,405	6,029	2,217	1,824	14,846	12,991	28,116	29,924	98,188	79,181	130,400	127,491
80.0%	20.0%	10,811	7,705	3,078	2,418	19,379	17,072	35,927	36,748	123,556	104,573	171,682	151,680
85.0%	15.0%	13,673	10,382	4,480	3,096	25,781	22,466	46,575	45,590	155,803	135,489	208,709	190,183
90.0%	10.0%	18,784	14,228	8,361	4,370	35,820	30,500	62,134	58,028	198,349	175,216	255,076	243,622
93.0%	7.0%	21,825	17,406	11,975	5,443	43,397	36,793	76,704	78,355	257,081	216,641	322,727	306,866
95.0%	5.0%	24,891	19,863	15,947	6,296	49,700	43,180	89,430	92,857	290,876	284,076	382,976	375,193
96.0%	4.0%	26,864	21,407	17,862	6,954	54,159	45,865	96,410	95,949	323,213	314,282	421,932	418,985
97.0%	3.0%	30,469	22,901	19,541	8,289	61,368	50,686	105,126	103,312	345,471	343,599	432,516	458,729
98.0%	2.0%	35,099	26,692	27,108	11,373	77,062	57,164	122,428	121,197	379,523	377,268	480,264	501,764
99.0%	1.0%	39,638	33,484	35,168	13,319	91,093	79,347	147,879	151,390	431,441	445,099	562,465	569,985
99.1%	0.9%	40,419	34,369	36,952	14,273	92,034	81,036	148,070	154,008	445,392	451,806	583,688	574,870
99.99%	0.01%	65,795	57,578	68,143	30,362	141,161	119,938	208,524	211,279	606,742	673,524	733,092	877,480

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE AND FROM WAM WITHOUT LAKE RALPH HALL

	RiverWare	WAM
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	79.6%	77.4%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	85.5%	83.9%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	FLOW AT LAKE RALPH HALL DAM SITE		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon	From RiverWare ac-ft/mon	From WAM ac-ft/mon
1.0%	99.0%	0	0	0	0	0	2	1	3	308	208	308	284
2.0%	98.0%	0	0	0	0	0	3	7	4	317	310	344	416
3.0%	97.0%	0	0	0	0	0	4	13	10	346	378	392	472
4.0%	96.0%	3	2	3	3	7	9	37	23	369	384	472	509
5.0%	95.0%	5	4	6	5	14	16	55	34	411	423	534	590
7.0%	93.0%	13	8	16	11	36	28	83	57	496	473	774	751
10.0%	90.0%	27	17	33	21	73	55	150	121	694	587	1,142	1,198
14.5%	85.5%	67	42	81	53	175	134	359	337	1,134	983	1,757	1,863
15.0%	85.0%	76	48	91	60	200	150	381	374	1,182	1,053	1,913	1,939
16.1%	83.9%	88	56	106	69	235	175	430	421	1,299	1,201	2,370	2,453
20.0%	80.0%	137	105	163	131	360	327	731	691	2,019	1,604	3,845	3,812
20.5%	79.6%	147	106	175	133	370	331	760	727	2,118	1,642	4,269	3,941
22.6%	77.4%	196	140	233	175	508	438	894	907	2,767	2,185	5,275	4,384
25.0%	75.0%	239	181	283	226	637	560	1,297	1,068	3,486	2,907	6,486	5,462
30.0%	70.0%	427	294	503	368	1,007	911	2,139	1,993	5,794	4,761	9,477	8,559
35.0%	65.0%	719	558	859	697	1,864	1,724	3,194	3,424	8,666	7,289	14,329	11,054
40.0%	60.0%	1,006	775	1,213	967	2,662	2,390	4,504	4,838	14,348	9,807	21,706	16,383
45.0%	55.0%	1,407	1,082	1,654	1,351	3,702	3,337	6,918	6,546	21,168	14,049	30,418	25,207
50.0%	50.0%	2,282	1,564	2,748	1,953	6,103	4,819	10,317	10,683	29,881	20,578	41,964	33,876
55.0%	45.0%	3,045	2,332	3,674	2,912	8,216	7,193	13,709	14,082	41,520	27,605	56,561	45,630
60.0%	40.0%	4,134	2,999	4,974	3,745	11,140	9,241	18,641	17,926	53,220	36,086	77,273	59,338
65.0%	35.0%	5,321	3,984	6,475	4,977	14,611	12,279	23,018	22,405	65,830	49,758	94,761	77,924
70.0%	30.0%	6,622	4,888	7,932	6,104	17,763	15,061	29,660	27,658	85,531	68,570	111,283	96,196
75.0%	25.0%	8,405	6,029	10,144	7,529	22,106	18,597	35,934	35,918	106,032	87,441	140,059	132,052
80.0%	20.0%	10,811	7,705	12,957	9,622	28,326	23,757	44,314	42,962	131,134	113,998	181,748	160,522
90.0%	10.0%	18,784	14,228	22,501	17,768	49,903	43,878	74,562	71,524	214,631	188,588	268,410	255,851
93.0%	7.0%	21,825	17,406	25,778	21,736	55,542	53,675	90,564	93,102	269,188	234,764	333,275	323,591
95.0%	5.0%	24,891	19,863	29,967	24,804	66,111	61,264	103,576	110,149	308,811	301,091	399,997	390,320
96.0%	4.0%	26,864	21,407	31,828	26,733	70,919	65,990	116,735	113,552	342,029	326,063	433,457	433,702
97.0%	3.0%	30,469	22,901	36,303	28,598	80,704	70,599	124,159	126,166	361,655	368,055	447,459	475,112
98.0%	2.0%	35,099	26,692	41,839	33,332	86,632	82,322	137,801	142,550	401,174	394,235	499,927	515,625
99.0%	1.0%	39,638	33,484	47,723	41,814	107,136	103,241	164,893	184,164	433,424	463,329	596,116	598,896
99.9%	0.1%	60,174	51,960	71,297	64,886	159,440	160,240	234,060	255,580	636,248	714,960	747,687	828,098
99.99%	0.01%	65,795	57,578	78,816	71,901	175,146	177,515	240,444	260,229	654,534	722,475	770,216	925,058

STATISTICAL ANALYSIS OF FLOWS FROM RIVERWARE WITH AND WITHOUT LAKE RALPH HALL

	With LRH	Without LRH
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	62.2%	79.6%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	82.1%	85.5%

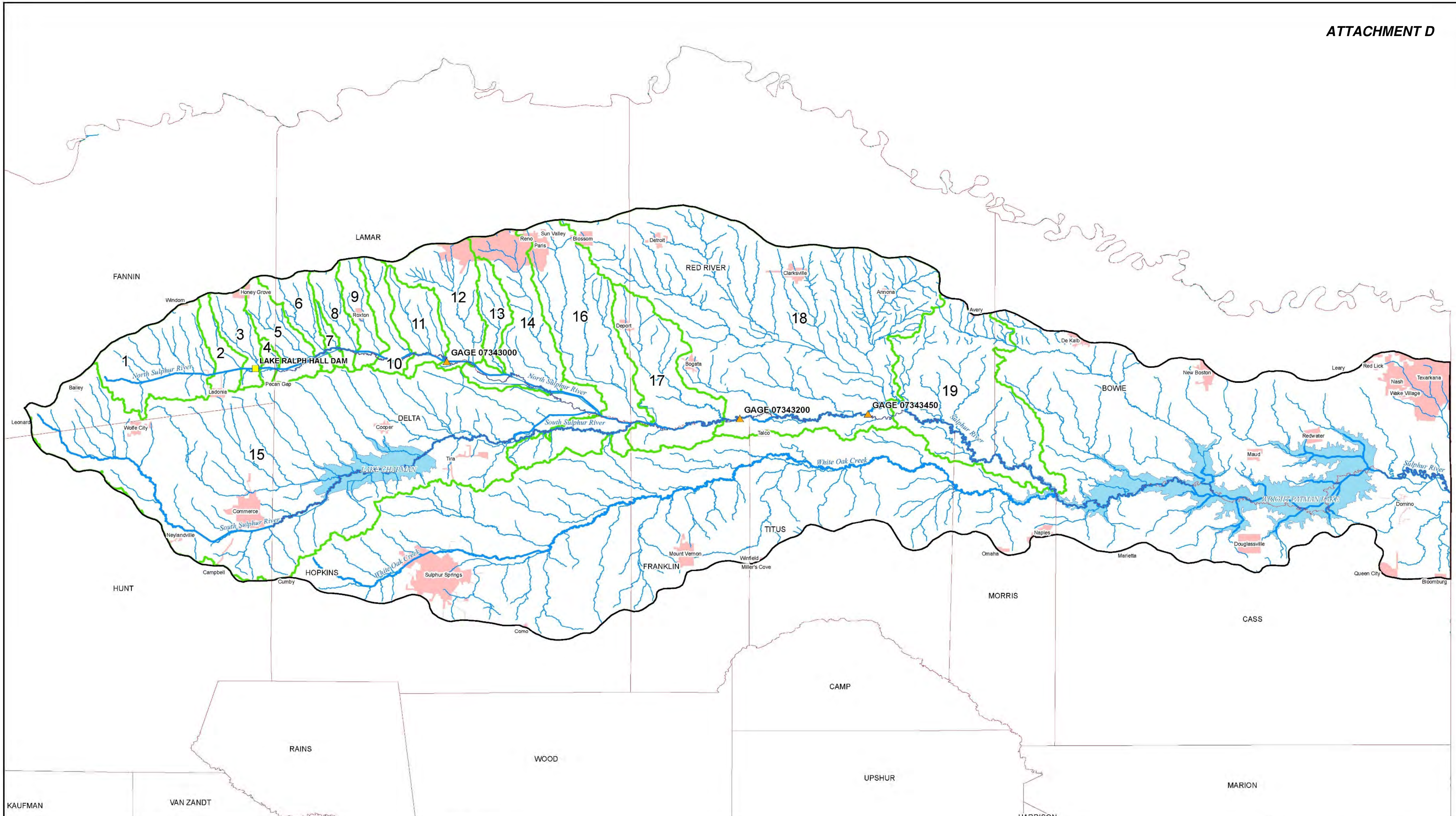
PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
%	%	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon	With LRH ac-ft/mon	Without LRH ac-ft/mon
1.0%	99.0%	0	0	0	0	0	0	1	1	308	308	308	308
2.0%	98.0%	0	0	0	0	0	0	5	7	316	317	341	344
3.0%	97.0%	0	0	0	0	0	0	11	13	343	346	369	392
4.0%	96.0%	3	3	1	3	4	7	30	37	350	369	442	472
5.0%	95.0%	5	5	1	6	9	14	38	55	394	411	527	534
7.0%	93.0%	13	13	3	16	22	36	63	83	455	496	720	774
10.0%	90.0%	27	27	5	33	45	73	114	150	658	694	1,046	1,142
14.5%	85.5%	67	67	13	81	106	175	283	359	1,008	1,136	1,661	1,759
15.0%	85.0%	76	76	14	91	115	200	288	381	1,051	1,182	1,740	1,913
18.0%	82.1%	111	111	21	134	175	281	420	528	1,463	1,599	2,802	3,012
20.0%	80.0%	137	137	26	163	217	360	510	731	1,727	2,019	3,657	3,845
20.5%	79.6%	147	147	27	175	228	370	550	760	1,835	2,118	3,788	4,269
25.0%	75.0%	239	239	46	283	385	637	985	1,297	3,086	3,486	5,774	6,486
30.0%	70.0%	427	427	74	503	622	1,007	1,495	2,139	4,750	5,794	8,313	9,477
35.0%	65.0%	719	719	136	859	1,133	1,864	2,494	3,194	7,525	8,666	13,183	14,329
37.8%	62.2%	901	901	175	1,072	1,464	2,331	2,974	3,938	10,207	11,672	17,118	18,683
40.0%	60.0%	1,006	1,006	200	1,213	1,653	2,662	3,481	4,504	12,496	14,348	19,602	21,706
45.0%	55.0%	1,407	1,407	289	1,654	2,401	3,702	5,245	6,918	18,340	21,168	28,830	30,418
50.0%	50.0%	2,282	2,282	464	2,748	3,858	6,103	8,023	10,317	26,824	29,881	40,908	41,964
55.0%	45.0%	3,045	3,045	623	3,674	5,163	8,216	10,668	13,709	37,805	41,520	53,370	56,561
60.0%	40.0%	4,134	4,134	883	4,974	7,131	11,140	14,234	18,641	47,497	53,220	71,843	77,273
65.0%	35.0%	5,321	5,321	1,211	6,475	9,225	14,611	18,076	23,018	61,125	65,830	88,631	94,761
70.0%	30.0%	6,622	6,622	1,521	7,932	11,757	17,763	23,588	29,660	79,418	85,531	103,849	111,283
75.0%	25.0%	8,405	8,405	2,217	10,144	14,846	22,106	28,116	35,934	98,188	106,032	130,400	140,059
80.0%	20.0%	10,811	10,811	3,078	12,957	19,379	28,326	35,927	44,314	123,556	131,134	171,682	181,748
85.0%	15.0%	13,673	13,673	4,480	16,198	25,781	35,713	46,575	58,546	155,803	163,200	208,709	218,084
90.0%	10.0%	18,784	18,784	8,361	22,501	35,820	49,903	62,134	74,562	198,349	214,631	255,076	268,410
93.0%	7.0%	21,825	21,825	11,975	25,778	43,397	55,542	76,704	90,564	257,081	269,188	322,727	333,275
95.0%	5.0%	24,891	24,891	15,947	29,967	49,700	66,111	89,430	103,576	290,876	308,811	382,976	399,997
96.0%	4.0%	26,864	26,864	17,862	31,828	54,159	70,919	96,410	116,735	323,213	342,029	421,932	433,457
97.0%	3.0%	30,469	30,469	19,541	36,303	61,368	80,704	105,126	124,159	345,471	361,655	432,516	447,459
98.0%	2.0%	35,099	35,099	27,108	41,839	77,062	86,632	122,428	137,801	379,523	401,174	480,264	499,927
99.0%	1.0%	39,638	39,638	35,168	47,723	91,093	107,136	147,879	164,893	431,441	433,424	562,465	596,116
99.9%	0.1%	60,174	60,174	61,662	71,297	133,926	159,440	194,211	234,060	597,068	636,248	725,870	747,687
99.99%	0.01%	65,795	65,795	68,143	78,816	141,161	175,146	208,524	240,444	606,742	654,534	733,092	770,216

STATISTICAL ANALYSIS OF FLOWS FROM WAM WITH AND WITHOUT LAKE RALPH HALL

	With LRH	Without LRH
Probability That Monthly Flow below Lake Ralph Hall Dam at Bakers Creek Exceeds Channel Pool Volume of 175 ac-ft:	73.0%	77.4%
Probability That Monthly Flow at North Sulphur River Gage near Cooper Exceeds Channel Pool Volume of 175 ac-ft:	83.8%	83.9%

PER-CENTILE	EXCEED-ENCE PROBA-BILITY	INFLOW TO LAKE RALPH HALL		FLOW BELOW LAKE RALPH HALL AT BAKERS CREEK Map Catchment 3		FLOW AT N SULPHUR RIVER COOPER GAGE Map Gage 07343000		FLOW AT PARKHOUSE 2 DAM SITE Map Catchment 14		FLOW AT N SULPHUR RIVER TALCO GAGE Map Gage 07343200		FLOW AT MARVIN NICHOLS DAM SITE Map Catchment 18	
		With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH	With LRH	Without LRH
%	%	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon	ac-ft/mon
1.0%	99.0%	0	0	0	0	2	2	3	3	208	208	284	284
2.0%	98.0%	0	0	0	0	3	3	4	4	310	310	416	416
3.0%	97.0%	0	0	0	0	4	4	10	10	378	378	472	472
4.0%	96.0%	2	2	3	3	9	9	23	23	384	384	509	509
5.0%	95.0%	4	4	5	5	16	16	34	34	423	423	590	590
7.0%	93.0%	8	8	9	11	28	28	57	57	473	473	751	751
10.0%	90.0%	17	17	19	21	54	55	121	121	587	587	1,180	1,198
15.0%	85.0%	48	48	47	60	149	150	364	374	1,053	1,053	1,919	1,939
16.1%	83.9%	56	56	53	69	167	175	421	421	1,190	1,201	2,329	2,453
16.2%	83.8%	57	57	53	72	175	180	425	425	1,201	1,206	2,389	2,506
20.0%	80.0%	105	105	93	131	290	327	677	691	1,539	1,604	3,713	3,812
22.6%	77.4%	140	140	113	175	381	437	874	906	2,070	2,182	4,275	4,377
25.0%	75.0%	181	181	148	226	531	560	1,057	1,068	2,708	2,907	5,251	5,462
27.0%	73.0%	210	210	175	262	612	651	1,365	1,393	3,706	4,016	6,034	6,184
30.0%	70.0%	294	294	216	368	801	911	1,925	1,993	4,630	4,761	8,534	8,559
35.0%	65.0%	558	558	279	697	1,417	1,724	3,058	3,424	6,802	7,289	10,734	11,054
40.0%	60.0%	775	775	399	967	2,002	2,390	4,583	4,838	9,491	9,807	15,409	16,383
45.0%	55.0%	1,082	1,082	580	1,351	2,687	3,337	5,949	6,546	12,596	14,049	23,245	25,207
50.0%	50.0%	1,564	1,564	703	1,953	3,686	4,819	9,206	10,683	18,267	20,578	32,715	33,876
55.0%	45.0%	2,332	2,332	873	2,912	5,292	7,193	11,533	14,082	24,879	27,605	42,984	45,630
60.0%	40.0%	2,999	2,999	1,045	3,745	6,710	9,241	14,376	17,926	33,221	36,086	54,994	59,338
65.0%	35.0%	3,984	3,984	1,241	4,977	8,393	12,279	18,587	22,405	45,782	49,758	73,743	77,924
70.0%	30.0%	4,888	4,888	1,470	6,104	10,596	15,061	22,868	27,658	65,486	68,570	92,557	96,196
75.0%	25.0%	6,029	6,029	1,824	7,529	12,991	18,597	29,924	35,918	79,181	87,441	127,491	132,052
80.0%	20.0%	7,705	7,705	2,418	9,622	17,072	23,757	36,748	42,962	104,573	113,998	151,680	160,522
90.0%	10.0%	14,228	14,228	4,370	17,768	30,500	43,878	58,028	71,524	175,216	188,588	243,622	255,851
93.0%	7.0%	17,406	17,406	5,443	21,736	36,793	53,675	78,355	93,102	216,641	234,764	306,866	323,591
95.0%	5.0%	19,863	19,863	6,296	24,804	43,180	61,264	92,857	110,149	284,076	301,091	375,193	390,320
96.0%	4.0%	21,407	21,407	6,954	26,733	45,865	65,990	95,949	113,552	314,282	326,063	418,985	433,702
97.0%	3.0%	22,901	22,901	8,289	28,598	50,686	70,599	103,312	126,166	343,599	368,055	458,729	475,112
98.0%	2.0%	26,692	26,692	11,373	33,332	57,164	82,322	121,197	142,550	377,268	394,235	501,764	515,625
99.0%	1.0%	33,484	33,484	13,319	41,814	79,347	103,241	151,390	184,164	445,099	463,329	569,985	598,896
99.9%	0.1%	51,960	51,960	30,086	64,886	108,282	160,240	207,607	255,580	666,987	714,960	779,543	828,098
99.99%	0.01%	57,578	57,578	30,362	71,901	119,938	177,515	211,279	260,229	673,524	722,475	877,480	925,058

ATTACHMENT D



- Dams
- Gages
- NHD Flowline
- Major Rivers
- Major Reservoirs
- County Boundary
- Sulphur River Basin
- Catchment Areas
- City

0 5 10 20
Miles

ATKINS

Sulphur River Basin
Texas

Prepared By: PITT6080	Scale: 1:300,000
Job No.: 100039493	Date: 16 July 2014
File: N:\Clients\S_T\Temp\LocationMap_vr3.mxd	

ATTACHMENT E

SUMMARY OF ANALYSIS OF FILLING RIVER CHANNEL POOLS DOWNSTREAM OF LAKE RALPH HALL WITH NORTH SULPHUR RIVER FLOWS SIMULATED WITH RIVERWARE MODEL AND WITH WAM FOR CONDITIONS WITHOUT AND WITH LAKE RALPH HALL PROJECT

STATION NO.	WATER COURSE	LOCATION DESCRIPTION	DRAINAGE AREA sq. mi.	DISTANCE ABOVE N SULPHUR GAGE miles	VOLUME REQUIRED TO FILL ALL D/S POOLS ac-ft	POOL VOLUME IN EACH D/S REACH ac-ft	% OF TIME POOLS ARE FILLED		
							Without Lake Ralph Hall	With Lake Ralph Hall	Deviation From Without LRH Case
FROM RIVERWARE MODEL (06-26-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	- -	- -	- -	- -
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	92.7%	83.6%	-9.1%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	86.7%	73.2%	-13.5%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	85.8%	82.0%	-3.8%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	86.7%	86.3%	-0.4%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	85.8%	85.4%	-0.4%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	85.4%	83.6%	-1.8%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	89.8%	89.6%	-0.1%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	85.1%	82.7%	-2.3%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	- -	- -	- -	- -
FROM WAM (04-06-15)									
LRH	North Sulphur R.	Lake Ralph Hall Dam Site	100.9	20.00	175.0	- -	- -	- -	- -
3	North Sulphur R.	Downstream of mouth of Baker Ck.	126.1	18.13	175.0	17.8	90.8%	90.2%	-0.6%
4	North Sulphur R.	Downstream of mouth of Bledsoe Ck.	132.1	16.29	157.2	46.4	84.8%	83.5%	-1.3%
5	North Sulphur R.	Downstream of mouth of Wafer Ck.	165.7	11.48	110.8	27.9	83.9%	83.8%	-0.1%
6	North Sulphur R.	Downstream of mouth of Ghost Ck.	191.8	8.59	82.9	11.2	85.4%	85.4%	0.0%
7	North Sulphur R.	Downstream of mouth of Morrison Ck.	198.3	7.42	71.7	6.0	83.9%	83.9%	0.0%
8	North Sulphur R.	Downstream of mouth of Rowdy Ck.	220.2	6.81	65.7	21.6	83.3%	83.2%	-0.1%
9	North Sulphur R.	Downstream of mouth of Cane Ck.	244.9	4.57	44.1	5.5	88.6%	88.6%	0.0%
10	North Sulphur R.	Downstream of mouth of Maxwell Ck.	270.8	4.00	38.6	38.6	83.2%	83.0%	-0.1%
B10	North Sulphur R.	USGS Gage 7343000 near Cooper	311.3	0.00	0.0	- -	- -	- -	- -