THE WATER INSTITUTE

Technical Memorandum

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MILL CREEK WATERSHED

Development and Application of a Hydrologic Model to Assess Reservoir Performance and Downstream Impacts

INTRODUCTION

The Mill Creek watershed is located in Allen Parish, Louisiana, and is a tributary to the Calcasieu River, with both its main Mill Creek and Little Mill Creek branches (Figure 1). The Mill Creek watershed is part of the West Bay Wildlife Management Area,[1] and most of the watershed is unpopulated agricultural land composed of pine plantations with scattered hardwoods along streambeds. The confluence of Mill Creek and the Calcasieu River is approximately 40 miles upstream of the nearest major urban center, Lake Charles, which itself is located along the east bank on the Calcasieu River. Smaller towns, such as Kinder, Oberlin, and Oakdale, also are located along the Calcasieu River reach that is abutting the Mill Creek watershed (Figure 1—green circles). White Oak Park and Hecker Road represent some of the closest populated areas downstream of Mill Creek (Figure 1—purple circles).

The Southwest Louisiana Regional Planning Commission (RPC) is interested in water level mitigation measures in the Mill Creek watershed. In particular, the RPC is considering the benefits resulting from installation of a reservoir on Mill Creek (i.e., Mill Creek reservoir) that was proposed by Allen Parish. The main benefits envisioned are: ability to store potable water, storage of water for agriculture production (rice and crawfish), firefighting, potential capacity to reduce water levels, recreational development, and increase aquifer recharge. The primary interest of the RPC and local stakeholders, as well as the focus of this study and memorandum, is the potential reduction of water levels downstream.

Through a long-term recovery agreement with the Federal Emergency Management Agency (FEMA), the National Park Service – Rivers, Trails & Conservation Assistance Program (NPS) is a partner in this planning study. NPS supports the stakeholder's vision to analyze a holistic management of the Mill Creek

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[1] West Bay | Louisiana Department of Wildlife and Fisheries

watershed via land use best practices, and the potential implementation of stormwater detention/retention features such as the Mill Creek reservoir proposed by Allen Parish.

The Allen Parish proposal is detailed in a preliminary design document prepared by Denmon Engineering Company in August 2006 on behalf of the Allen Parish Reservoir Commission (Denmon Engineering, 2006). This document defines the proposed reservoir, its detention capacity, spillway and dam, and outflow hydrographs for several design storm events. Allen Parish engineers have since revised and shared the design of the proposed reservoir with The Water Institute (the Institute), and that design is the one used in this analysis. The proposed dam would be located on Mill Creek approximately 2 miles upstream from its confluence with the Calcasieu River and approximately 6 miles northwest of the town of Oberlin, LA (Figure 1). The proposed reservoir has a watershed of 49,466 acres and impounds 39,556.9 acre-feet of water. Figure 2 shows the general project area and the proposed reservoir footprint (with a dam along the southern end), along with proximity to the Calcasieu River in the southeast corner of the image. The revised reservoir shared by Allen Parish (Figure 2) follows a 200-year reservoir design of its choice, and the reservoir was evaluated as provided without any additional modifications.

The work described in this technical memorandum aims to analyze the downstream effects of the proposed Mill Creek reservoir. The 2006 preliminary engineering report did not evaluate downstream effects, rather focused on hydraulic and hydrologic reservoir characteristics and on examining the potential benefit to potable water service.

During this project, the Institute developed a hydrologic model to evaluate downstream impacts resulting from the implementation of the Mill Creek reservoir, such as potential flow reduction in the Calcasieu River during storm events and corresponding changes in water levels. The Institute utilized the United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) to evaluate local hydrology. This modeling software is a standard analysis software used by the Federal Emergency Management Agency (FEMA) and the USACE, and it is the industry standard for hydrologic studies. The modeling software is free and open source and includes many pre- and post-processing and visualization tools (USACE, 2022).

This technical memorandum is structured as follows:

- The first section summarizes the available stage and discharge observations along the Calcasieu River both upstream and downstream of the project site. This information was compiled to analyze the impact of the Mill Creek reservoir on the Calcasieu River flow. This information together with the HEC-HMS model results will help NPS and local stakeholders to determine the effect of the proposed structure on the local hydrology.
- The second section summarizes the development of the HEC-HMS model, describes the data that were used to inform the model, the model calibration and validation, and the scenarios that were analyzed.
- The final section presents the results of the model scenarios that were evaluated and provides recommendations for future analysis.

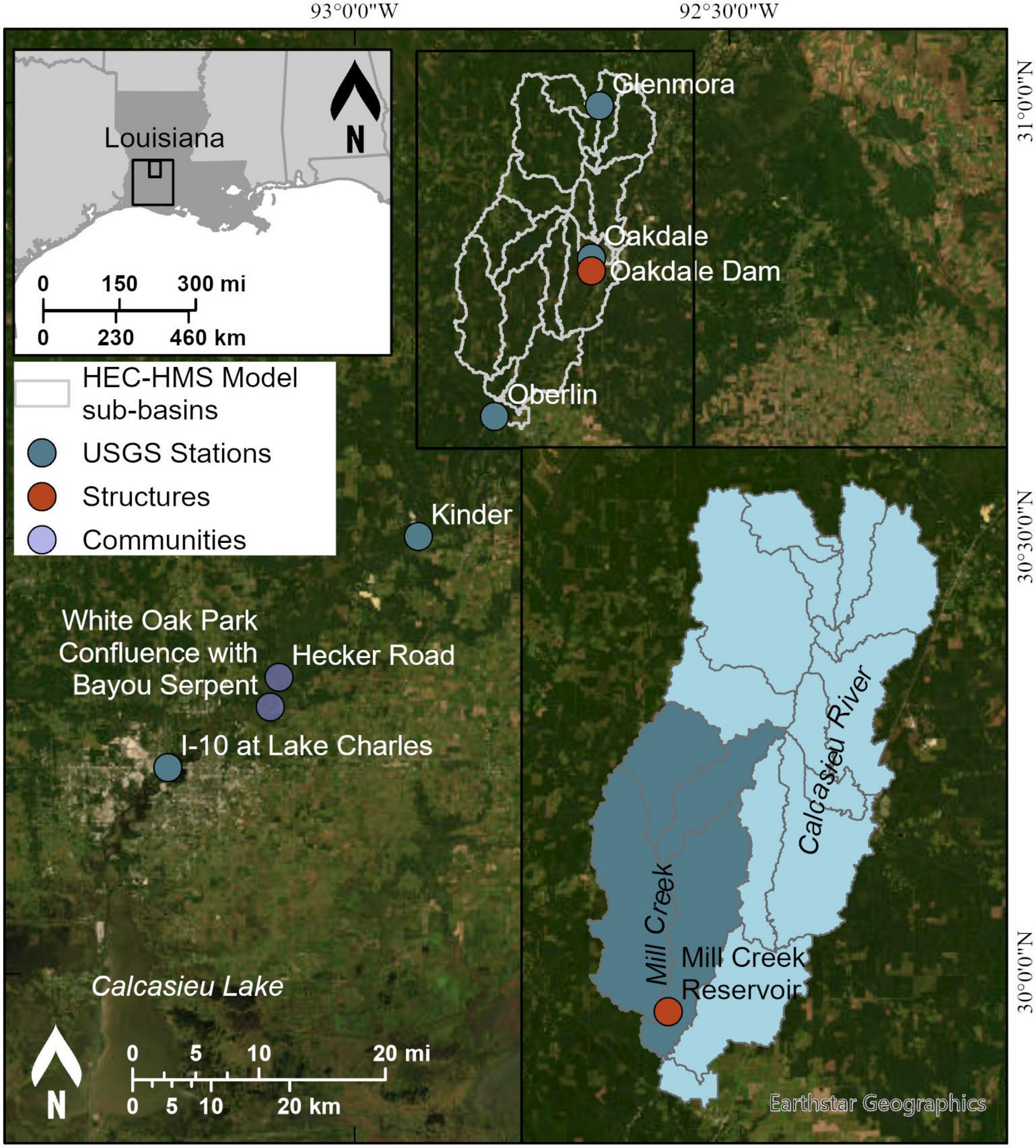


Figure 1. Area of interest and geographic location of the Mill Creek reservoir. United States Geological Survey (USGS) stations located near main towns (green circles), closest communities (purple circles), Oakdale dam and proposed Mill Creek reservoir (orange circles), modeled Calcasieu watershed (light blue,) and Mill Creek watershed (green).

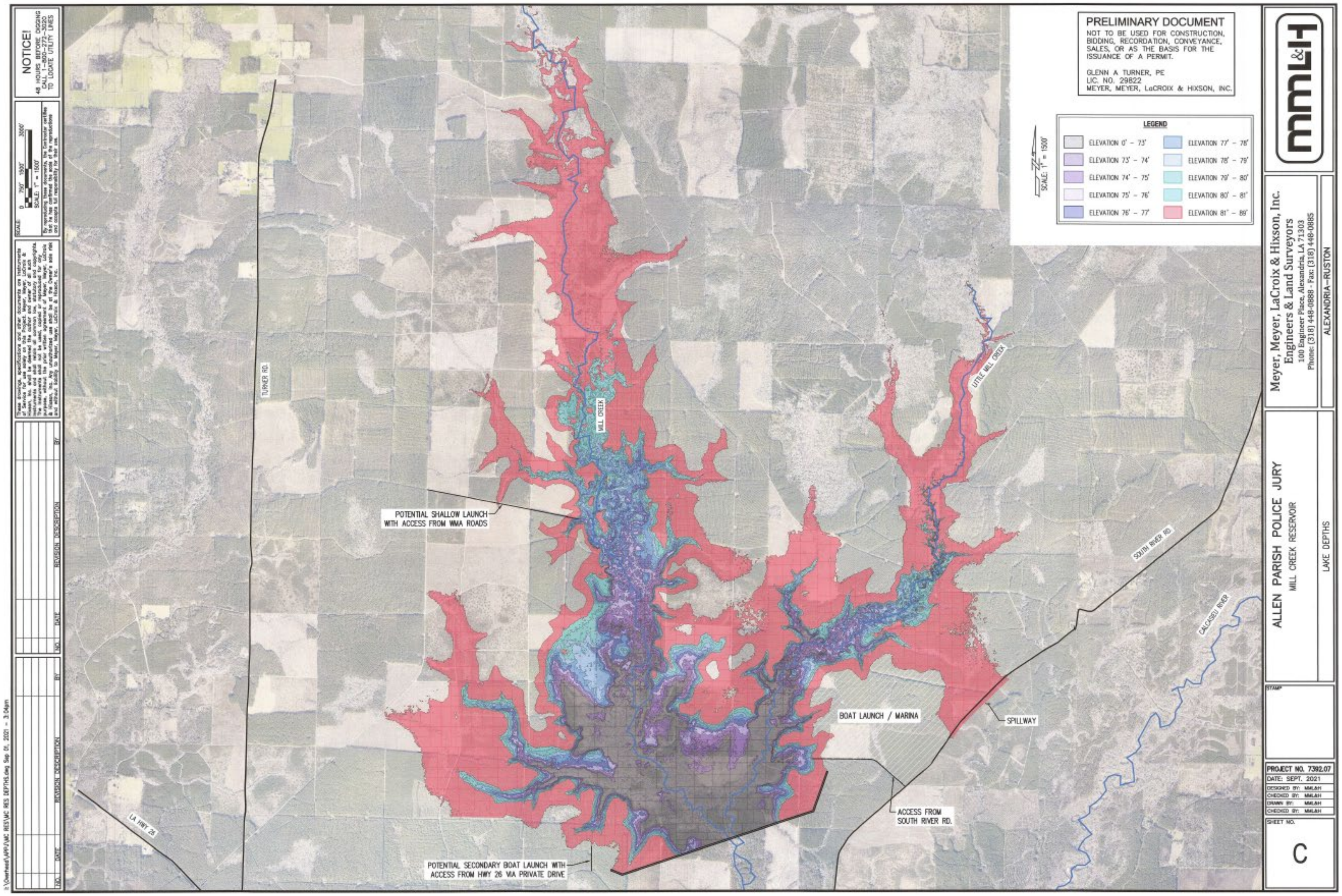


Figure 2. Proposed Allen Parish 200-year reservoir for Mill Creek.

FLOW CONTRIBUTION AND DATA ANALYSIS

There are multiple United States Geological Survey (USGS) stream gauges in place along the Calcasieu River, both upstream and downstream of the project site (i.e., Mill Creek Reservoir, Figure 1). Flow magnitude of the Calcasieu River upstream of Lake Charles was analyzed. Five gauges were considered for this analysis and are summarized in Table 1. Station USGS#08017044 did not include discharge data and therefore was not used in this analysis. Table 2 shows the statistics for the available discharge data at the remaining four USGS gauges. For this analysis, instantaneous (i.e., every 30-min) discharge records were used. Table 2 includes the number of recorded discharge observations, the mean discharge, standard deviation, the minimum and maximum discharge, and the 25, 50, 75 and 95 discharge percentiles. A longer record of daily data (i.e., daily discharge) also exists for the stations of Glenmora, Oberlin, and Kinder; statistics were also calculated using this longer record (Table 3). Higher maximum discharge can be observed in the historic record, while mean, standard deviation, minimum, and the 25, 50, 75 and 95 percentiles of discharge remain similar.

Table 1. USGS gauges considered for the analysis—their location and record of data availability.

USGS ID	Station name	Lat	Lon	Data from	Data to	Location
08013000	Calcasieu River near Glenmora, LA	30.99667	-92.6736	10/1/1995	present	Upstream of Mill Creek
08013250	Calcasieu River near Oakdale, LA	30.82228	-92.6847	4/22/2021	present	Upstream of Mill Creek and downstream of #08013000
08013500	Calcasieu River near Oberlin, LA	30.64048	-92.814	10/1/1995	present	Downstream of Mill Creek
08015500	Calcasieu River near Kinder, LA	30.50256	-92.9154	10/1/1995	present	Downstream of Mill Creek and of #08013500
08017044	Calcasieu River at I-10 at Lake Charles, LA	30.23715	-93.2474	10/2/2007	present	Downstream of Mill Creek and of #08015500

Table 2. Flow statistics from USGS gauges using instantaneous observations. Statistics are approximately based on a 30-year data record, except for Oakdale where only 3 years of discharge data were available. Data have a 30-min frequency.

Statistics (Values in cfs)	USGS#08013000 Calcasieu River near Glenmora, LA	USGS# 08013250 Calcasieu River near Oakdale, LA	USGS# 08013500 Calcasieu River near Oberlin, LA	USGS# 08015500 Calcasieu River near Kinder, LA
Number of observations	582,869	32,580	497,578	454,310
Mean	732	844	1,090	2,460
Standard Deviation	1,839	1,300	2,206	4,793
Minimum	10	31	8	95
25%	44	85	84	418
50%	141	264	290	911
75%	630	977	1,170	2,370
95%	3,170	4,060	4,510	9,080
Maximum	44,900	8,000	35,900	78,100

Table 3. Flow statistics from USGS gauges using daily observations. Statistics are based on a data record of approximately 100 years. Data have a 1-day frequency.

Statistics (Values in cfs)	**USGS#08013000 Calcasieu River near Glenmora, LA**	**USGS# 08013250 Calcasieu River near Oakdale, LA**	**USGS# 08013500 Calcasieu River near Oberlin, LA**	**USGS# 08015500 Calcasieu River near Kinder, LA**
Number of observations	29,294	n/a	31,623	28,656
Mean	754	n/a	1,113	2,515
Standard Deviation	1,849	n/a	2,334	4,769
Minimum	11	n/a	10	109
25%	48	n/a	90	455
50%	156	n/a	298	984
75%	692	n/a	1,220	2,740
95%	3,214	n/a	4,510	9,013
Maximum	55,900	n/a	67,600	166,000

Instantaneous and monthly averaged discharge at the four USGS locations where discharge data was available is shown in Figure 3 through Figure 6. Figure 7 shows the comparison of the discharge at these four locations for the time period of overlap (i.e., April 2021 to present). Figure 8 shows the exceedance probability for the same four locations.

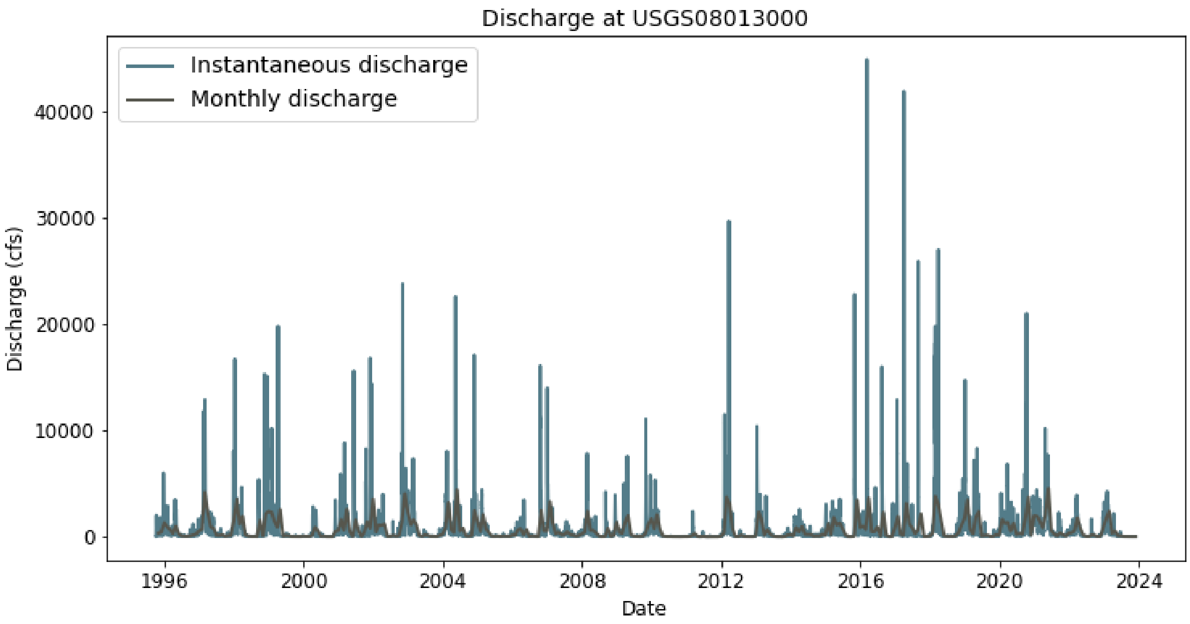


Figure 3. Instantaneous and monthly average discharge at USGS gauge #08013000, Calcasieu River near Glenmora, LA, upstream of Mill Creek. Flow peaks range from 8,000 to 20,000 cfs (from 1996 to 2012) with flows rarely exceeding 20,000 cfs, while recently record flows exceeding 40,000 cfs are notable in 2016 and 2017.

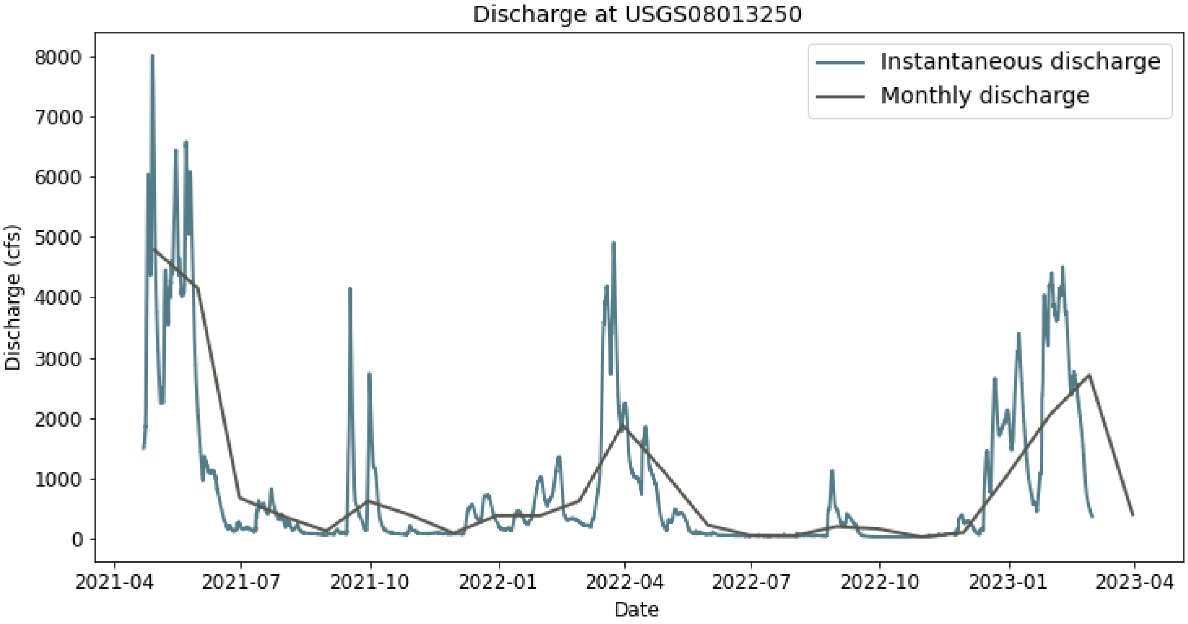


Figure 4. Instantaneous and monthly average discharge at USGS gauge #08013250, Calcasieu River near Oakdale, LA, upstream of Mill Creek. The flow record at Oakdale is relatively short and thus recorded flows are low but do agree with the flow trends from other gauges as flows in the Calcasieu River basin in the last three years are low.

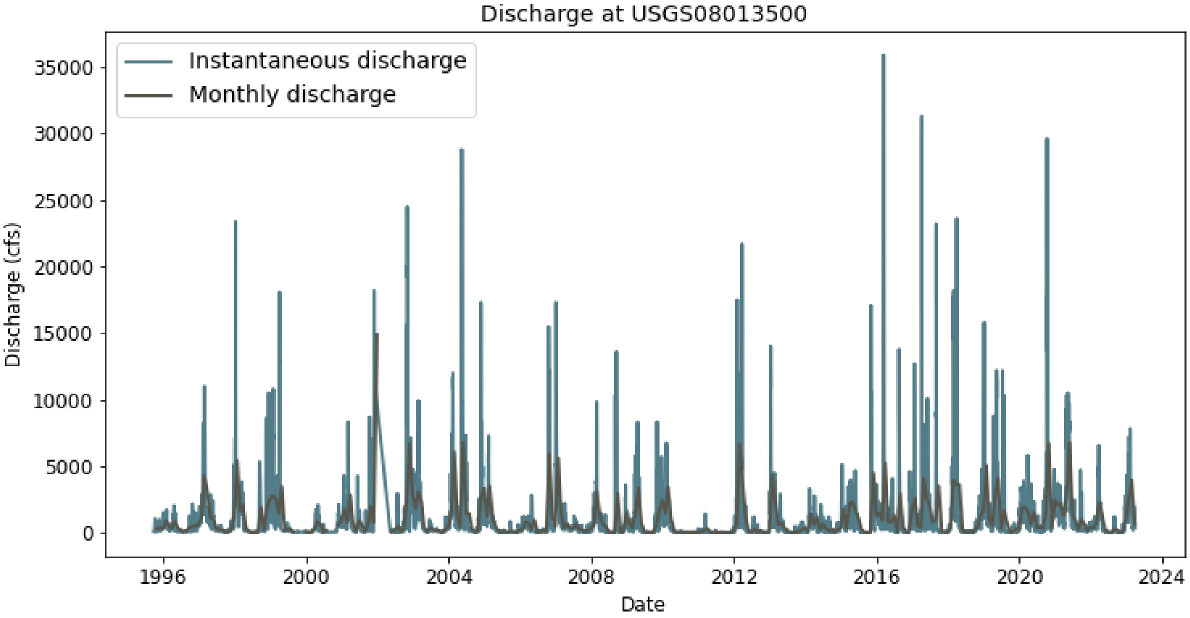


Figure 5. Instantaneous and monthly average discharge at USGS gauge #08013500, Calcasieu River near Oberlin, LA, downstream of Mill Creek. Flow peaks range from 8,000 to 25,000 cfs (from 1996 to 2012) with flows rarely exceeding 25,000 cfs, while flows exceeding 30,000 cfs are notable in 2016, 2017, and 2021.

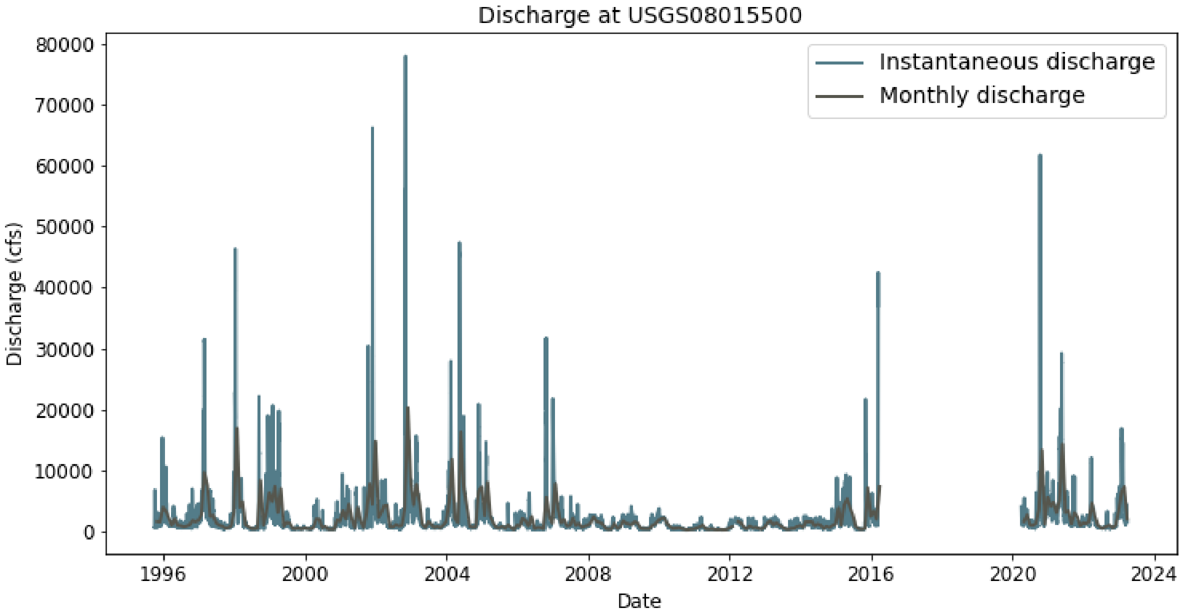


Figure 6. Instantaneous and monthly average discharge at USGS gauge #08015500, Calcasieu River near Kinder, LA, downstream of Mill Creek. Flow peaks range from 10,000 to 78,000 cfs with at least three to four instances where flow neared or exceeded 50,000 cfs in 2002, 2003, 2005, and 2021. Data was missing from 2016 to 2020.

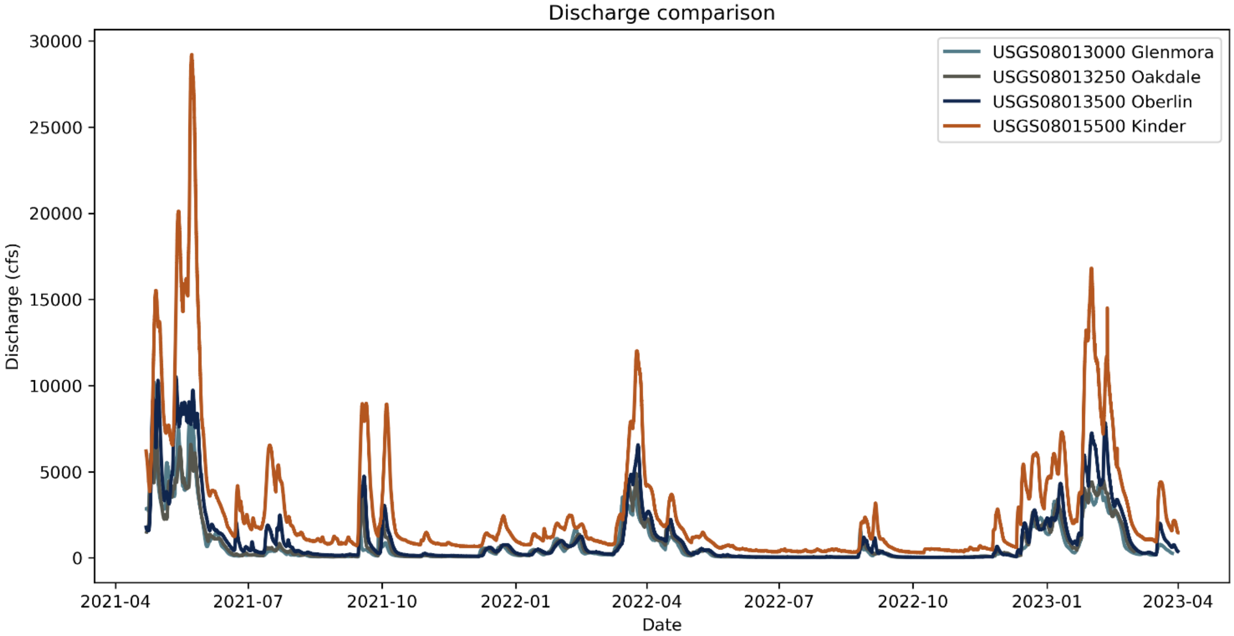


Figure 7. Comparison of the instantaneous discharge at the four USGS stations. Flows at Glenmora and Oakdale are similar, suggesting that there is lower flow contribution from the watershed along that reach of the Calcasieu River. Flows at Oberlin are proportionally larger. At Kinder, the flow increase is appreciably higher, signifying the flow contribution of Mill Creek.

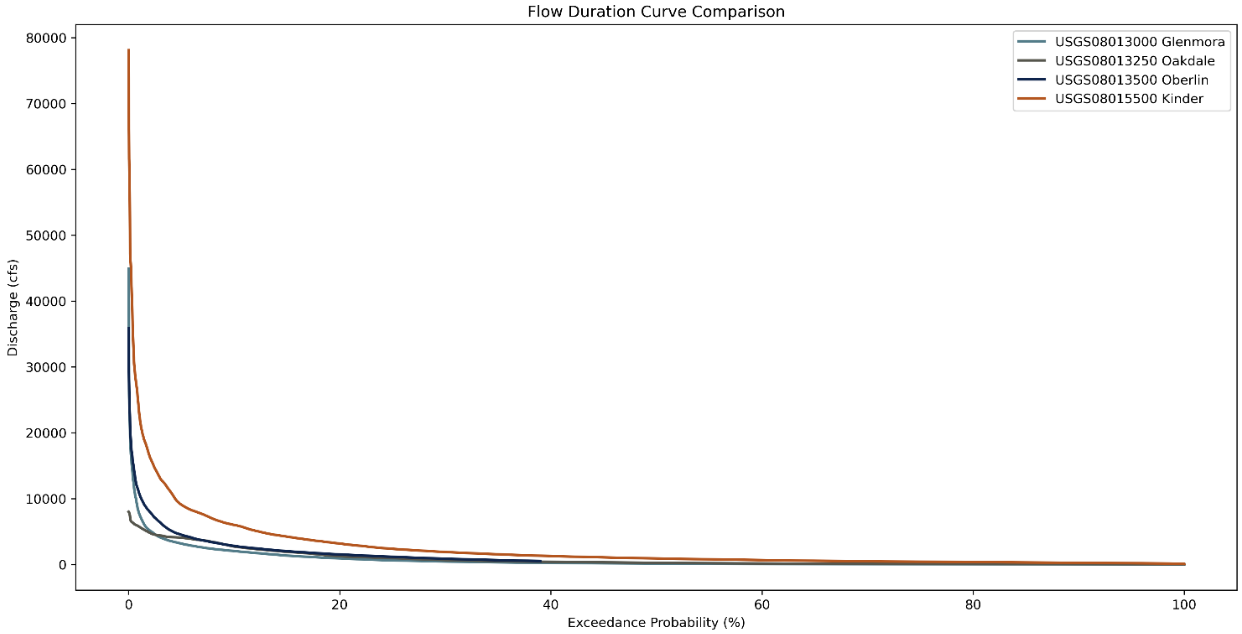


Figure 8. Discharge exceedance probability for four USGS stations, two upstream of Mill Creek (i.e., Glenmora and Oakdale) and two downstream of Mill Creek (i.e., Oberlin and Kinder). Exceedance probability was calculated using the instantaneous (every 30-min) discharge record (Table 1).

Both Figure 7 and Figure 8 show the increase in the Calcasieu River discharge in the downstream direction, from Glenmora to Oberlin to Kinder, noting that the length of the record used for the exceedance probability plot (Figure 8) is based on 28 years of data for Glenmora, Oberlin and Kinder, and only on 3 years of data for Oakdale. Upstream of Kinder, the flow exceedance for corresponding flows is similar for exceedances more than 40%, suggesting similarity during baseflow or non-storm conditions. During storms (Figure 7), flows at Glenmora and Oakdale are similar suggesting little flow contribution from the watershed along that reach of the Calcasieu River. Flows at Oberlin are proportionally larger; at Kinder, the flow increases appreciably signifying the flow contribution of Mill Creek. The response is also evident in the exceedance probability analysis, where there is significant divergence at Kinder for the highest 30% of the conditions observed.

The Mill Creek watershed contributes flow to the Calcasieu River approximately 1.4 miles upstream of Oberlin. Curtis Creek also contributes flow to the Calcasieu River along that reach (i.e., between Oakdale and Oberlin), but the associated watershed is a much smaller comparatively. Downstream of Oberlin and just upstream of Kinder, there is the confluence between Calcasieu River and Whisky Chitto Creek.

Figure 9 and Figure 10 show the discharge versus stage relationships at Oberlin and Kinder, which were developed using available observations at existing USGS stations. These curves are typically used to estimate the stage reduction that corresponds to a reduction in flow, such as the potential flow reduction by the proposed Mill Creek reservoir.

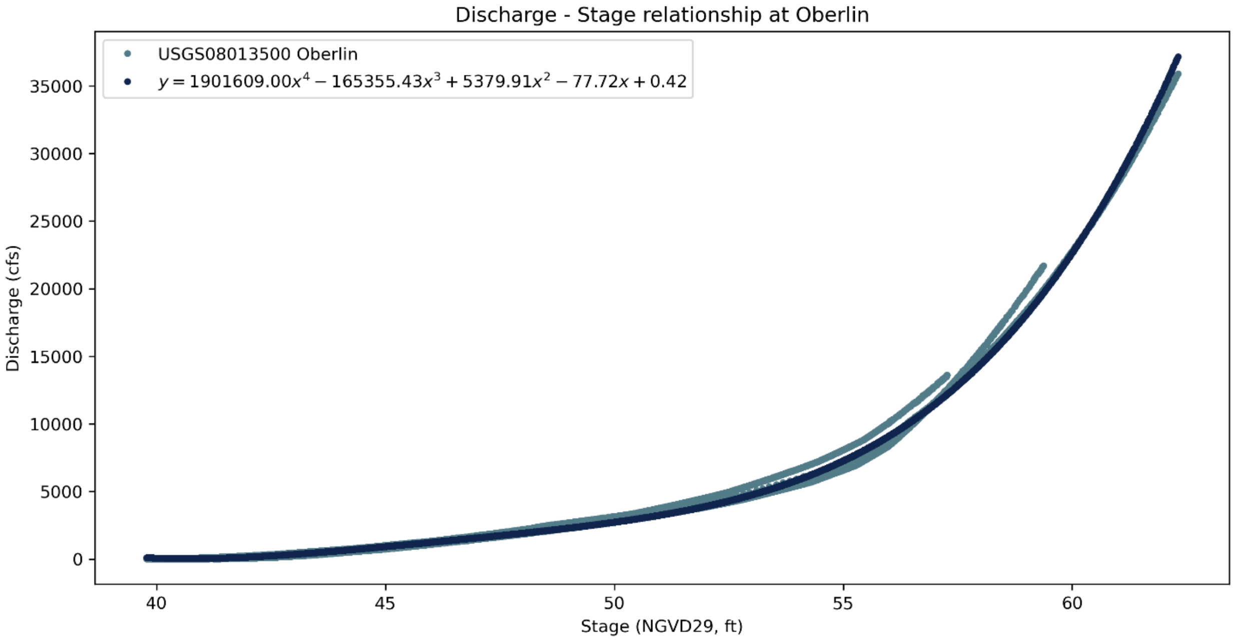


Figure 9. Discharge/stage relationship at Oberlin developed using observation data collected at USGS station #08013500.

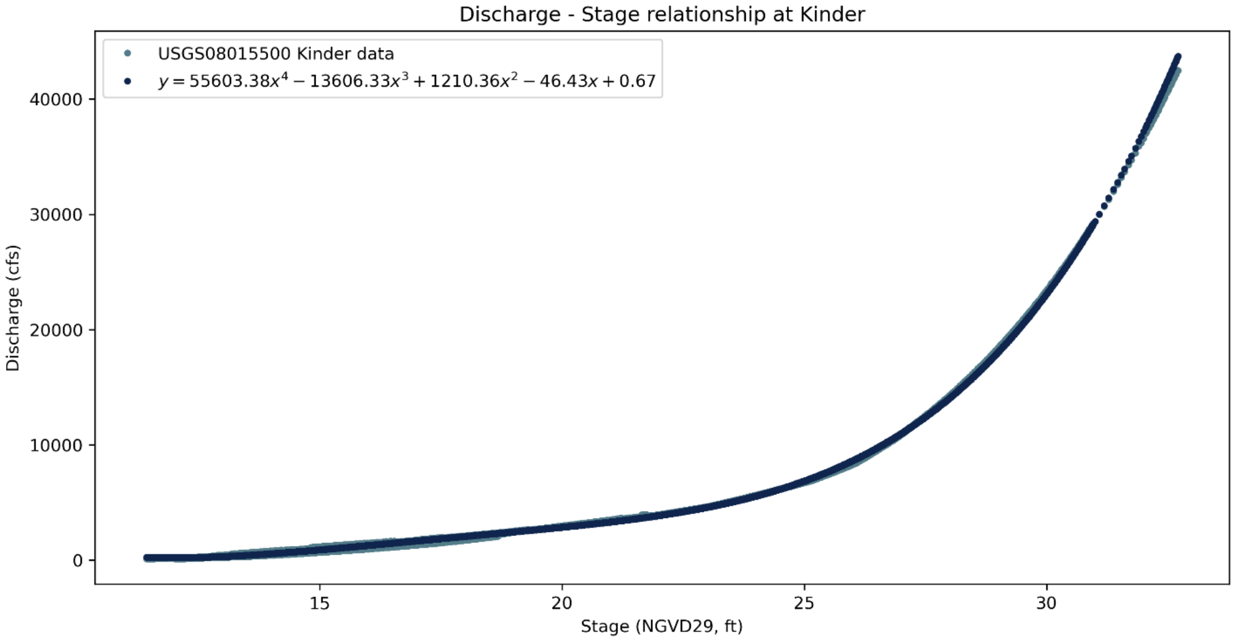


Figure 10. Discharge/stage relationship at Kinder developed using observation data collected at USGS station #08015500.

FLOW MODELING AND MITIGATION POTENTIAL

The HEC-HMS version 4.11 software was used to develop the hydrologic model for Mill Creek watershed and part of the proximal Calcasieu River watershed.

Glenmora, LA, was selected as the upstream boundary condition for the model because of the availability of a long-term record of stage and discharge observations by USGS. Oberlin was selected as the model downstream boundary to exclude the Whiskey Chitto watershed which contributes flow to the Calcasieu River downstream of Oberlin.

The Whiskey Chitto watershed was excluded from this analysis for the following reasons. First, to reduce the number of parameters and variables for this study and maintain the focus on Mill Creek and the proposed reservoir. Second, the Whiskey Chitto watershed includes another reservoir which could have added complexity, additional variance, and uncertainty to the model and subsequent analysis. Moreover, existing models covering the Whiskey Chitto basin are under development within the Louisiana Watershed Initiative (LWI). The Institute recommends that stakeholders put forward requests to evaluate multiple reservoirs, including any reservoirs that are situated outside of the Mill Creek footprint, to LWI.

HYDROLOGY MODEL DEVELOPMENT

Data Collection

The datasets listed in Table 4 were acquired and compiled to develop the HEC-HMS model. The terrain data, with a resolution of 10 m, was obtained from the USGS National Map Viewer (USGS, 2023b). Subsequently, the terrain was projected onto the “NAD 1983 State Plane Louisiana South” coordinate system, with horizontal units in feet and vertical data in meters. Additional spatial datasets were incorporated, including a shapefile depicting published streams from the National Hydrography Dataset (NHD) and another shapefile representing USGS stream gauges within the study area.

Imperviousness data were sourced from the Multi-Resolution Land Characteristics (MRLC) Consortium (MRLC, n.d.).

For precipitation information, Analysis of Record of Calibration (AORC) data with a 4 km resolution were downloaded from the National Oceanic and Atmospheric Administration (NOAA; (NOAA, 2023b).

Streamflow data for model calibration/validation at Oakdale and Oberlin, as well as the upstream boundary at Glenmora, were obtained from the USGS National Water Information System (USGS, 2023c). To maintain consistency, all geographic information system (GIS) layers were projected onto the NAD 1983 State Plane Louisiana South coordinate system.

Table 4. List of input data for the watershed model

Name	Source	Data
Digital Elevation Model/ Terrain	USGS National Map Viewer (USGS, 2023b)	USGS 1/3 Arc Second n31w093 20220831 USGS 1/3 Arc Second n32w093 20230609 USGS 1/3 Arc Second n32w094 20211115
NHD and USGS Monitoring gauges		USGS National Hydrography Dataset Best Resolution (NHD) for Hydrological Unit (HU) 8 - 08080203 (published 20230308) Shapefile
National Land Cover Database (NLCD) Imperviousness	MRLC Consortium(MRLC, n.d.)	nlcd_2021_impervious_l48_20230630
Gridded Precipitation	(NOAA, 2023b)	July 2019; September 2021; March–April 2022; July 2021
USGS Flows	USGS National Water Information System: Mapper (USGS, 2023c)	July 2019; September 2021; March–April 2022; July 2021 at Glenmora (08013000), Oakdale (08013250), and Oberlin (08013500), LA.

Watershed Delineation

The subbasin and reach elements, which encompass the reach of the Calcasieu River from Glenmora (upstream) to Oberlin (downstream), were delineated and defined using the delineation tools available within HEC-HMS. The digital elevation model (DEM)/terrain data underwent correction through the application of the “Preprocess Sinks” tool to fill gaps in the DEM. Subsequently, flow direction and accumulation were computed based on the corrected DEM data using the “Preprocess Drainage” tool. The watershed was automatically delineated through the employment of the watershed delineation tool. This process involved specifying target outlets, including monitoring gauges (i.e., Oakdale and Oberlin stations), as well as existing and anticipated structures such as the Oakdale dam and Mill Creek reservoir (Figure 1). The watershed comprises a total of 21 subbasins and 12 reaches spanning from Glenmora to Oberlin. Table 5 shows the respective areas of each subbasin within the watershed.

Table 5. Areas of each HEC-HMS model subbasin

Outlet	River/stream	Subbasin name	Area (mi^2)	Comments
Oakdale	Calcasieu River	S_CalcRi_4_NW_03	33.8	Upstream inflows from Glenmora
		S_CalcRi_4_NW_02	14.9	
		S_CalcRi_7_NW_01	8.0	
		S_CalcRi_8	0.5	
		S_CalcRi_6_NE_01	8.6	
		S_CalcRi_7	4.6	
		S_CalcRi_5_NE_01	16.9	
		S_CalcRi_6	1.4	
		S_CalcRi_5	18.3	
		S_CalcRi_4_NW_01	6.2	
		S_CalcRi_4	4.1	
Oberlin	Calcasieu River	S_CalcRi_3b	2.8	Downstream of Oakdale
		S_CalcRi_3a	21.8	
		S_CalcRi_2_NW_01	12.9	
		S_CalcRi_2	22.2	
		S_CalcRi_1	3.6	
	Mill Creek	S_MillCr_4	11.9	Upper Mill Creek Reservoir
		S_MillCr_3	14.6	
		S_MillCr_2	30.1	
		S_LittleMillCr_1	22.0	
		S_MillCr_1	4.2	Lower Mill Creek Reservoir

Structures

The Oakdale dam is located on the Calcasieu River downstream of Oakdale. Specific information about this structure was made available by Allen Parish and is summarized in Figure 11. To simulate the dam, a function of elevation and area was developed by calculating the upstream area of the dam according to the relative bottom elevation of the reservoir (EL) of 81.5 ft NAVD88 (Figure 12).

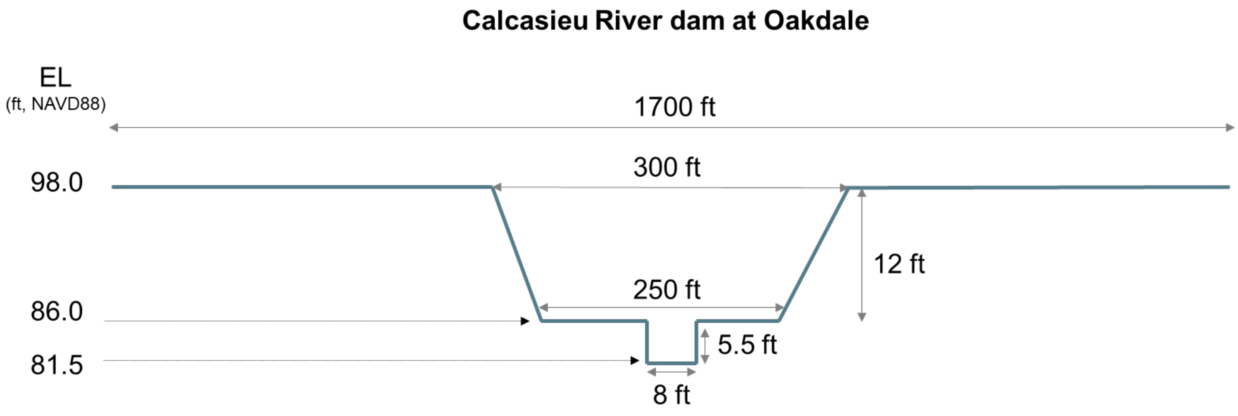


Figure 11. Oakdale dam size and dimensions. Elevations (EL) are referenced to NAVD88.

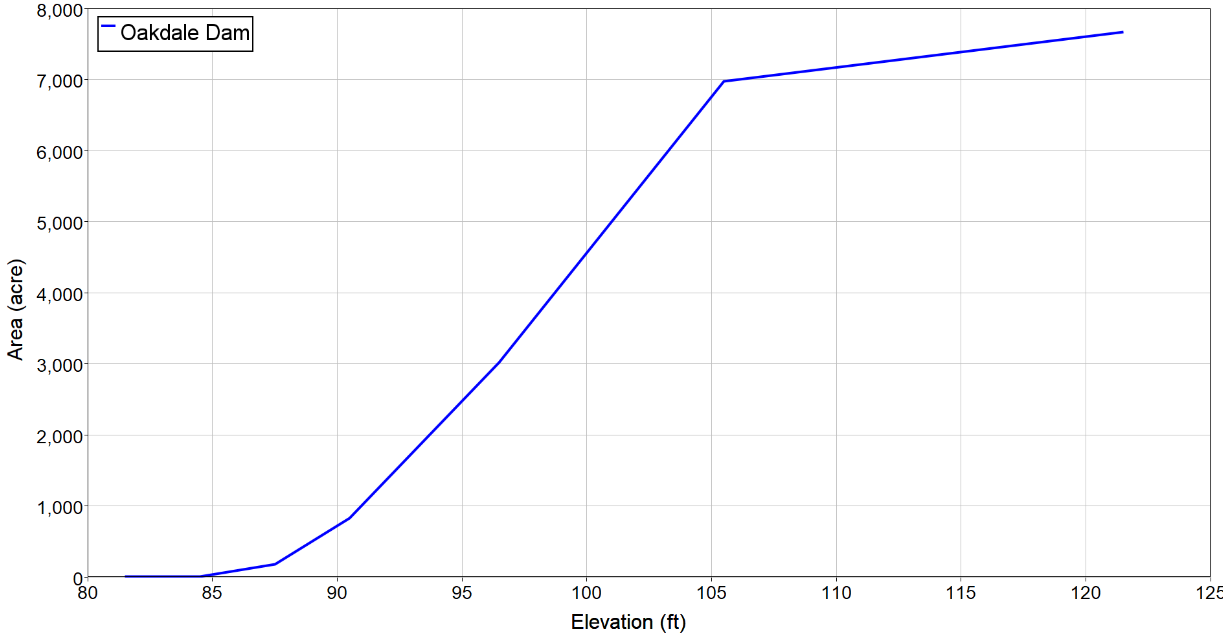


Figure 12. Reservoir storage shown as a function of water elevation and area at the Oakdale dam on the Calcasieu River. The elevation is a relative elevation from the bottom elevation of the dam (EL 81.5 ft, NAVD88).

HEC-HMS MODEL CALIBRATION AND VALIDATION

The watershed model was calibrated using watershed parameters for three event periods (Table 6). The three calibration periods were selected to reproduce different flow conditions to ensure the model performed equally well under different riverine conditions. Calibration parameters were adjusted to match model predicted discharge to the observed discharges data collected at Oakdale and Oberlin USGS stations (Figure 13 to Figure 15). Table 6 shows the ranges of parameters used for each calibration. The calibration results were evaluated using statistics such as root mean square error, standard deviation (RMSE, Stdev), Nash Sutcliffe, Percent Bias, and R^2 (Table 7).

The calibration parameters from the three calibration periods were averaged to represent the watershed. These averaged calibration parameters were used for the model validation run. Model results were validated against observed data at Oakdale and Oberlin from 07/07/21 to 07/18/21 (Table 7 and Figure 16).

Evaluation and assessment of calibration and validation statistics (Table 6 and Table 7) shows that the model accomplished sufficiently high R^2 and Nash Sutcliffe scores and low bias and RMSE scores, rendering the model ready for use in evaluation of the Mill Creek Reservoir.

Table 6. Watershed parameters for model calibration

Method		Parameters	Calibration period		
			07/10/19–07/21/19	03/04/22–04/12/22	09/12/22–09/27/22
Loss	Deficit and Constant Loas	Initial Deficit (in) Maximum Storage (in) Constant Rate (in/h) Impervious (%)	0.5 2.82–10.7 0.05–0.5 0.19–16.1	0.05–1 2.82–10.7 0.05–2 0.19–16.1	0.5 2.82–10.7 0.05–0.5 0.19–16.1
Transform	ModClark	Time of Concentration (h) Storage Coefficient (h)	10–100 10–60	5–150 9.3–70	15–140 10–60
Baseflow	Recession method	Initial Discharge (cfs) Recession Constant Threshold Flow (cfs)	0.9 0.1 0.01–0.05	0.5–0.9 0.1–0.9 0.05–0.2	0.9 0.1 0.01–0.05
Routing	Lag method	Lag Time (min)	40–500	20–1500	40–500

Table 7. Statistics for the model calibration and validation results.

	Station	Period	RMSE Stdev. (cfs)	Nash Sutcliffe	Percent Bias (%)	R^2
Calibration	Oakdale	07/10/19–07/21/19	n/a	n/a	n/a	n/a
	Oberlin		0.1	0.995	2.02	1.00
	Oakdale	03/04/22–04/12/22	0.2	0.956	7.76	0.97
	Oberlin		0.3	0.929	9.71	0.95
	Oakdale	09/12/22–09/27/22	0.1	0.994	-0.76	0.99
	Oberlin		0.1	0.992	1.68	0.99
Validation	Oakdale	07/07/21–07/18/21	0.4	0.873	7.19	0.92
	Oberlin		0.4	0.837	-20.91	0.94

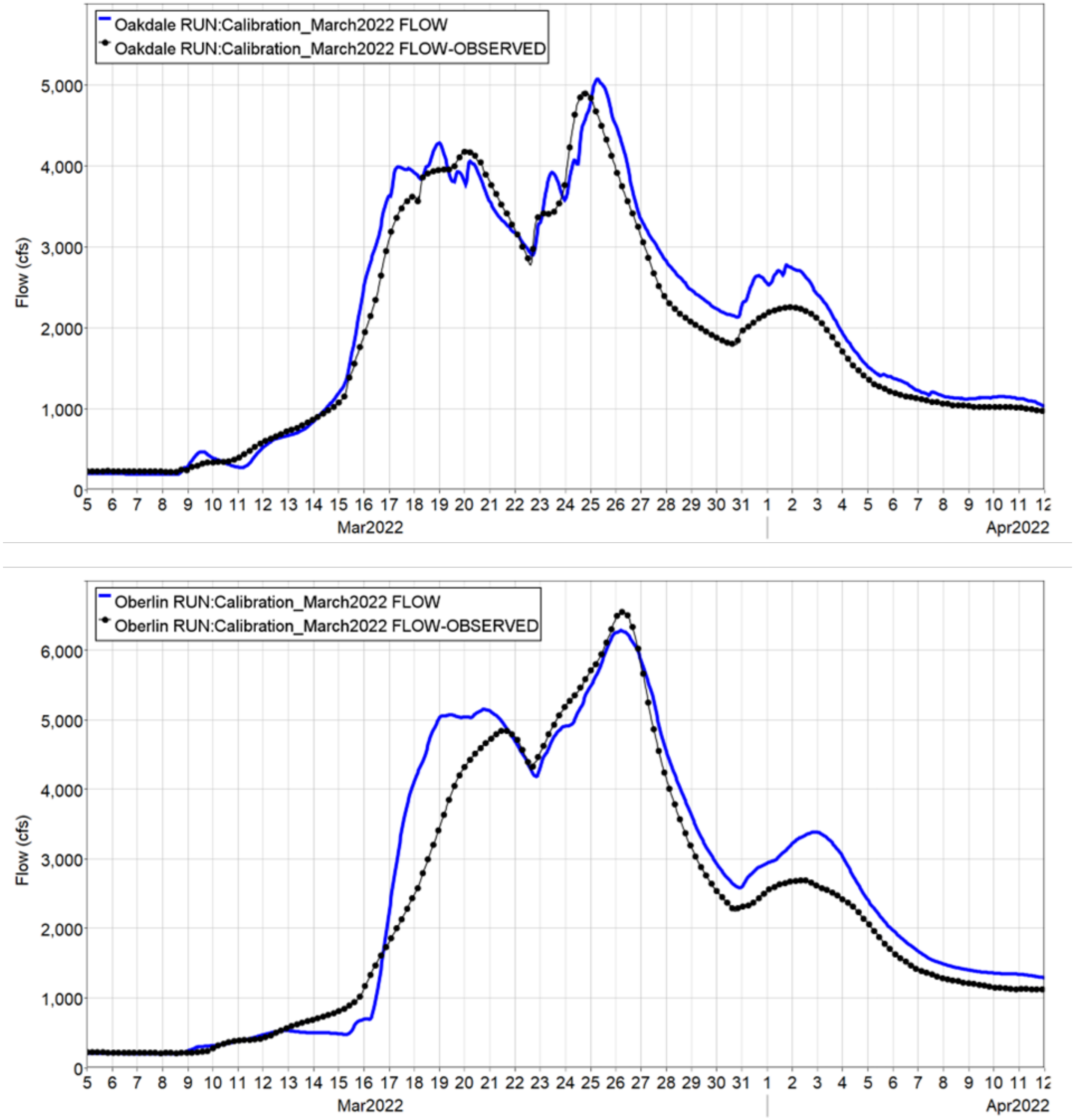
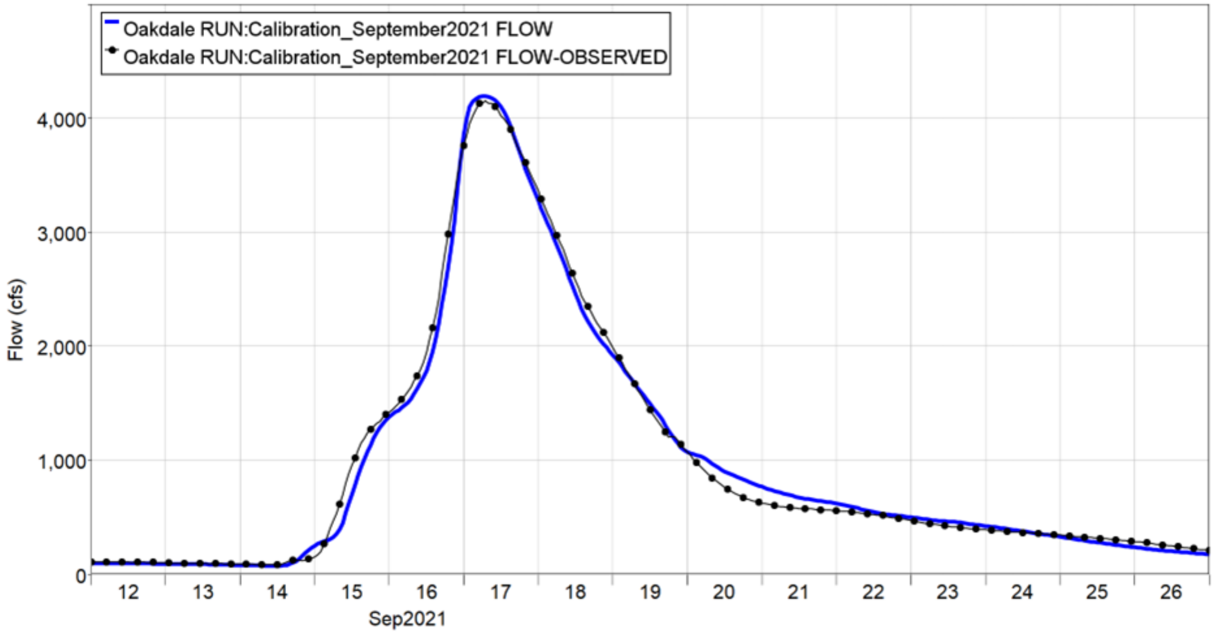


Figure 13. Comparison of observed and model results at Oakdale (top) and Oberlin (bottom) from March 5 to April 12, 2022.



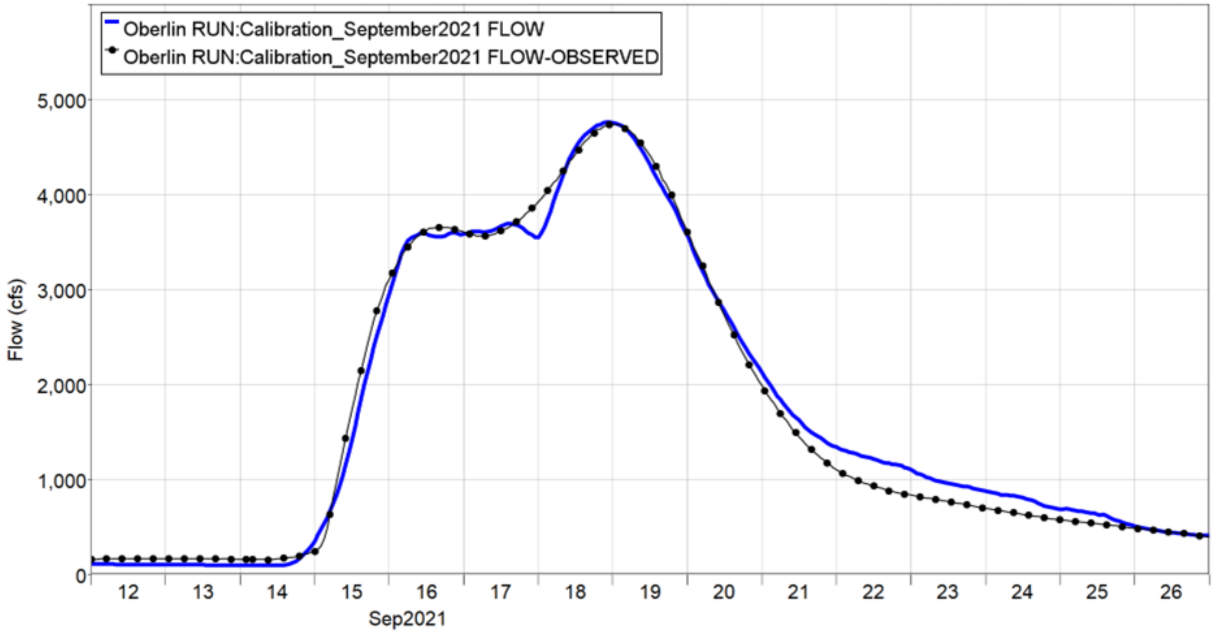


Figure 14. Comparison of observed and model results at Oakdale (top) and Oberlin (bottom) from September 12 to September 27, 2022.

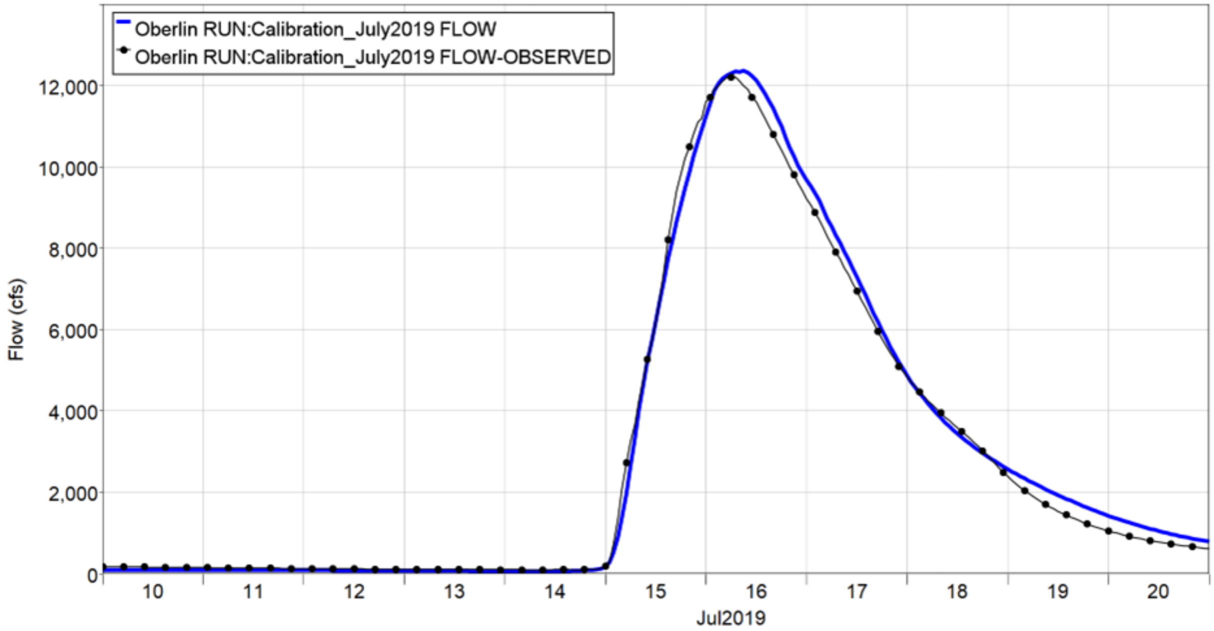


Figure 15. Comparison of observed and model results at Oberlin from July 10 to July 20, 2019. Discharge data at Oakdale were not available for this time period.

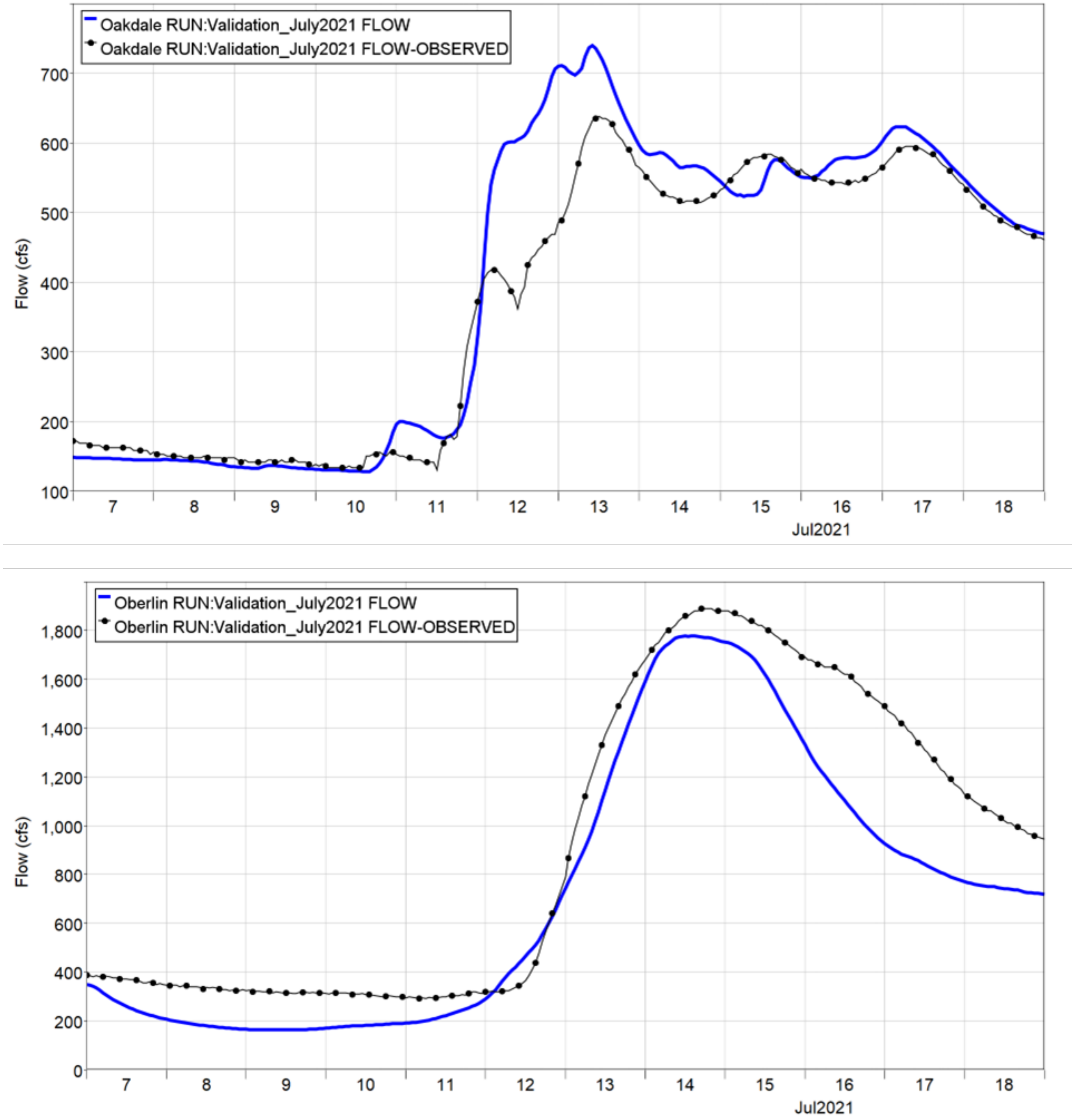


Figure 16. Comparison of observed and model results at Oakdale (top) and Oberlin (bottom) from July 7 to July 18, 2022.

RESERVOIR IMPLEMENTATION AND ALTERNATIVES

The validated model was employed to simulate the impact of the Mill Creek reservoir on downstream discharge at Oberlin. The Mill Creek reservoir was implemented in the model by incorporating the reservoir structure (Figure 17) and a rating curve (Figure 18), establishing a relationship between water elevation (in feet) and reservoir storage (in acre-feet) based on inputs from Allen Parish engineers. The reservoir storage at 93.5 ft in Figure 18 was determined based on the previous 100-year reservoir design because the model requires the reservoir storage curve to surpass the top (i.e., 92 ft) of the designed dam crest elevation (Denmon Engineering, 2006). The simulations used to evaluate the reservoir focused on two storm events (i.e., **10- and 100-year storm events**) determined through frequency analysis of partial duration series (PDS) from NOAA (NOAA, 2023a). Table 8 provides the rainfall distribution details selected for the 10-year/1-day and 100-year/1-day duration storms. Finally, two additional assumptions were made. First, that both the 10-year and the 100-year precipitation fell on both the Mill Creek and the Calcasieu watershed, and second, that the precipitation only fell on the Mill Creek watershed, enabling the analysis to evaluate flow reduction **from both local and regional precipitation**.

To establish the upstream boundary condition at Glenmora, historical precipitation data in the study area were examined. The longest precipitation dataset was found at Little River near Rochelle, LA (USGS, 2023a). The highest recorded precipitation rate was 1.18 inches on April 18, 2023. Flow rates in the vicinity of Glenmora (USGS gauge #08013000) around April 18, 2023, were reviewed, and a flow rate of 2,190 cfs (recorded on April 15, 2023) was selected as the upstream boundary condition occurring during the 100-year storm event. For the 10-year storm event, the median flow value of 141 cfs at Glenmora (USGS gauge #08013000) was selected as the model upstream boundary condition.

Two initial water level elevations in the reservoir were tested: 77 and 75 ft NAVD88. The combination of all these elements (i.e., precipitation, flow at Glenora and reservoir presence and initial elevation) resulted in a suite of twelve simulations.

Table 8. Precipitation distribution for the 10-year/1-day and 100-year/1-day duration storms. From https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=la

Duration	Precipitation (in) 10-year storm	Precipitation (in) 100-year storm
5 minutes	0.856	1.25
10 minutes	1.25	1.83
15 minutes	1.53	2.23
30 minutes	2.29	3.37
1 hour	3.07	4.72
2 hours	3.84	6.06
3 hours	4.36	7.13
6 hours	5.42	9.31
12 hours	6.69	11.9
1 day	7.96	14.3

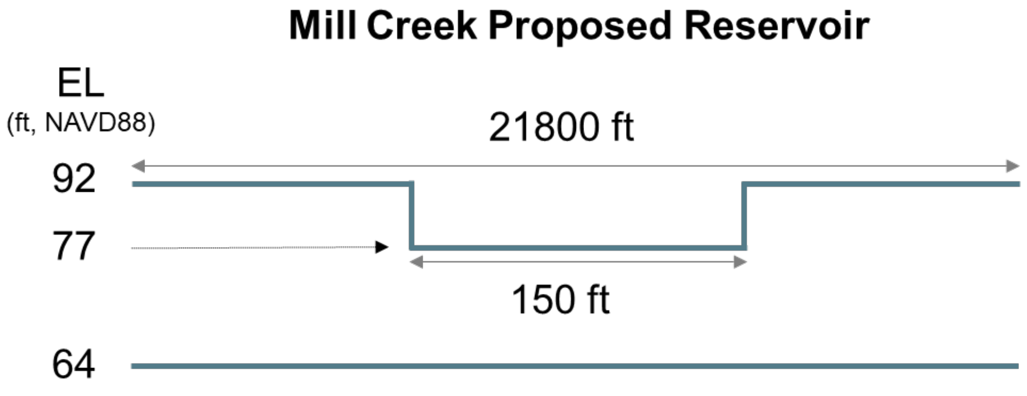


Figure 17. Size and configuration of the Mill Creek reservoir.

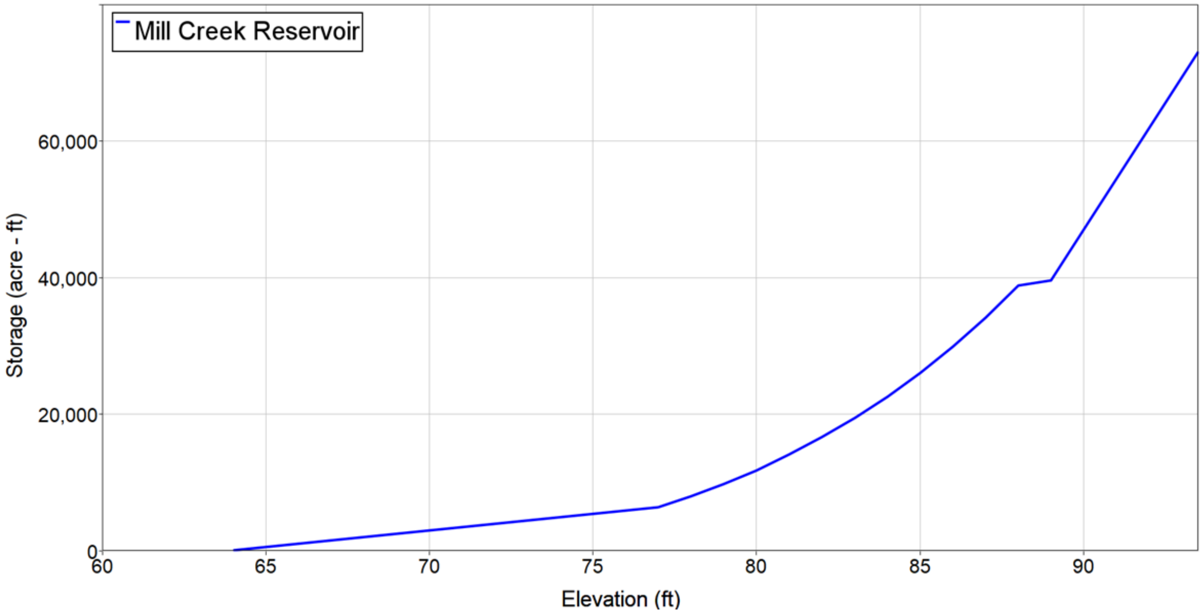


Figure 18. Storage is shown as a function of water elevation and corresponding storage at the Mill Creek reservoir.

RESULTS AND DISCUSSION

The results from the four different scenarios (Table 9), both with and without the Mill Creek reservoir (for a total of twelve simulations), were compared to understand the impacts of the proposed reservoir on Mill Creek flow and on the Calcasieu flow downstream of the reservoir, particularly at Oberlin. Figure 19 to Figure 22 show the comparisons between with- and without-reservoir results at two different initial elevations for each scenario. Table 9 reports the flow values at Mill Creek and at Oberlin for all 12 simulations, including the delay in the arrival of the peak discharge between with and without the reservoir.

Results show that for all scenarios the **presence of the reservoir led to a change in both the magnitude and timing of the peak discharge** on Mill Creek and on the Calcasieu River at Oberlin (Table 9, Figure 19 to Figure 22).

For **scenario one** (#1; Table 9), in which the study evaluates the 100-year/1-day event precipitation on **all sub-basins** with the reservoir installed, **flows at Mill Creek were reduced by approximately 24%** (from 8,397 cfs to 6,391 and 6,339 cfs, based on the initial reservoir elevation; Figure 19) compared to the scenario without the reservoir. The initial drawdown of the reservoir by an additional 2 ft (reduced from 77 ft to 75 ft NAVD88) produced a minor flow difference at Mill Creek, reduced by an additional 52 cfs from 6,391 cfs to 6,339 cfs, and within a few hours of the flow peak arriving at the reservoir, the stage within the reservoir was identical throughout the storm duration (Figure 19; Table 9). This suggests that the **initial 2 ft drawdown has negligible influence on the results**, and a larger drawdown is likely needed to capture the flows produced by a 100-year event. For the same scenario (#1) the flow reduction of the Calcasieu River at Oberlin, located below the confluence with Mill Creek, varied marginally and was reduced from 20,777 cfs to 20,111 cfs (for the 77 ft NAVD88 reservoir initial water surface elevation) and from 20,777 cfs to 19,967 cfs for when the reservoir had a 2 ft drawdown (i.e., 75 ft NAVD88 reservoir initial water surface elevation), corresponding to a **flow reduction of approximately 3.2–3.9%** (666 cfs and 810 cfs) respectively. The small flow reduction in the Calcasieu River suggests that when the entire watershed is subjected to precipitation comparable to the **100-year event, the influence of the Mill Creek reservoir is modest in terms of reducing flow downstream**. This is because the Calcasieu River at Glenmora is already high, coupled with the input from additional tributary flows between Glenmora and the confluence of the Mill Creek. With this small reduction in flow (up to 3.9%), the corresponding stage reduction at Oberlin based on the stage-discharge relationship is of the order of 0.03 ft.

For **scenario two** (#2; Table 9), in which the study evaluates the 100-year/1-day precipitation event **only on the Mill Creek sub-basins** with the reservoir installed, flows at Mill Creek were identical to scenario one (#1) where flows were reduced by approximately 24% (from 8,397 cfs to 6,391 and 6,339 cfs based on the initial reservoir elevation; Figure 20) compared to the scenario without the reservoir. The initial drawdown of the reservoir by an additional 2 ft (reduced from 77 ft to 75 ft NAVD88) produced identical results for Mill Creek, reducing by an additional 53 cfs from 6,658 cfs to 6,605 cfs, and within a few hours of the flow peak arriving at the reservoir, the stage within the reservoir was identical throughout the storm duration (Figure 20; Table 9). As with scenario one (#1), the initial 2 ft drawdown has negligible influence on the results, and a larger drawdown is likely needed to capture the flows produced by a 100-year event. For the same scenario (#2) the flow reduction at Calcasieu River at Oberlin, located below the confluence with Mill Creek, was larger than what observed in scenario one (#1). This was primarily driven by a generally lower flow in the Calcasieu River, and an absence of rainfall on the Calcasieu Basin. The Calcasieu River flow at Oberlin was reduced from 8,756 cfs to 6,658 cfs (for the 77 ft NAVD88 reservoir initial water surface elevation) and from 8,756 cfs to 6,605 cfs for when the reservoir had a 2 ft drawdown (i.e., 75 ft NAVD88 reservoir initial water surface elevation), corresponding to a flow reduction of approximately 24%. The observed larger flow reduction in the Calcasieu River compared to scenario one (#1), when there is heavy rainfall everywhere, suggests that when precipitation comparable to the 100-year event falls only on the Mill Creek watershed, the influence of the Mill Creek reservoir on the Calcasieu River is larger in terms of reducing flow downstream because the flow in the

Calcasieu River is much lower (141 cfs instead of 2,190 cfs) to begin with. This flow reduction at Oberlin is of the **order of 24%, instead of ~4%** for scenario one (#1) and is met with a corresponding stage reduction at Oberlin based on the stage-discharge relationship of the order of 1.1 ft.

Table 9. Summary of all simulations performed with the HMS model and their results. Table summarizes the precipitation scenario implemented, the upstream flow at Glenmora, and the reservoir initial elevation (or absence of reservoir). The peak discharge value and the delay in the peak arrival at Mill Creek and at Oberlin are provided.

Scenario	Precipitation	Flow at Glenmora	Reservoir Initial Elevation	Mill Creek outflow (cfs) / Delay of peak discharge (hours)	Oberlin flow (cfs) / Delay of peak discharge (hours)
#1	100-year storm on all sub-basins	2,190 cfs	No Reservoir	8,397	20,777
	100-year storm on all sub-basins	2,190 cfs	77 ft NAVD88	6,391 / 14	20,111 / 14
	100-year storm on all sub-basins	2,190 cfs	75 ft NAVD88	6,339 / 14	19,967 / 14
#2	100-year storm on Mill Creek sub-basin	141 cfs	No Reservoir	8,397	8,756
	100-year storm on Mill Creek sub-basin	141 cfs	77 ft NAVD88	6,391 / 14	6,658 / 13
	100-year storm on Mill Creek sub-basin	141 cfs	75 ft NAVD88	6,339 / 14	6,605 / 14
#3	10-year storm on all sub-basins	2,190 cfs	No Reservoir	3,912	10,785
	10-year storm on all sub-basins	2,190 cfs	77 ft NAVD88	2,877 /14	10,266 / 15
	10-year storm on all sub-basins	2,190 cfs	75 ft NAVD88	2,808 / 14	10,208 / 17
#4	10-year storm on Mill Creek sub-basin	141 cfs	No Reservoir	3,912	4,156
	10-year storm on Mill Creek sub-basin	141 cfs	77 ft NAVD88	2,877 / 14	3,077 / 14
	10-year storm on Mill Creek sub-basin	141 cfs	75 ft NAVD88	2,808 / 14	3,006 / 15

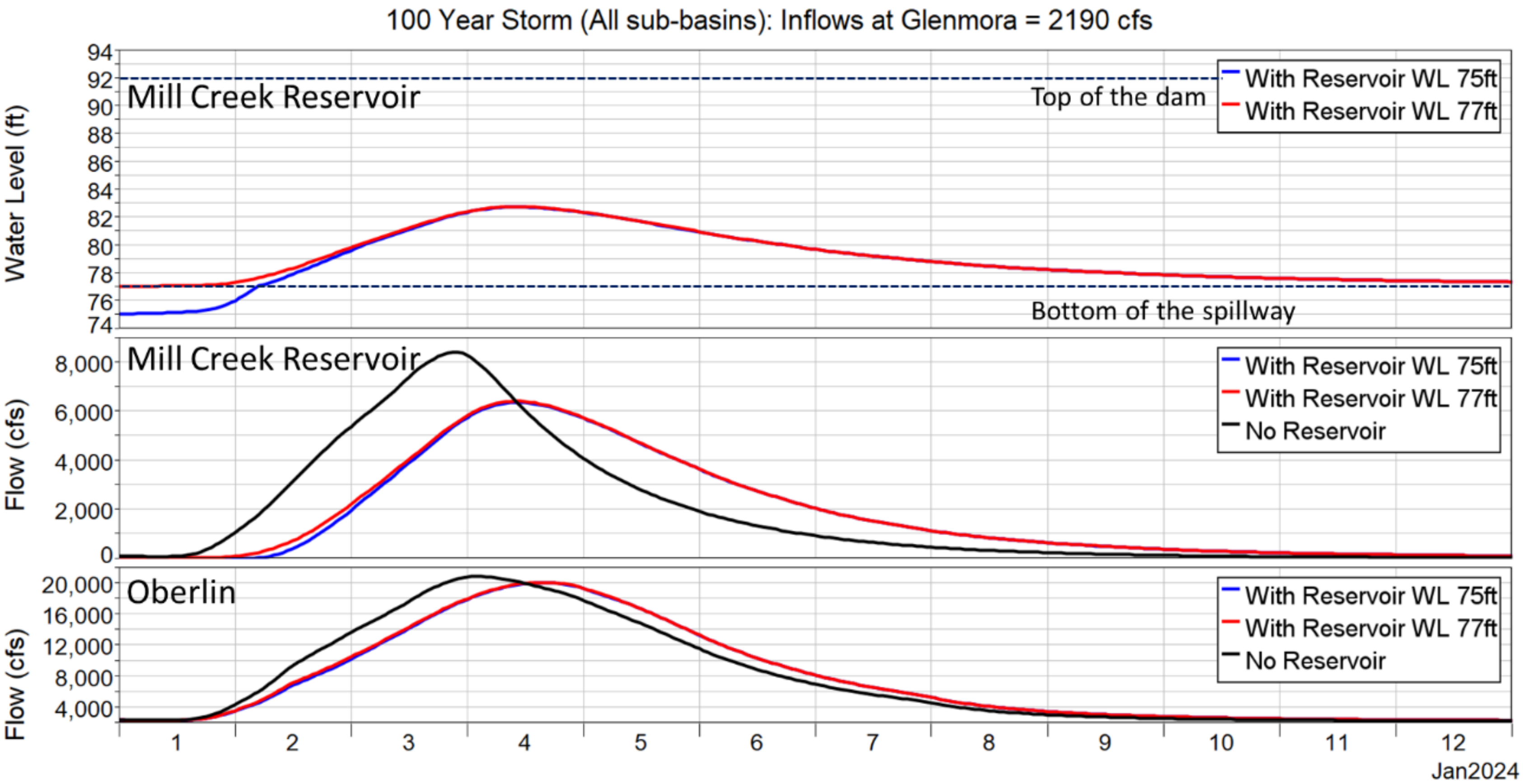


Figure 19. Reservoir water level (top), flow at Mill Creek reservoir (middle), and flow at Oberlin (bottom) comparison between simulation with no reservoir (black line), simulation with reservoir and initial elevation of 75 ft NAVD (blue line), and simulation with reservoir and initial elevation of 77 ft NAVD (red line). All three simulations included 100-year/1day storm on all sub-basins and the upstream inflow condition at Glenmora was set equal to 2,190 cfs.

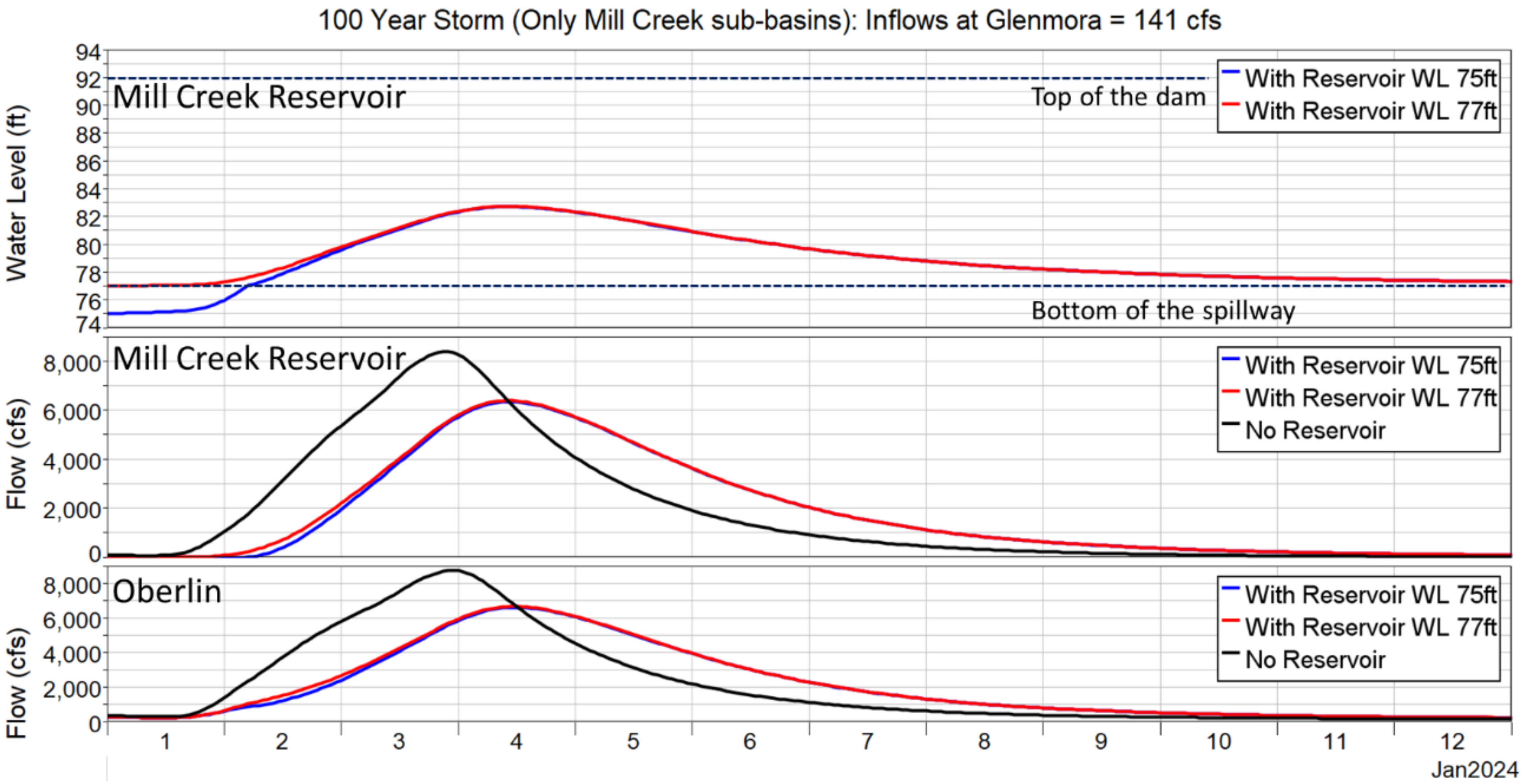


Figure 20. Reservoir water level (top), flow at Mill Creek reservoir (middle) and flow at Oberlin (bottom) comparison between simulation with no reservoir (black line), simulation with reservoir and initial elevation of 75 ft NAVD (blue line), and simulation with reservoir and initial elevation of 77 ft NAVD (red line). All three simulations included 100-year/1-day storm on the Mill Creek sub-basins only and the upstream inflow condition at Glenmora was set equal to 141 cfs.

For **scenario three** (#3; Table 9) where the study evaluates the 10-year/1-day precipitation event on **all sub-basins** with the reservoir installed, flows at Mill Creek were reduced by approximately 27% (from 3,912 cfs to 2,877 and 2,808 cfs based on the initial reservoir elevation; Figure 21) compared to the scenario without the reservoir. The initial drawdown of the reservoir by an additional 2 ft (reduced from 77 ft to 75 ft NAVD88) produced a minor flow difference at Mill Creek, reduced by an additional 58 cfs from 2,877 cfs to 2,808 cfs, and within a few hours of the flow peak arriving at the reservoir, the stage within the reservoir was identical throughout the storm duration (Figure 21; Table 9). This suggests that the initial 2 ft drawdown has negligible influence on the results, and that a larger drawdown is likely needed to capture the flows produced by a 10-year event. The reduction at Calcasieu River from this scenario at Oberlin, located below the confluence with Mill Creek, varied marginally and was reduced from 10,785 cfs to 10,266 cfs (for the 77 ft NAVD88 reservoir initial water surface elevation) and from 10,785 cfs to 10,208 cfs for when the reservoir had a 2 ft drawdown (i.e. 75 ft NAVD88 reservoir initial water surface elevation), corresponding to a flow reduction of approximately 4.8–5.4 % (519 cfs and 577 cfs) respectively. The small flow reduction in the Calcasieu River suggests that when the Calcasieu River at Glenmora is already high (i.e., 2,190 cfs), and is coupled with additional tributary flows between Glenmora and the confluence of the Mill Creek, the influence of the Mill Creek reservoir is modest in terms of reducing flow downstream. With this **small reduction in flow (up to 5.4%)**, the corresponding stage reduction at Oberlin based on the stage-discharge relationship is of the order of 0.24 ft.

For **scenario four** (#4; Table 9) where the study evaluates the 10-year/1-day precipitation event only on the **Mill Creek sub-basins** with the reservoir installed, flows at Mill Creek were identical to scenario one (#1) where flows were reduced by approximately 27% (from 3,912 cfs to 2,877 and 2,808 cfs based on the initial reservoir elevation; Figure 22) compared to the scenario without the reservoir. The initial drawdown of the reservoir by an additional 2 ft (reduced from 77 ft to 75 ft NAVD88) produced identical results for Mill Creek, reduced by an additional 69 cfs from 2,877 cfs to 2,808 cfs, and within a few hours of the flow peak arriving at the reservoir the stage within the reservoir was identical throughout the storm duration (Figure 22; Table 9). As with scenario three (#3) the initial 2 ft drawdown has negligible influence on the results, and a larger drawdown is likely needed to capture the flows produced by a 10-year event. For the same scenario (#4), the flow reduction on the Calcasieu River at Oberlin, located below the confluence with Mill Creek, was larger than what observed in scenario three (#3). This was primarily due to a generally lower flow in the Calcasieu River and absence of rainfall on the Calcasieu basin. The Calcasieu River flow at Oberlin was reduced from 4,156 cfs to 3,077 cfs (for the 77 ft NAVD88 reservoir initial water surface elevation) and from 4,156 cfs to 3,006 cfs for when the reservoir had a 2 ft drawdown (i.e., 75 ft NAVD88 reservoir initial water surface elevation), corresponding to a flow reduction of approximately 27%. The observed larger flow reduction in the Calcasieu River compared to scenario three (#3) suggests that the influence of the Mill Creek reservoir is larger in terms of reducing flow downstream **when the flow in the Calcasieu River is much lower** (141 cfs instead of 2,190 cfs).

This flow reduction at Oberlin is of the order of **27%, instead of ~5%** for scenario three (#3) and is met with a corresponding stage reduction at Oberlin based on the stage-discharge relationship of the order of 1.8 ft.

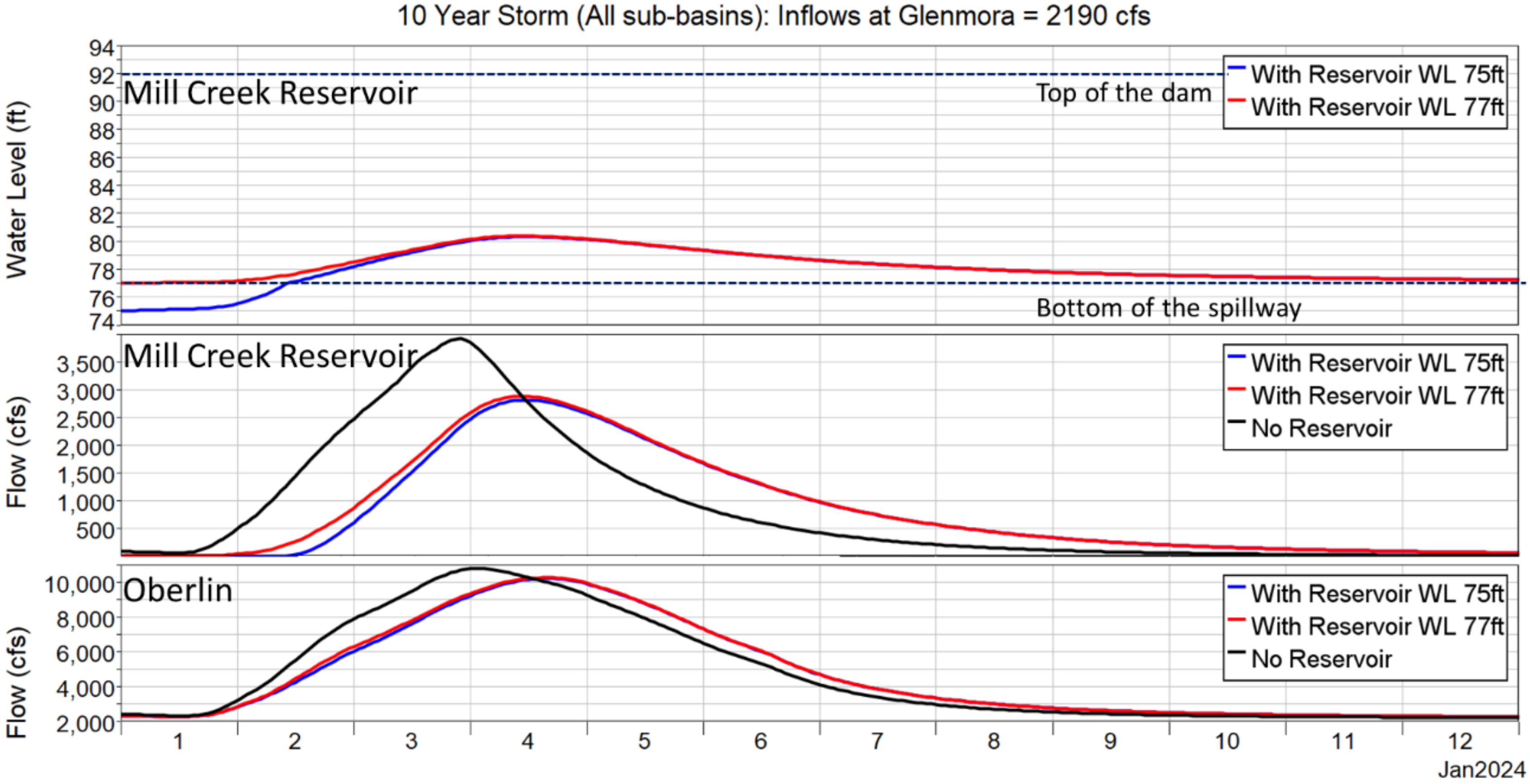


Figure 21. Reservoir water level (top), flow at Mill Creek reservoir (middle,) and flow at Oberlin (bottom) comparison between simulation with no reservoir (black line), simulation with reservoir and initial elevation of 75 ft NAVD (blue line), and simulation with reservoir and initial elevation of 77 ft NAVD (red line). All three simulations included 10-year/1-day storm on all sub-basins and the upstream inflow condition at Glenmora was set equal to 2,190 cfs.

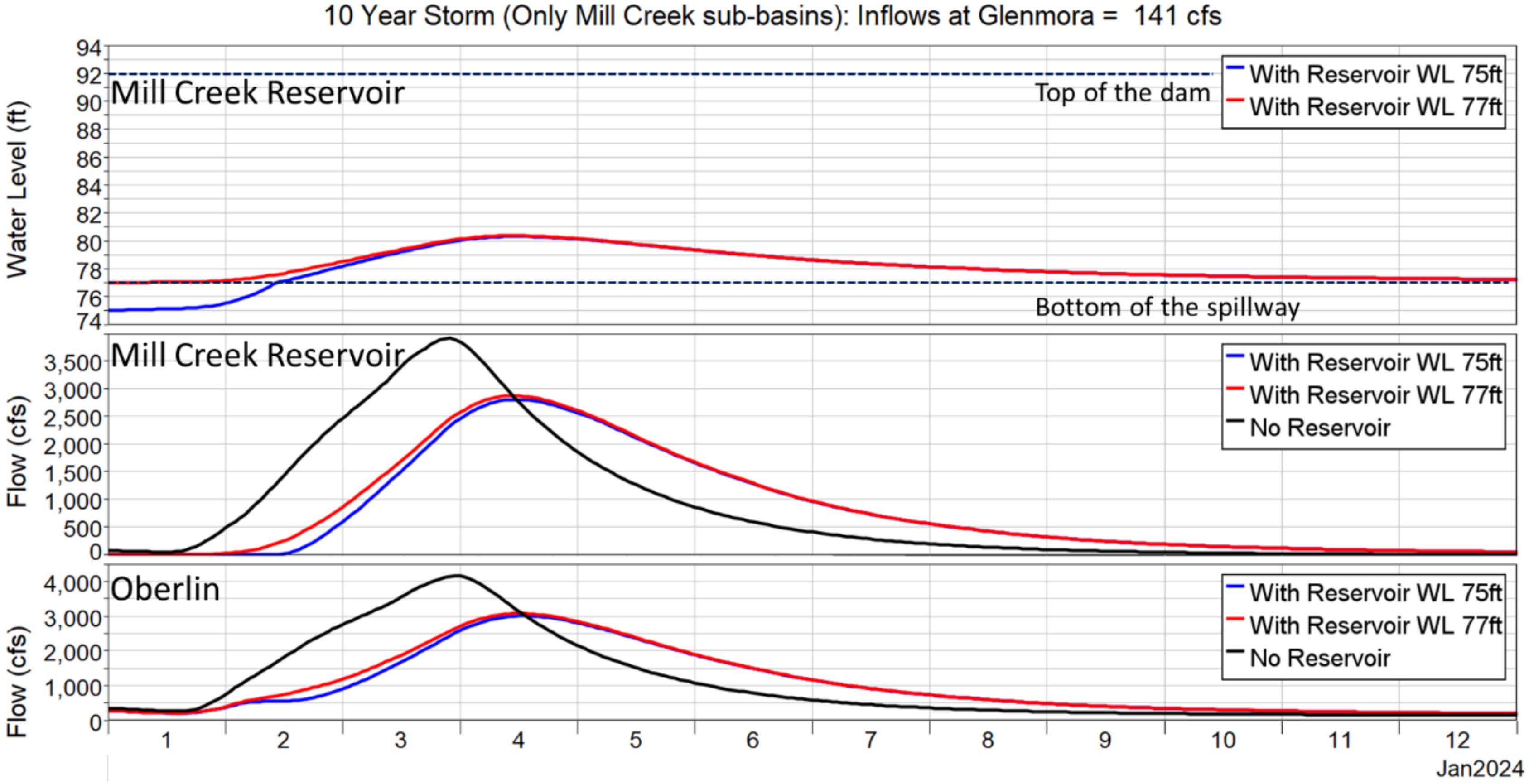


Figure 22. Reservoir water level (top), flow at Mill Creek reservoir (middle), and flow at Oberlin (bottom) comparison between simulation with no reservoir (black line), simulation with reservoir and initial elevation of 75 ft NAVD (blue line), and simulation with reservoir and initial elevation of 77 ft NAVD (red line). All three simulations included 10-year/1-day storm on all sub-basins and the upstream inflow condition at Glenmora was set equal to 141 cfs.

SUMMARY

For high discharges at Glenmora (i.e., 2,190 cfs; when the storm evaluated assumes precipitation falling on both the Mill Creek and the Calcasieu basins), the flow reduction at Oberlin, induced by the Mill Creek reservoir, was approximately 4% and 5% (i.e., 738 and 548 cfs) for the 100-year and the 10-year precipitation scenario, respectively, compared to the scenario without the reservoir. This minor reduction in flow translates into a stage reduction at Oberlin of less than 0.3 ft, suggesting there is minimal reduction in river stages downriver of the reservoir during storms.

For lower discharges at Glenmora (i.e., 141 cfs), the flow reduction at Oberlin, induced by the Mill Creek reservoir, varied between **24% and 27%** (i.e., 2,125 and 1,115 cfs) for the **100-year and the 10-year** precipitation scenario, respectively, compared to the scenario without the reservoir. This reduction in flow translates into a stage reduction at Oberlin of approximately 1.8 ft.

Model results suggest that the installation of the Mill Creek reservoir will **produce a delay in the arrival of the peak discharge by approximately 14 hours at the site of the Mill Creek reservoir, and between 13 and 17 hours at Oberlin**.

Maintaining the reservoir at the elevation of 77 ft NAVD88 versus drawing down the reservoir by 2 ft ahead of the storm, produced minor differences in the results; namely less than 70 cfs flow reduction at Mill Creek in the vicinity of the reservoir and approximately 145 cfs flow reduction on the Calcasieu River at Oberlin. However, it should be noted that the initial reservoir water level of 75 ft NAVD88 exhibited slightly better performance in terms of flow reduction and delay of peak discharge at Oberlin compared to the 77 ft NAVD elevation. This is because with a lower initial water level (i.e., 75 ft NAVD88), the reservoir was able to store water for a longer period before releasing it downstream when reaching the bottom of the spillway elevation (i.e., 77 ft NAVD88). The modeling results suggest that if storms can be anticipated (i.e., via a real-time forecasting system), the Mill Creek reservoir can be drawn lower to maximize storage capture during a storm. The gradual release ahead of the storm could have additional benefits, such as maintaining higher base flows downriver of Mill Creek and enabling other benefits and uses including potentially rechanging aquifers located downriver of Mill Creek.

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