Utilizing Upper Diversions in River Water Management Case Study: 2019 Mississippi Floods, Phase 1

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Executive Summary

The Bonnet Carré Spillway (BCS) is a flood-control structure and part of an overall flood control system for the Lower Mississippi River managed by the United States Army Corps of Engineers (USACE). Recently the BCS has been operated more often than it has been in previous decades. Specifically, for the first time since construction, it has been operated in three consecutive years, namely in 2018, 2019, and 2020; also for the first time in its history it was operated twice in the same calendar year (2019). The BCS diverts fresh floodwaters from the Mississippi River (along with sediment and nutrient loads) into Lake Pontchartrain. The flood protection benefits from BCS are well documented by the USACE. The 2011 flood event is a prime example of the substantial safety and economic benefits from the existence of the BCS and the overall Mississippi River flood protection system.

Operating the BCS in late spring and early summer of 2019, dictated by high discharge events, and due to higher temperatures reportedly triggered water quality issues, reduced salinities, and algal bloom formation in Lake Pontchartrain and the coastal area of the State of Mississippi. Therefore, this report examines the utility of upper river diversions identified and defined in the 2017 Coastal Master Plan —Maurepas, Union, and Ama — to function as auxiliary flood control options with a goal of reducing the magnitude or duration of operating the BCS. This first phase of the study focuses on the riverside. For this study, the Hydrologic Engineering Center-River Analysis System (HEC-RAS) model was used to quantify the possible reduction in magnitude and duration of operating the BCS through using the upper river diversions. The analysis shows that for the 2018 and 2019 combined flood events, when the Ama North (just north of the location depicted in the 2017 Coastal Master Plan) and Union diversions are operated jointly, the reduction in the flow volume released through the BCS ranged from 57% - 61% depending on the operation plan used for the Union diversion, while also reducing the duration needed to operate the spillway from 143 days to 96 days. The second phase of the study will focus on the basin-side. A Delft3D modeling study will analyze the potential benefits from utilizing the upper river diversions on water quality, salinity, and overall water circulations in Lake Pontchartrain and the State of Mississippi Coastal area.

1. Introduction

The Lowermost Mississippi River (LMR) experienced high river stage events in both years of 2018 and 2019. Heavy rainfall and snowmelt in the upper Mississippi River drainage basin resulted in the flood threats to the city of New Orleans and other downstream areas. Therefore, the Bonnet Carré Spillway (BCS), near RM 129 (river miles above Head of Passes) was operated three times during 2018-19 to divert flood water into Lake Pontchartrain (Figure 1), allowing downstream discharge flowing through New Orleans to be capped at approximately 1,250,000 cubic feet per second (cfs). The operations of the BCS during 2018-2019 mark several records: it was the first time ever to operate BCS in back to back years; as well as it was the first time to operate twice in the same year of 2019. The opening of the BCS and diverting large amount of nutrient-rich (e.g. nitrogen and phosphorus) and suspended sediment laden freshwater reportedly triggered water quality issues in Lake Pontchartrain and the coastal area of the State of Mississippi. Further, the nutrients spurred the formation of algal blooms, including blue-green algae. These conditions potentially affect fish, birds and mammals, and may cause human illness.

Previously, harmful algae blooms (HABs) and hypoxic conditions potentially triggered by the BCS opening and subsequent disturbances to aquatic life were reported by several studies (e.g., Poirrier and King 1998; Mishra and Mishra, 2010). Due to the recent increase in the frequency of operating the BCS, there is an interest to identify river management strategies to optimize the operation of the spillway and study the impacts on water quality and ecological health of Lake Pontchartrain and its adjacent estuaries.

The 2017 Coastal Master Plan (CPRA, 2017) proposed freshwater and sediment diversions from the Mississippi River as a restoration strategy. Diversions have been proposed for their capacity to build land and sustain land, modulate salinity, and change nutrient distribution in the receiving basins. Two of the large-scale sediment diversions—Mid-Barataria and Mid-Breton—

proposed in the master plan, are now moving through permitting to construction. Upper river diversions as defined in the 2017 Coastal Master Plan include the River Reintroduction into Maurepas Swamp (Maurepas) Diversion, which is also close to construction now). They also include Union Freshwater Diversion (Union) and Ama Sediment Diversion (Ama) which are in locations vital for river water management (Figure 1) but to-date have not undergone feasibility analyses. An additional location for the Ama diversion, termed Ama North, was also explored in this study which moved the conceptual diversion north/upstream of the BCS. The upper river diversions could be used to distribute floodwaters during high water events, and potentially reduce the duration or magnitude of the pulse from the BCS. The goal of this study is to explore these river management strategies. Future phases will further examine these options through a basin-side Delft model to evaluate the environmental benefits, such as: a) restoration targets (sediment and salinity); and b) reduction of nutrients in the Louisiana and Mississippi coastal zone.

This report focuses on the riverside analysis representing the first phase of the study. Here we explore whether upper river diversions (Union, Ama, Ama North and Maurepas) can distribute floodwaters during high water events, thereby reducing the magnitude or duration of the BCS pulses. The riverside analysis will be performed using the Hydrologic Engineering Center-River Analysis System (HEC-RAS) for recent years where the BCS was operated. The analysis evaluated and quantified the potential reduction of duration or magnitude of the BCS pulses through engaging individual or combination of upper-river diversions. Specifically, we analyzed Union, Ama, Ama North and Maurepas diversions individually and cumulatively (see Figure 1 for the locations of these upper-river diversions).

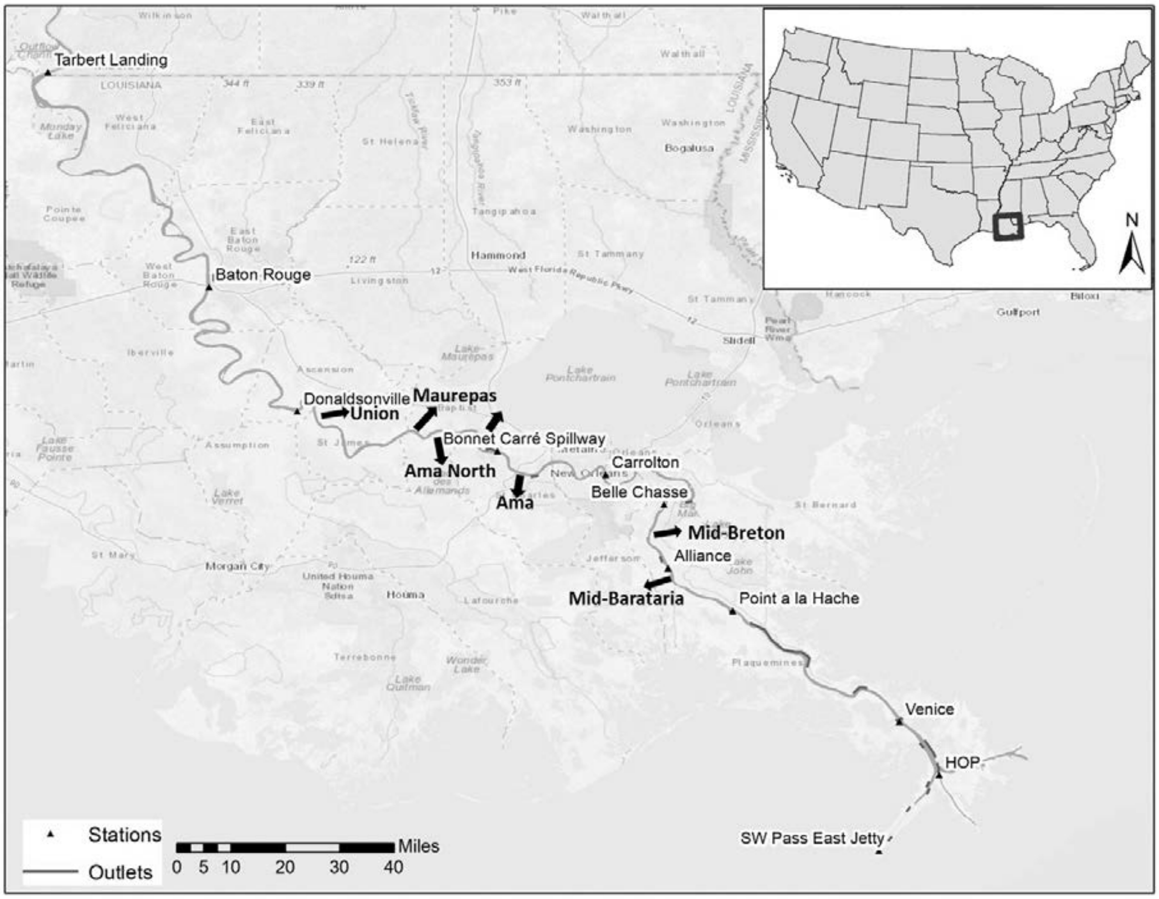


Figure 1. Study locations, the triangles with names represent the monitoring stations; black lines along the channel represent the outlet locations; and arrows indicate main diversions.

1-1. Bonnet Carré Spillway (BCS)

Following the flood in 1927, which was the most catastrophic in the history of the Lower Mississippi River (LMR) region with more than 200 lives lost, the Mississippi River and Tributaries (MR&T) Project was authorized by Congress (Barry, 2007). The MR&T Project is a comprehensive and complex project, which involved construction of features to manage the river for flood protection and navigation, such as levees, cut-offs, dikes, bypass floodways, massive upgrades, and water control structures. The BCS is one of the MR&T components. The BCS was completed in 1931, about 12 miles west of New Orleans (see location in Figure 1), and is designed to divert excess floodwaters from the Mississippi River to flow into Lake Pontchartrain, and ensure downstream discharge flowing by New Orleans is less than ~1,250,000 cfs. The main regulation structure consists of 350 flood bays and each bay has 20 creosote wooden timbers (each with 0.65 × 1 ft, and 10.1 – 11.8 ft in length). The structure is opened by removing the timbers (or reinstalling the timbers when closing) one at a time; therefore, it can take more than a week to completely open (or close) the entire structure (Lane et al., 2001, Day et al., 2012).

The BCS openings generally coincides with the peak hydrograph of the Mississippi River when rainfall or snowmelt in the upper basin increase discharge and stage in the lower part of the river beyond a mandated trigger of 1,250,000 cfs. The USACE also considers water surface elevations to prevent overtopping of the Mississippi River & Tributaries levee system. For the analysis performed in this study, and as a proxy to elevated water levels, the water level at the Carrollton gauge is to be maintained at/below ~16.18 ft reference to NAVD88 (North American Vertical Datum of 1988).

Since its first opening in 1937, the BCS has been opened 16 times during flood events of the Mississippi River (the 1994 opening was for experimental intent, not for flood control). In previous openings, the estimated peak discharge ranges from 90,000 to 318,000 cfs (Table 1). The year of 2019 was the first time that the BCS was operated twice in a given year. After heavy rainfall in the Mississippi and Ohio River valleys increased river stages, the BCS was opened on February 27, 2019. Following the BCS closure on April 11, 2019, heavy rainfall events across the river valley prompted a second opening on May 10, 2019 and remained open until July 27, 2019. The total duration for the 2019 BCS opening is the longest operation on record. It is also worth noting that operating BCS in 2018 and 2019 was the first time the spillway was operated in consecutive years. Most recently a 2020 opening marked the first time the spillway was operated in three consecutive years.

Table 1. Bonnet Carré Spillway (BCS) operation record. Maximum water discharge, number of bays opened, and the duration of each event are listed. Note: the 1994 opening was not for flood control, but for experimental purposes.

Year	Duration (Month/ Day)	Max bays opened	Maximum discharge (cfs)
1937	01/28 – 03/16	285	211,000
1945	03/23 – 05/18	350	318,000
1950	02/10 – 03/19	350	228,000
1973	04/08 – 06/21	350	207,000
1975	04/14 – 04/26	225	110,000
1979	04/17 – 05/31	350	228,000
1983	05/20 – 06/23	350	268,000
1994	05/16 – 05/26	30	14,000
1997	03/17 – 04/18	298	243,000
2008	04/11 – 05/08	160	160,000
2011	05/09 – 06/20	330	316,000
2016	01/10 – 02/01	210	203,000
2018	03/08 – 03/30	186	196,000
2019	02/27 – 04/11	206	213,000
2019	05/10 – 07/27	168	161,000
2020	04/03 – 05/01	90	90,000

2. Analysis

2-1. Model setup

This study focuses on exploring the utility of upper river diversions (e.g. Ama, Union, Maurepas) to potentially reduce the duration or magnitude of the water pulse from the BCS. A set of riverside numerical model simulations were conducted to evaluate the water levels and discharge along the length of the LMR channel for various scenarios including existing conditions, and with individual (and cumulative) activation of upper river diversions.

An existing HEC-RAS model for the LMR acquired from the United States Army Corps of Engineers (USACE) was used as the starting point of the analysis presented here. The model domain extends from Tarbert Landing (TBL), Louisiana to the Mississippi River Delta (see Figure 1). Figure 2 shows a sample of the cross-sections along the river length as well as lateral outlets capturing the exchange of flow between the river channel and the adjacent basins.

The upstream boundary of the model was driven by the daily water discharge record at TBL monitored by USACE (USACE Gauge # 01100Q). We also examined the possibility of truncating the model at Baton Rouge and using the discharge record at the USGS site (U.S. Geological Survey) at Baton Rouge (USGS Gauge # 07374000) as the upstream boundary. For both versions of the model, the downstream boundary was driven by the daily water level record at Southwest (SW) Pass at East Jetty from USACE (USACE Gauge # 01670). Figure 3 displays the time series records for the upstream and downstream boundary conditions used for the two models (TBL-Gulf and Baton Rouge-Gulf).

The HEC-RAS model for the LMR contains 16 outlets (or passes). The flow extraction through five of the outlets were represented through time-series observations, while the remainder of the outlets are represented through rating curves. The rating curves estimate the extracted flow based on an upstream river discharge. The time-series observations were obtained from the USGS website, while the rating curves were employed by considering the HEC-RAS model by Dahl et al. (2018).

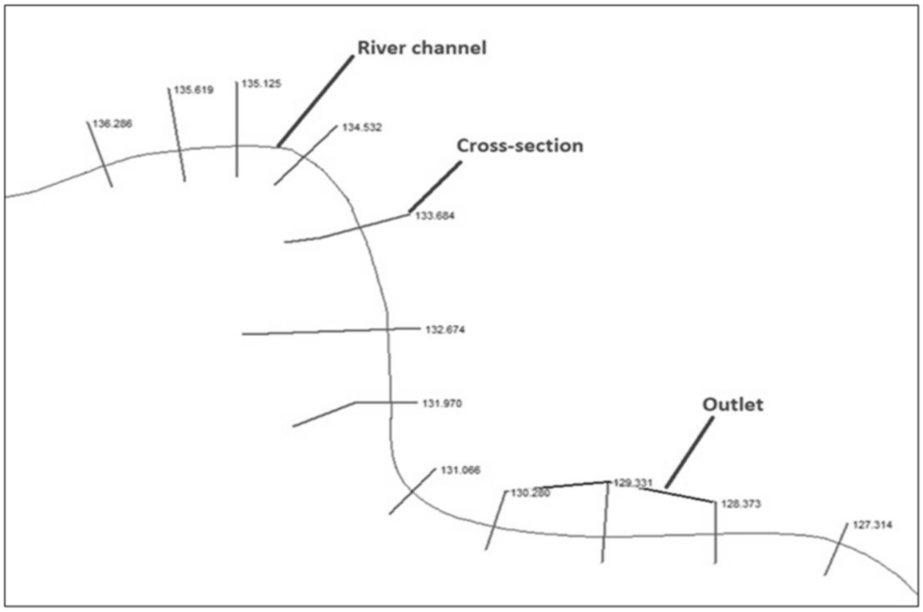
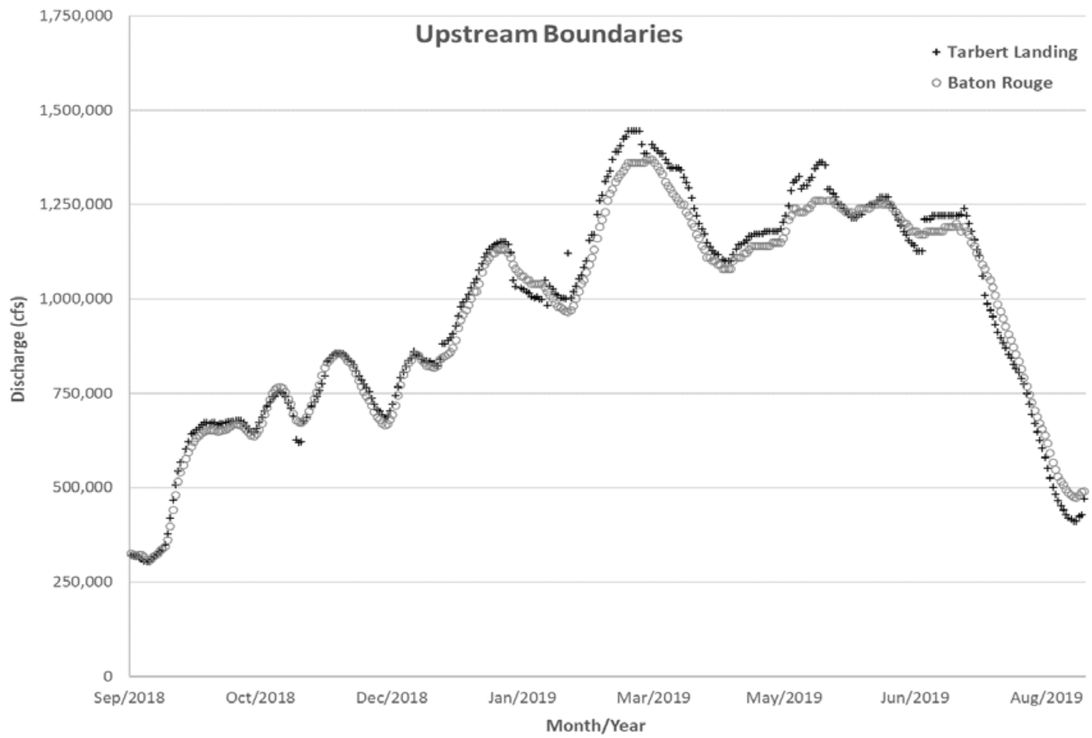


Figure 2. An illustration of the river channel, cross-sections and sample of outlets included in the HEC-RAS model.

(A)



(B)

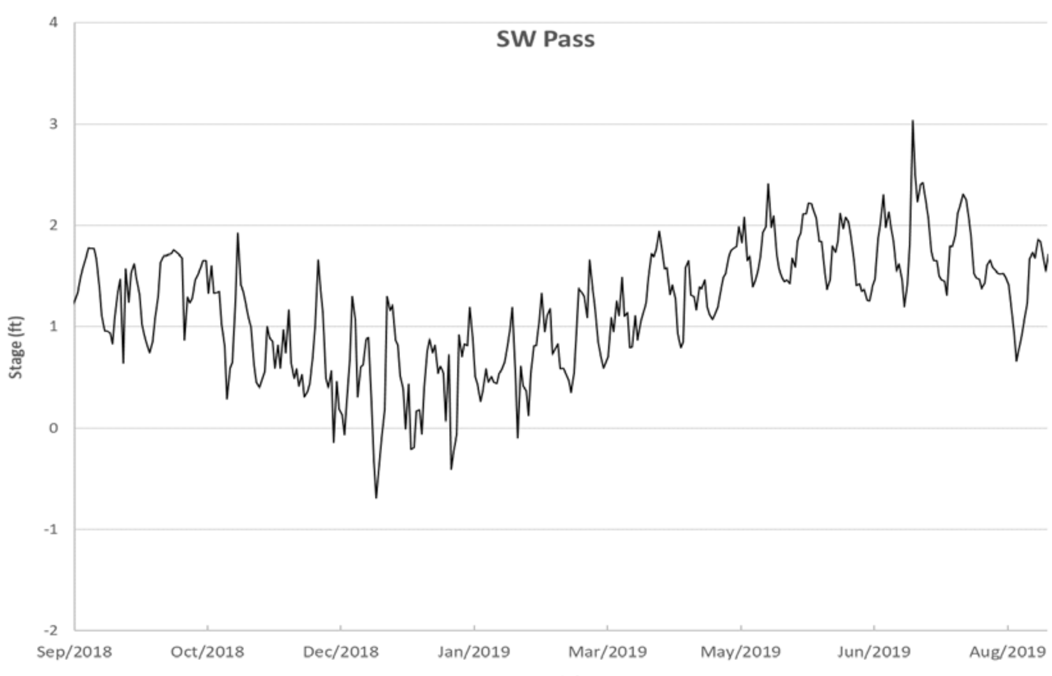


Figure 3. (A) Daily time series of the water discharge record used as an upstream boundary at Tarbert Landing (TBL) and Baton Rouge (for the two model setups). (B) Daily time series for the water level at SW Pass used as the downstream boundary condition.

2-2. Model calibration and validation

We calibrated the LMR HEC-RAS model for the September 1, 2018 - September 1, 2019 time period and validated the model for the flood events of 2011 and 2016. We used the water level and water discharge data collected at interior points within the model domain to evaluate the model performance against field observations. Figure 1 shows all the monitoring stations (Baton Rouge, Donalsonville, BCS, Carrollton, Belle Chasse, Alliance, Pointe a La Hache, Venice, and Head of Passes (HOP)) used to calibrate and validate the model.

The primary parameter we used to calibrate the model was the Manning roughness coefficient (Manning's n). The roughness coefficient is variable in space (from one cross-section to another), within each cross-section (overbank versus the main channel) and with respect to the water discharge. On average, Manning's n ranging between a 0.035 to 0.018 is considered to be reasonable (Arcement and Schneider, 1989; Dahl et al., 2018). Given the spatial extent of the river reach considered within the study area as well as the large range of discharge and water level variations, adjustments to Manning's roughness coefficient were required with respect to distance along the river channel and with respect to the flow discharge. Manning's coefficient decreased from upstream to downstream and decreased with the increase in flow discharge. Tables 2 to 5 summarize the Manning's n and the flow-roughness factors we employed for both models of TBL-Gulf and Baton Rouge-Gulf in this study.

The calibration process included visual inspection and statistical evaluation of the agreement between the calculated and measured water level and discharge. The statistical tools used to evaluate the model performance included root-mean-square error (RMSE), bias, coefficient of efficiency (COE), and coefficient of determination (r^2). The same statisticss were calculated for the 2016 and 2011 validation years.

Table 2. Manning’s n roughness values for the Baton Rouge-Gulf model. The Upstream (US) and downstream (DS) indicate the limits of applicability of Manning’s n in river Miles above the Head of Passes.

US (River Miles)	DS (River Miles)	Manning's n Channel	Manning's n Overbank
238.1	150.8	0.024	0.075
150.8	82.5	0.025	0.075
82.5	63.2	0.023	0.075
62.2	47.6	0.022	0.075
47.6	1.1	0.02	0.075
1.1	-17.9	0.018	0.075

Table 3. Manning’s n for the TBL-Gulf model. Upstream (US) and downstream (DS) are in river miles above Head of Passes.

US	DS	Manning's n Channel	Manning's n Overbank
305.1	285.7	0.027	0.075
285.7	268.0	0.026	0.075
268.0	238.1	0.025	0.075
238.1	150.8	0.024	0.075
150.8	82.5	0.025	0.075
82.5	63.2	0.023	0.075
62.2	47.6	0.022	0.075
47.6	1.1	0.02	0.075
1.1	-17.9	0.018	0.075

Table 4. Flow-roughness factors for the TBL-Gulf model. The US and DS are in river miles above Head of Passes.

US	305		238		228		176		140		105		11		3	
DS	238		228		176		140		105		11		3		-17	
Flow-Roughness	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor
	0	1.03	0	1.05	0	1.05	0	1.15	0	1.2	0	1.2	0	1.1	0	1.02
	250000	1.03	250000	1.05	250000	1.05	250000	1.15	250000	1.1	250000	1.15	300000	1.15	200000	1
	500000	1.18	500000	1	500000	1.05	500000	1.15	500000	1.1	500000	1.1	600000	1.05	300000	0.8
	750000	1.03	750000	1.2	750000	1.05	750000	1.05	750000	1.05	750000	0.95	700000	0.9	700000	0.8
	1000000	0.92	1000000	1.5	1000000	1	1000000	0.95	1000000	1	1000000	0.95	1000000	0.9	1000000	0.8
	1250000	1.13	1250000	1.2	1250000	1	1250000	0.95	1250000	1	1250000	1	1250000	0.9	1250000	0.8
	1400000	1.29	1400000	1	1500000	1	1500000	0.95	1500000	1	1500000	1	1500000	0.9	1500000	0.8
	1750000	1.29	1750000	0.9	1750000	1	1750000	0.95	1750000	1	1750000	1	1750000	0.9	1750000	0.8
	2000000	1.29	2000000	0.9	2000000	1	2000000	0.95	2000000	1	2000000	1	2000000	0.9	2000000	0.8

Table 5. Flow-roughness factors for the Baton Rouge-Gulf model. The US and DS are in river miles above Head of Passes.

US	238		228		176		140		105		11		3	
DS	228		176		140		105		11		3		-17	
Flow-Roughness	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor	Flow	Factor
	0	1.05	0	1.05	0	1.15	0	1.2	0	1.2	0	1.1	0	1.02
	250000	1.05	250000	1.05	250000	1.15	250000	1.1	250000	1.2	300000	1.15	200000	1
	500000	1	500000	1.05	500000	1.15	500000	1.1	500000	1.15	600000	1.05	300000	0.8
	750000	1.1	750000	1.05	750000	1.05	750000	1.1	750000	1.2	700000	0.9	700000	0.8
	1000000	1.5	1000000	1	1000000	0.97	1000000	0.95	1000000	1.01	1000000	0.9	1000000	0.8
	1250000	1.3	1250000	1	1250000	1	1250000	1	1250000	1	1250000	0.9	1250000	0.8
	1400000	1	1500000	1	1500000	1.01	1500000	1	1500000	1	1500000	0.9	1500000	0.8
	1750000	0.9	1750000	1	1750000	1.01	1750000	1	1750000	1	1750000	0.9	1750000	0.8
	2000000	1	2000000	1	2000000	1.01	2000000	1	2000000	1	2000000	0.9	2000000	0.8

2-3. Model applications: utilizing river upper diversions for flood control

After validating the LMR HEC-RAS model, it was used to evaluate the utility of upper river diversions for flood control. Specifically, the following runs were performed:

- Ama diversion at River Mile 115 (location as approximated in the 2017 Coastal Master Plan, see CPRA, 2017), and Ama North at River Mile 138
- Union diversion (location as approximated in the 2017 Coastal Master Plan, see CPRA, 2017) at River Mile 170.
- Ama North and Union diversions together.
- Ama North, Union, and Maurepas diversion (location as in the 2017 Louisiana Master Plan) at River Mile 153.

The operation plan for each of the diversions is described below. Note that the 2017 Coastal Master Plan locates the Ama diversion downstream of the BCS. For this study, we explored both the Coastal Master Plan location of the Ama diversion and moving the Ama diversion upstream of the BCS (Ama North), which may add benefit for diverting flood water upstream of the BCS compared to the downstream location.

As outlined in the 2017 Master Plan (CPRA, 2017), the Ama diversion suggested operational plans are to follow the process described below:

- divert 50,000 cfs when the Mississippi River flow reaches 1,000,000 cfs,
- shut off the diversion when the Mississippi River flow falls below 200,000 cfs,
- divert an amount linearly interpolated between 0 and 50,000 cfs for Mississippi River flow between 200,000 cfs and 1,000,000 cfs,
- divert a linearly extrapolated amount exceeding the 50,000 cfs when the Mississippi River flow is larger than 1,000,000 cfs.

The Union diversion as a freshwater diversion was originally intended to operate during low river flow (reciprocal of other proposed sediment diversions in the 2017 Coastal Master Plan). Specifically, Union was intended to be shut off if river flow is below 200,000 cfs or above 600,000 cfs. In the analysis presented here, we suggest also operating the Union diversion at full capacity (25,000 cfs) when the Mississippi River flow exceeds 1,000,000 or 1,250,000 cfs (two different scenarios, see more detail in Section 3-1). Finally, the operation plans for the Maurepas diversion is to extract a constant flow of 2,000 cfs independent of the LMR flow.

3. Results

3-1. Calibration and validation

Figures 4 through 13 displays modeled output of water levels and discharge from the Baton Rouge-Gulf model. The overall performance demonstrates that the Baton Rouge-Gulf model compares well against the field observations. It should be noted that there are uncertainties associated with the field observations of water flow discharge (Dahl et al., 2018; Lewis et al., 2017). Lewis et al. (2017) found significant discrepancies between the reported discharges at TBL and Baton Rouge.

In addition to the visual comparison illustrated in the figures, the statistical tools used to evaluate the model performance are summarized in Tables 6 through Table 11 for the Baton Rouge-Gulf model. Tables 6 and 7 summarize the validation results of water levels for 2016 and 2011, respectively, while Table 8 is evaluating the model output to the measured discharge at Belle Chasse. Similar validation results of the TBL-Gulf model are summarized in Tables 9 through 11. Overall, both versions of the model showed reasonable level of agreement with the field measurements. Discrepancies between the model and field observations are reflected in the calculations of COE and r^2 in the most downstream stations: Venice and HOP. Possible sources of uncertainties contributing to this issue include lack of direct measurements of the flow through the various passes and outlets. The flow through these outlets is estimated through rating curves developed based on discrete measurements.

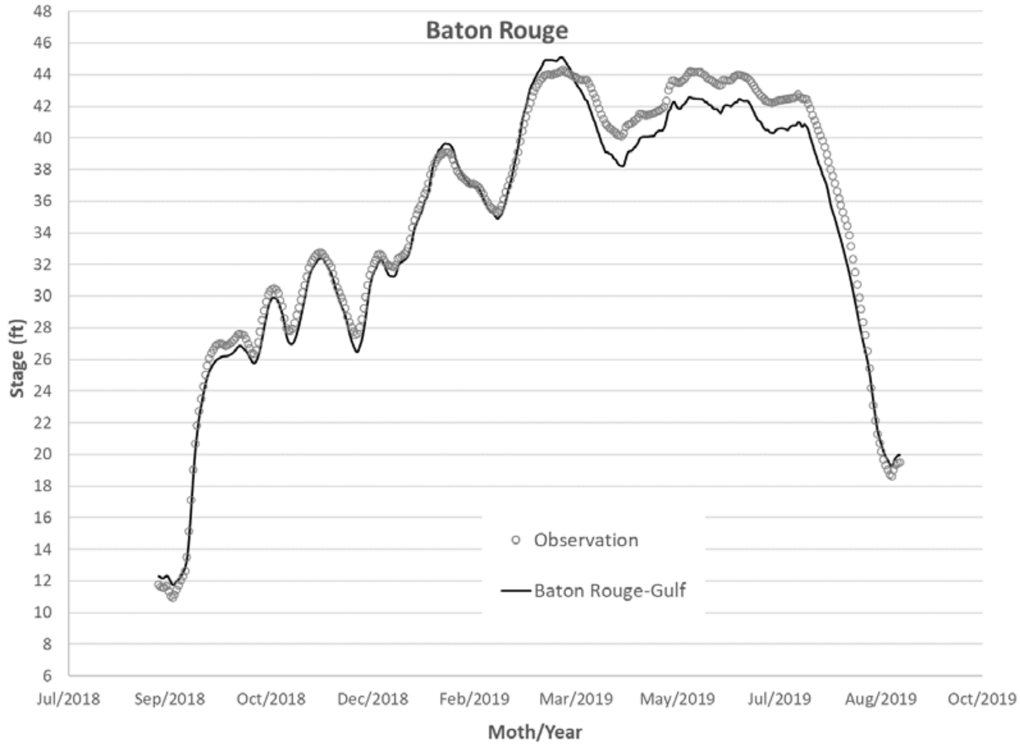


Figure 4. Calibration results between model output and field observations at Baton Rouge.

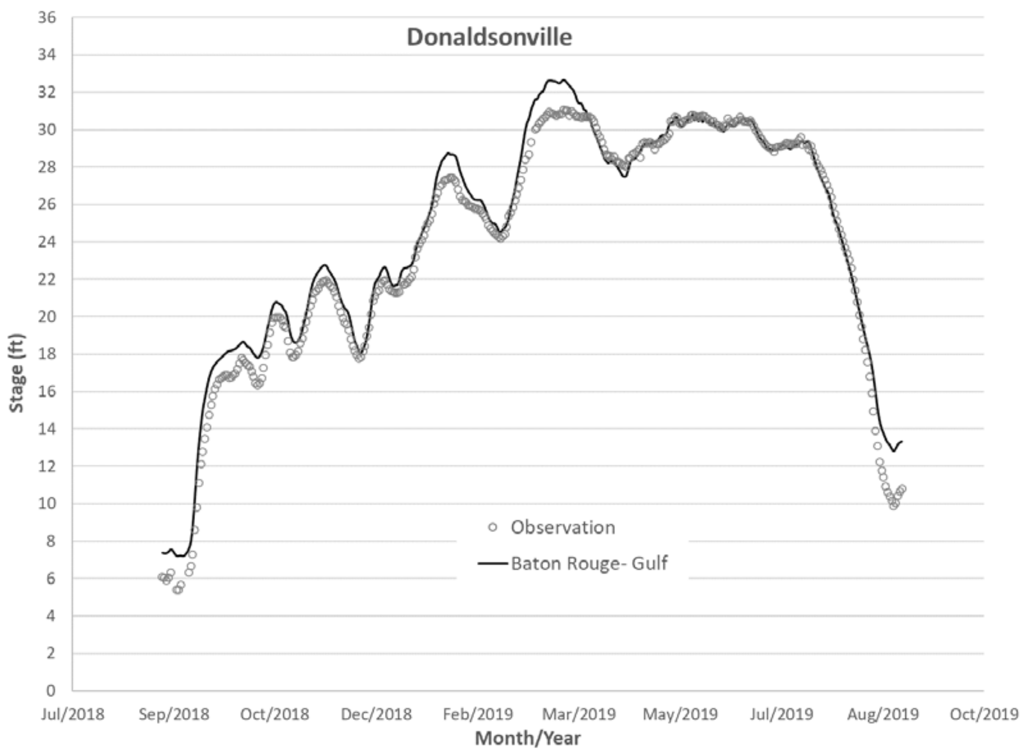


Figure 5. Calibration results between model output and field observations at Donalsonville.

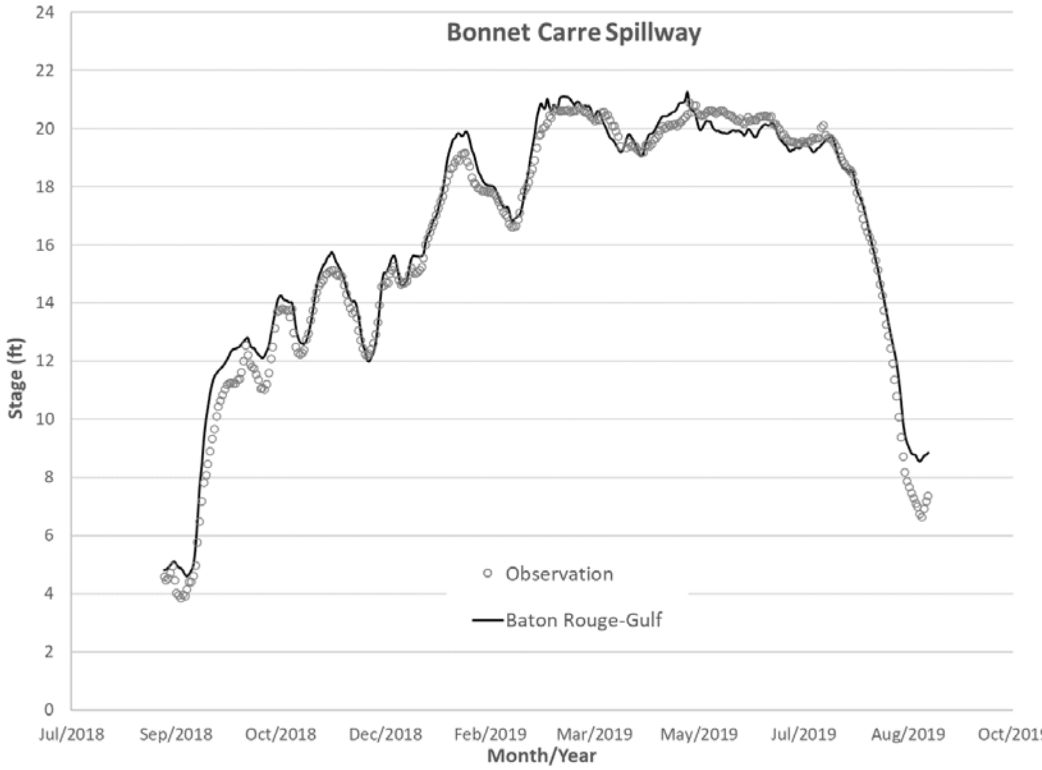


Figure 6. Calibration results between model output and field observations at BCS.

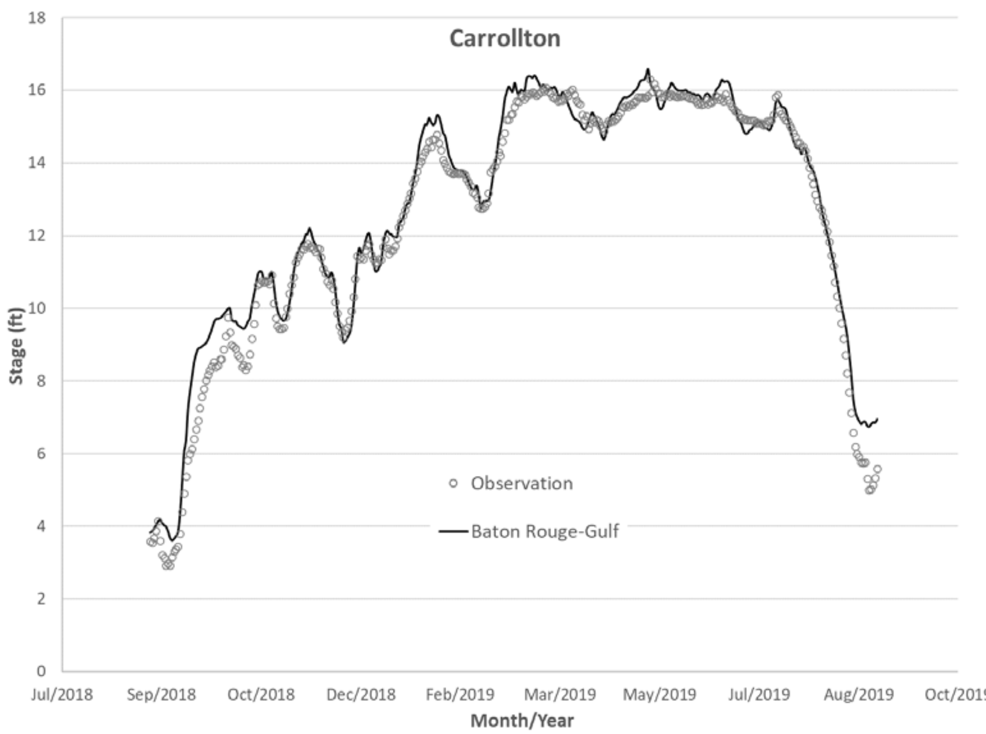


Figure 7. Calibration results between model output and field observations at Carrollton.

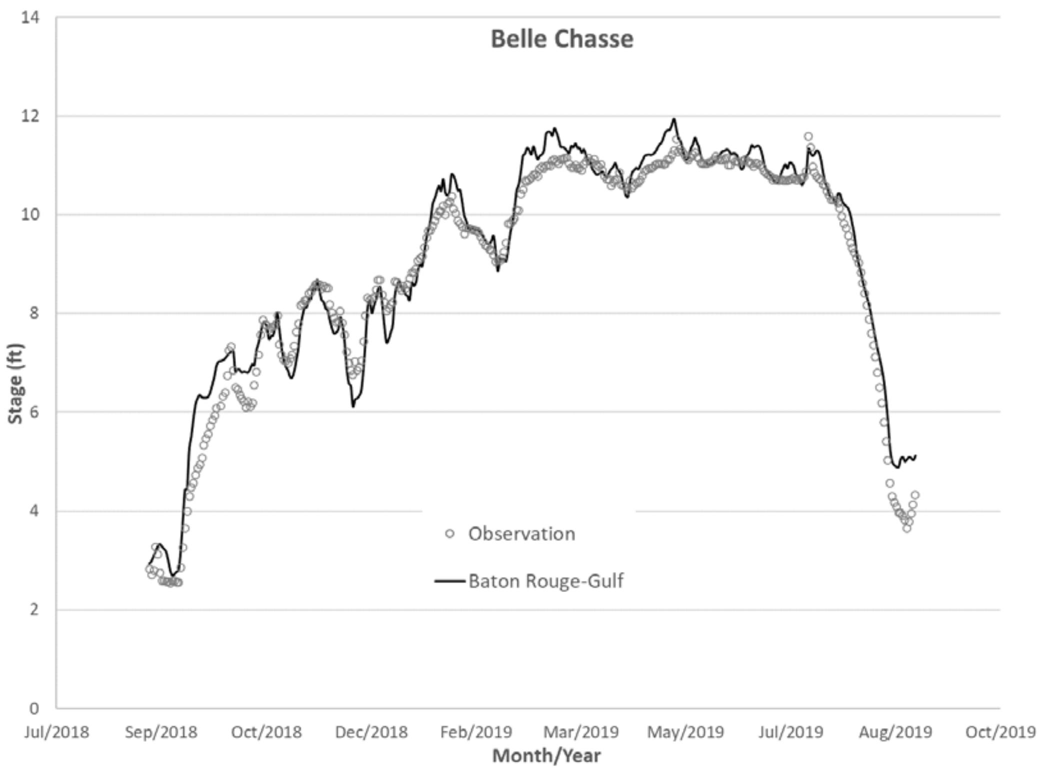


Figure 8. Calibration results between model output and field observations at Belle Chasse.

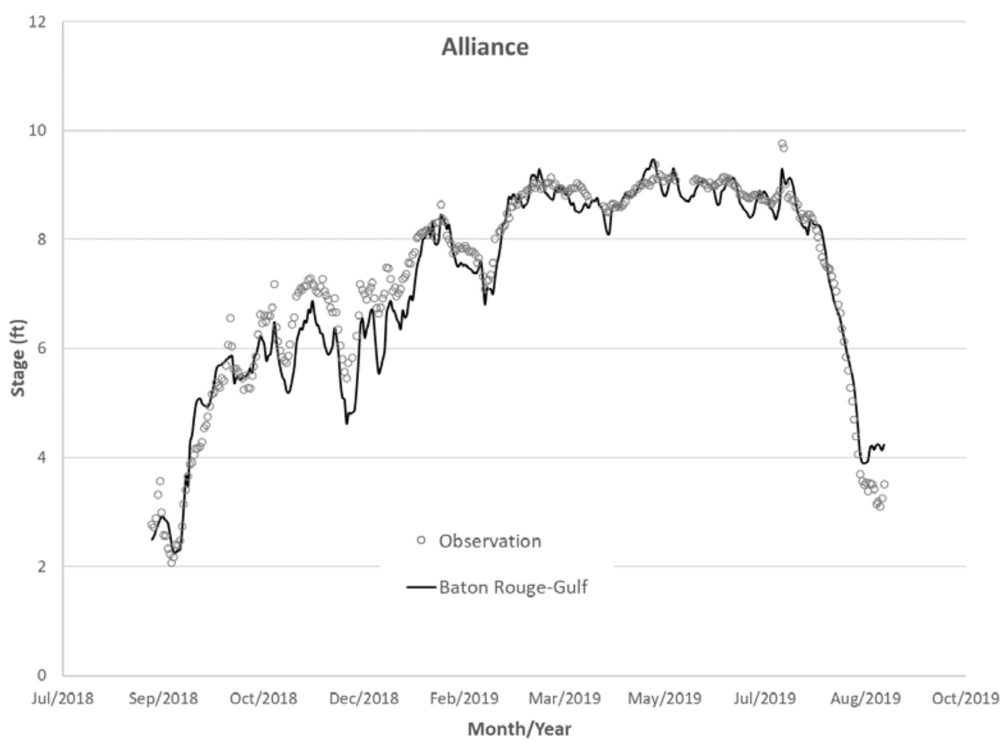


Figure 9. Calibration results between model output and field observations at Alliance.

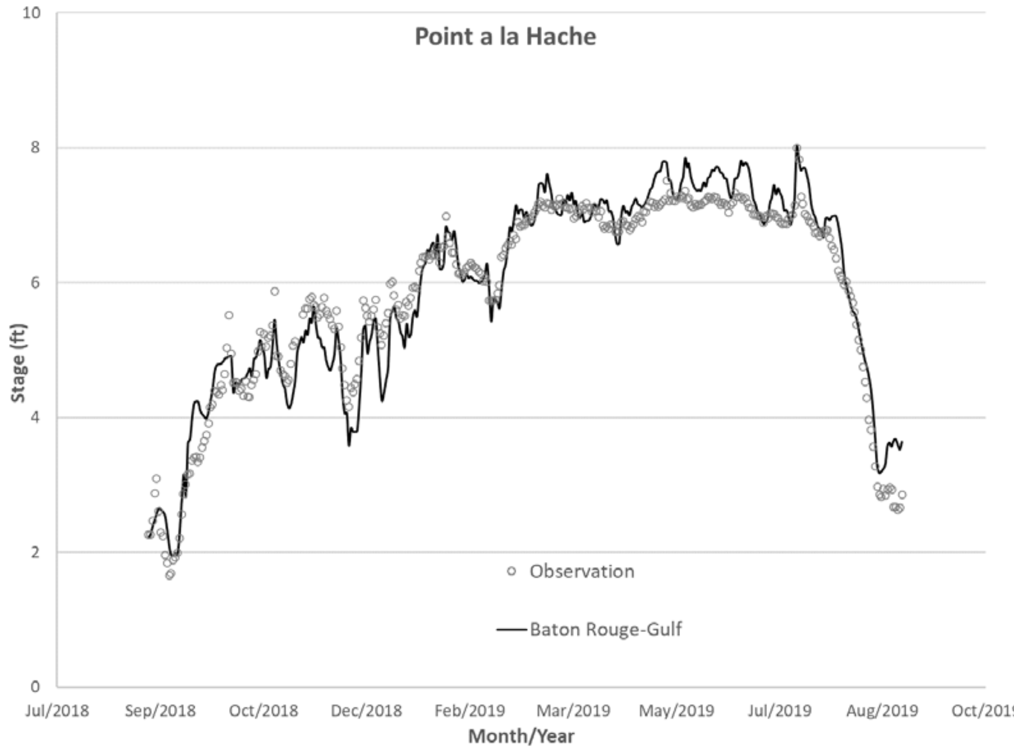


Figure 10. Calibration results between model output and field observations at Pointe a la Hache.

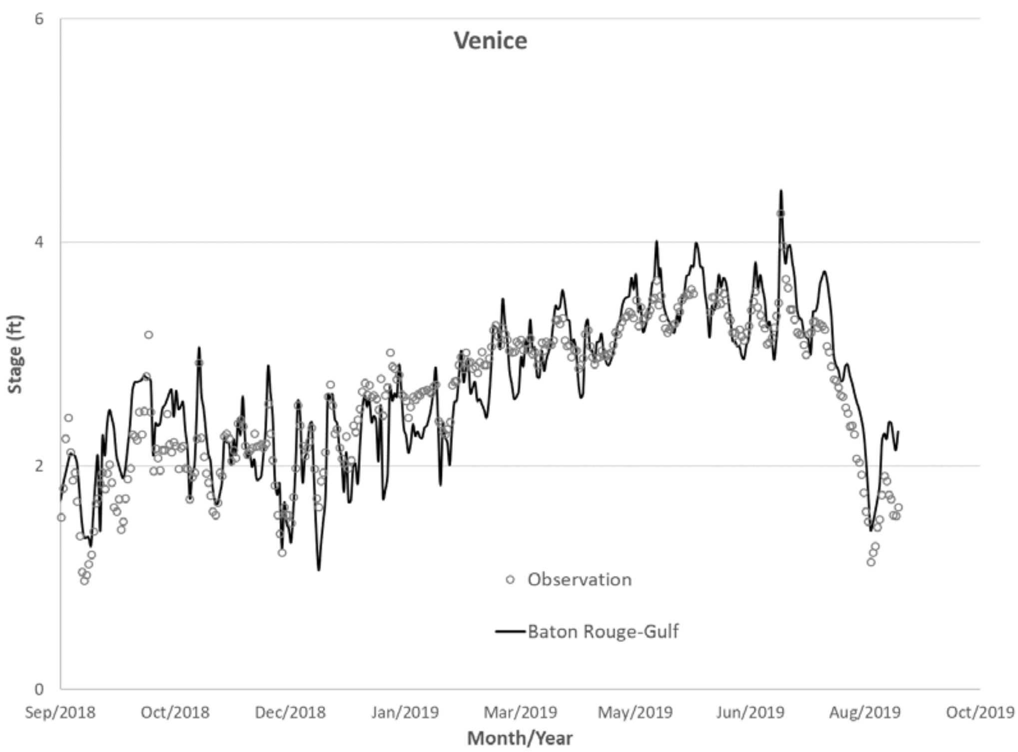


Figure 11. Calibration results between model output and field observations at Venice.

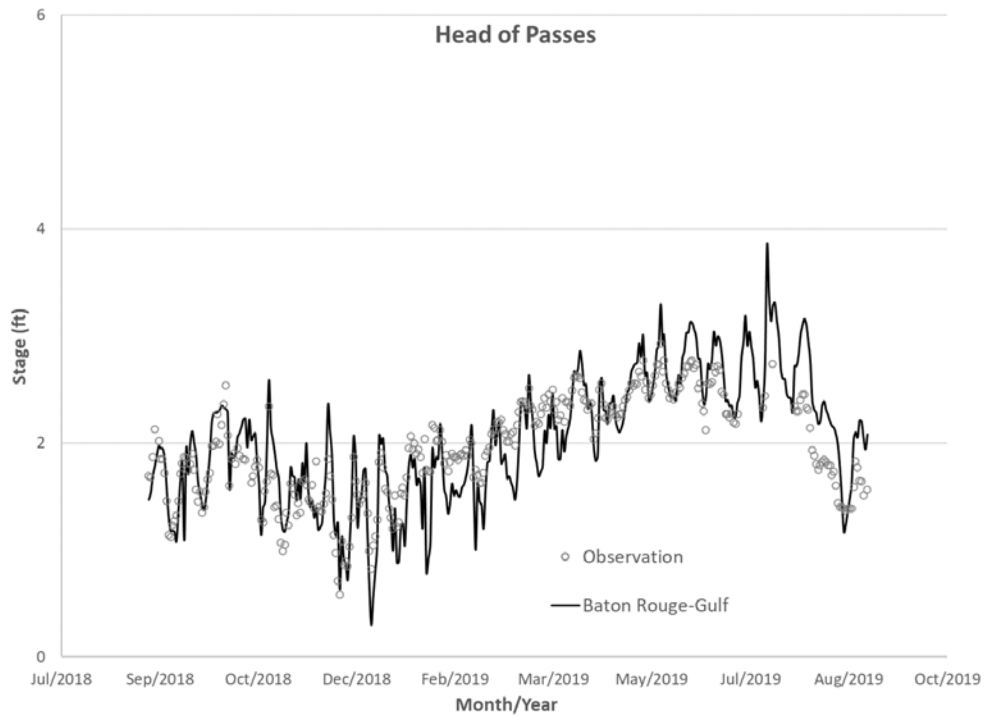


Figure 12. Calibration results between model output and field observations at Head of Passes (HOP).

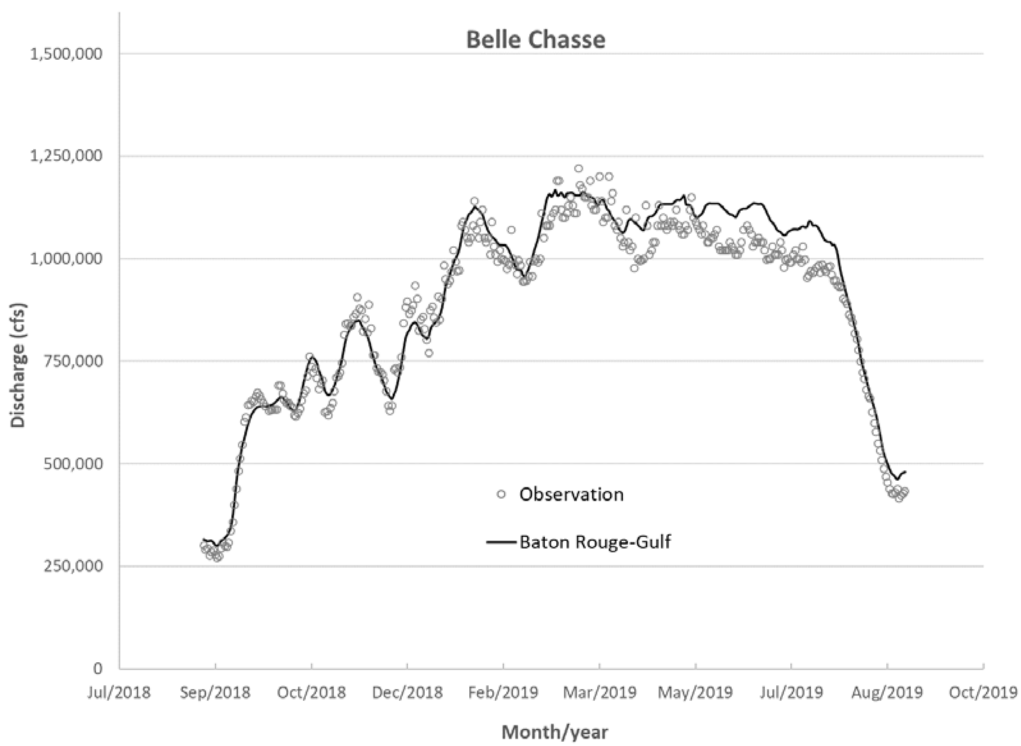


Figure 13. Calibration results between model output and field observations at Belle Chasse.

Table 6. The Baton Rouge-Gulf model validation results for 2016 water stage data.

	RMSE (ft)	R^2	Bias (ft)	COE
Baton Rouge	0.551	0.997	-0.042	0.996
Donalsonville	1.183	0.996	-1.078	0.971
BCS	0.689	0.992	-0.537	0.980
Carrollton	0.654	0.989	-0.510	0.971
Belle Chasse	0.396	0.984	-0.203	0.978
Alliance	0.322	0.979	-0.054	0.977
Pointe a La Hache	0.364	0.962	0.044	0.952
Venice	0.357	0.660	-0.089	0.635
HOP	0.354	0.543	-0.161	0.134

Table 7. The Baton Rouge-Gulf model validation results for 2011 water stage data.

	RMSE (ft)	R^2	Bias (ft)	COE
Baton Rouge	0.646	0.998	0.185	0.997
Donalsonville	0.791	0.998	-0.570	0.993
BCS	0.627	0.992	0.180	0.990
Carrollton	0.565	0.990	0.240	0.987
Belle Chasse	0.602	0.989	0.430	0.970
Alliance	0.703	0.972	0.508	0.936
Pointe a La Hache	0.547	0.981	0.443	0.944
Venice	0.248	0.957	0.058	0.951
HOP	1.456	0.953	1.441	-1.491

Table 8. The Baton Rouge-Gulf model validation results for 2016 and 2011 discharge data.

Station/year	RMSE (cfs)	R^2	Bias (cfs)	COE
Belle Chasse				
2016	40,247	0.973	-3,476	0.972
2011	38,757	0.983	1,381	0.982

Table 9. The TBL-Gulf model validation results for 2016 water stage data.

	RMSE (ft)	R^2	Bias (ft)	COE
Baton Rouge	1.166	0.990	0.595	0.981
Donalsonville	0.850	0.987	-0.229	0.985
BCS	0.651	0.989	0.341	0.982
Carrollton	0.744	0.985	0.407	0.963
Belle Chasse	0.728	0.974	0.488	0.925
Alliance	0.730	0.968	0.535	0.881
Pointe a La Hache	0.557	0.957	0.339	0.888
Venice	0.322	0.728	-0.092	0.704
HOP	0.344	0.610	-0.184	0.186

Table 10. The TBL-Gulf model validation results for 2011 water stage data.

	RMSE (ft)	R^2	Bias (ft)	COE
Baton Rouge	1.437	0.990	0.028	0.985
Donalsonville	1.204	0.989	-0.433	0.983
BCS	0.842	0.989	0.428	0.982
Carrollton	0.896	0.986	0.667	0.967
Belle Chasse	0.912	0.981	0.779	0.930
Alliance	0.995	0.963	0.836	0.872
Pointe a La Hache	0.697	0.971	0.573	0.909
Venice	0.230	0.960	0.025	0.958
HOP	1.415	0.958	1.403	-1.355

Table 11. The TBL-Gulf model results for 2018-2019, 2016 and 2011 discharge data.

Station/year	RMSE (cfs)	R^2	Bias (cfs)	COE
Baton Rouge				
2018-19	40,056	0.992	-19,764	0.984
2016	32,287	0.989	8,887	0.985
2011	49,403	0.989	-16,433	0.979
Belle Chasse				
2018-19	48,545	0.981	16,778	0.977
2016	46,894	0.967	7,760	0.962
2011	52,577	0.982	-15,214	0.968

3-2. Simulations

For all the remainder of the simulations presented here, the Baton Rouge-Gulf model was used. It should be noted, that the primary criterion to trigger the operation of the BCS is exceedance of 1,250,000 cfs water discharge at TBL (Allison and Meselhe, 2010), with accounting of lag/travel time between TBL and the BCS. Accordingly, maximum water discharge allowed to flow past the BCS is 1,250,000 cfs. If that criterion cannot be accommodated even with the BCS operating at maximum capacity, the operation of the Morganza spillway is triggered. Guidance on the operation of the various flood control structures along the LMR can be found in Allison et al. (2013).

Additional guidance for operating the BCS is to ensure that water levels in the vicinity of New Orleans do not endanger overtopping of the MR&T levee system. The need to consider multiple factors results in a complex decision system to operate the BCS in terms of when, how long and how much. To emulate the criteria used to trigger and operate the BCS, we focused on two factors to examine the utility of the upper river diversions as flood control. First, we ensured that no more than 1,250,000 cfs passes downstream of the BCS. Second, we optimized the operation of the BCS such that the water level at the Carrollton gauge does not exceed ~16.18 ft reference to NAVD88. Note that all the simulations also considered the BCS spillway has a constant leakage of 5,000 cfs.

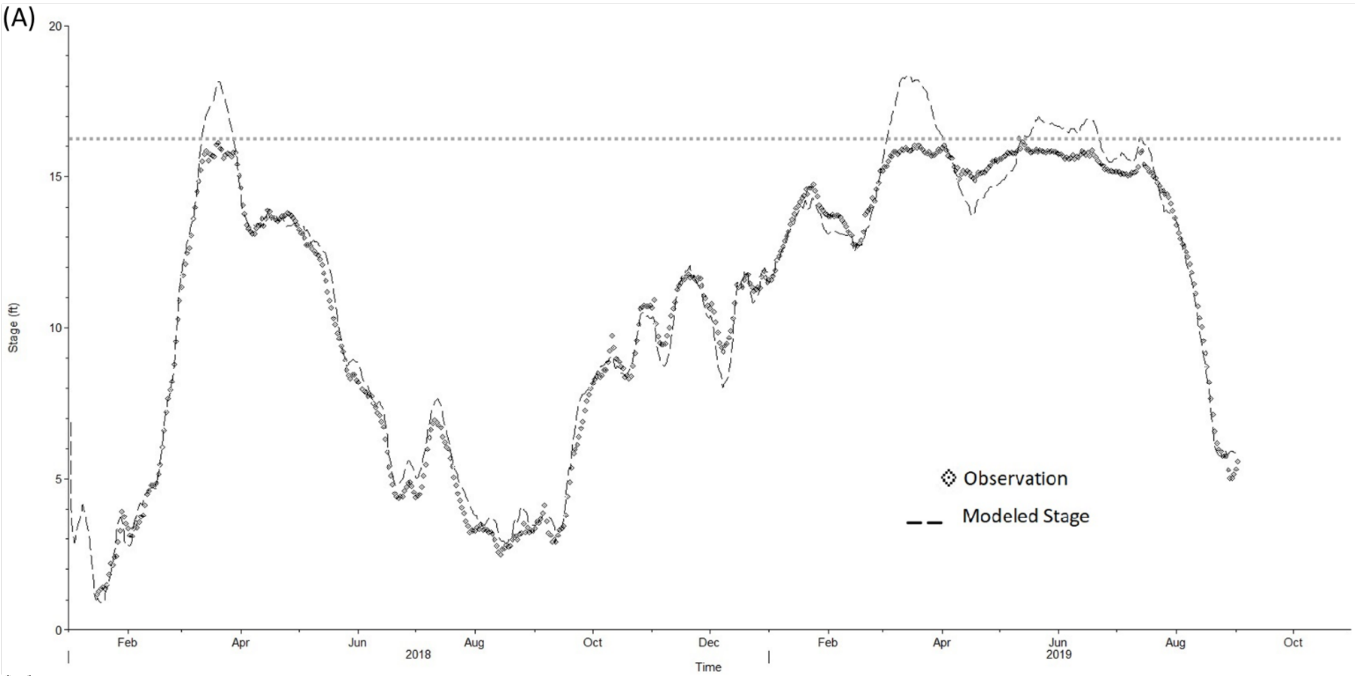
It should also be noted that the difference in the level of floodwater reduction benefits between the two locations of the Ama diversion was not discerned clearly by the model. Conceptually, the Ama North would be more effective since it is located upriver of the spillway. Future detailed modeling effort would highlight and quantify the benefit of the exact location of the proposed diversion. For this study, we used that Ama North location for all simulations. Figure 14 shows the potential discharge reduction at the BCS when the Ama North diversion is used as a supplementary flood control outlet. Figure 14A shows that we opened Ama North while keeping the BCS closed. Clearly, Ama did not have sufficient capacity as a stand-alone potential flood control feature to divert the excess floodwaters. This is reflected in the modeled stages exceeding the threshold stage of Carrollton (dashed line in Figure 14A). Therefore, Figure 14B represents the operation of Ama North and BCS jointly. Figure 14C shows the reduction in magnitude and direction of the BCS pulse resulting from using Ama North as a supplement flood control outlet. As seen in the figure, the Ama North diversion reduced the output discharges from BCS by nearly 48%, and reduced the duration of the pulse by 14 days (Table 12).

Similarly, the Union diversion was examined as a supplement flood control outlet. The results of using Union to supplement the BCS is shown in Figure 15 and Table 12. Utilizing Union as a flood control outlet resulted in a reduction of approximately 8% of the BCS discharge magnitude but did not reduce the duration of the BCS pulse.

Another scenario we examined is utilizing both Ama North and Union jointly, while assuming two different operation triggers for the Union diversion; operating to output 25,000 cfs when the Mississippi River exceeds 1,250,000 cfs (Case 1), or 1,000,000 cfs (Case 2). The results show Case 1 would reduce the magnitude of the BCS pulse by 57 %; while the reduction of Case 2 is 61% (Figure 16 and Table 12). In addition, the BCS opening duration was reduced by 14 days (from 110 days to 96 days) from Case 1 to Case 2. It is worth noting that, as seen in Figure 16, Case 2 would result in a brief shutdown of the operation of the BCS during the second pulse in 2019. The practicality of such a brief shutdown given that closing the BCS gates takes approximately one week should be examined. Further, the potential ecological benefits from the shutdown should be explored through detailed basin-side water quality modeling.

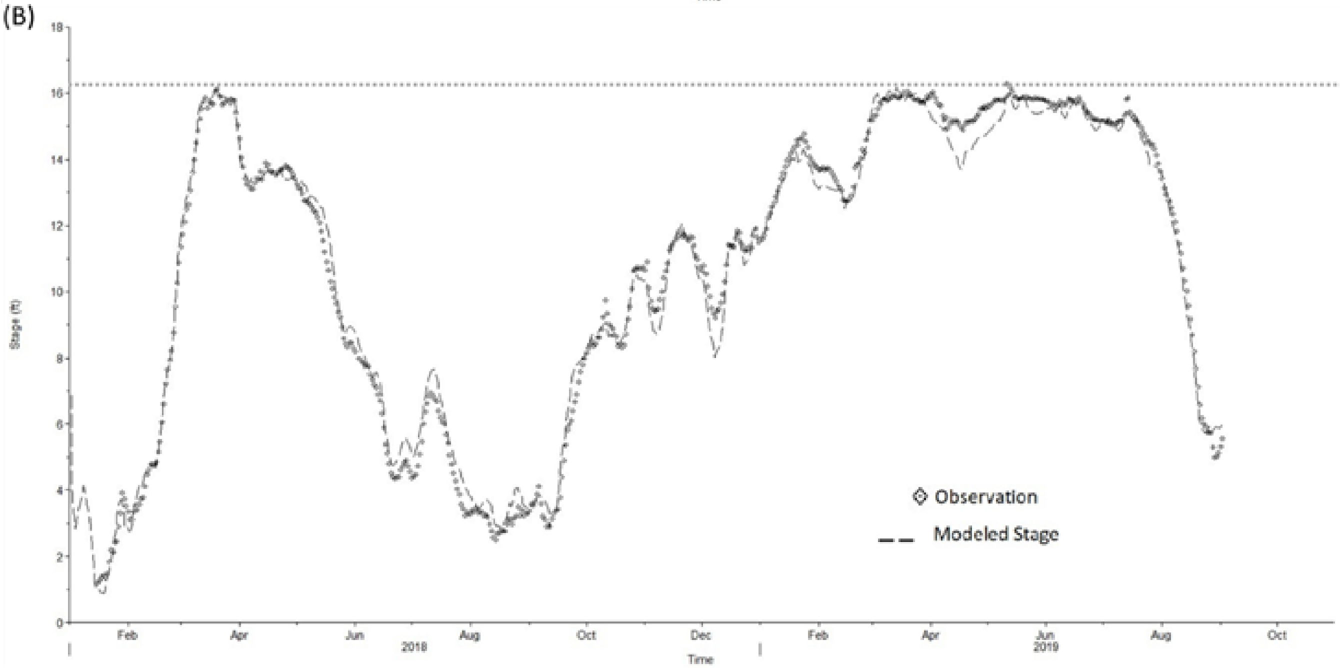
Finally, we also examined utilizing the Maurepas diversion jointly with Ama North and Union as a supplement flood control outlet system to the BCS. The operation plan for the Maurepas diversion is simple; a constant flow of 2,000 cfs. Given the small size of the Maurepas diversion, there was no discernable difference from the results of Case 1 or Case 2 in Table 12. In other words, given the small size of the Maurepas diversion, as well as its operation strategy, it could only provide very marginal reduction in the operation of the BCS during flood events.

(A)



20
15
10
5
0
Stage (ft)
Feb
Apr
Jun
2018
Aug
Oct
Dec
Feb
Apr
Jun
2019
Aug
Oct
Time
Observation
Modeled Stage

(B)



18
16
14
12
10
8
6
4
2
0
Stage (ft)
Feb
Apr
Jun
2018
Aug
Oct
Dec
Feb
Apr
Jun
2019
Aug
Oct
Time
Observation
Modeled Stage

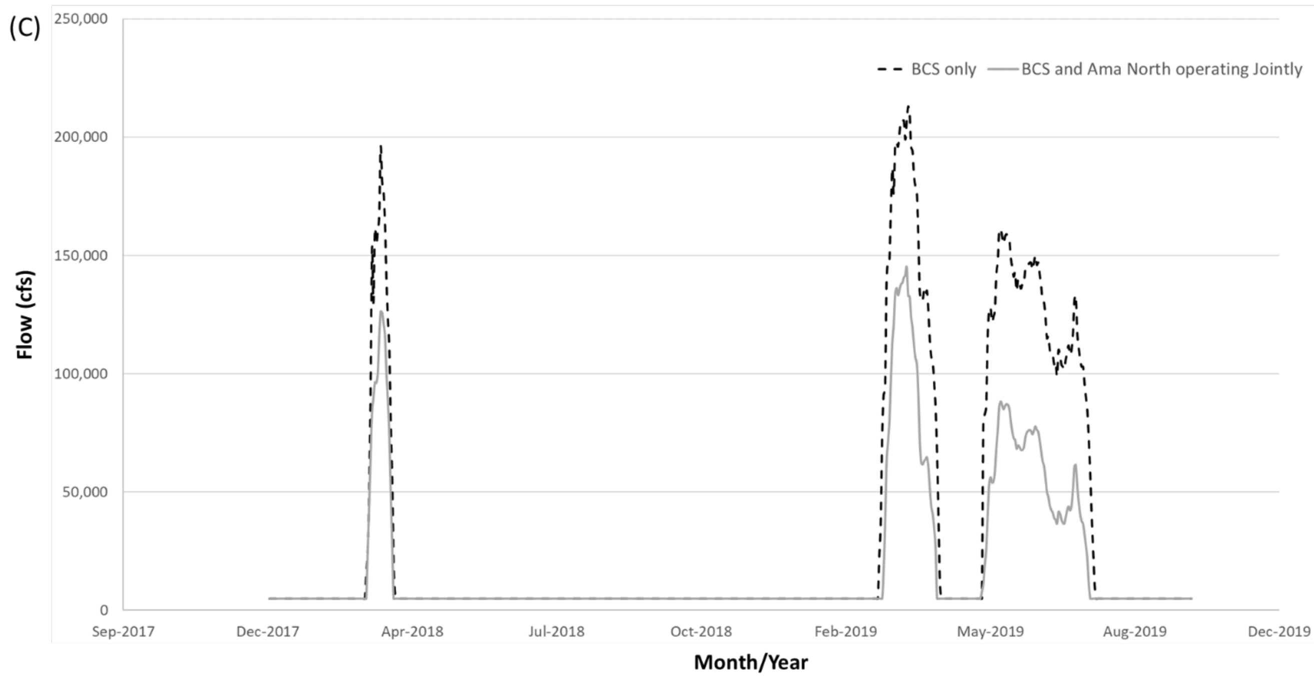


Figure 14. Results for the Ama North diversion. (A) Ama North operating while keeping BCS fully closed; (B) Ama North and the BCS operating jointly. (C) is the flow diverted through BCS while operating alone and augmented by Ama North. Notes: the BCS spillway leakage of 5,000 cfs is also considered; the threshold stage at Carrollton is displayed by a horizontal dotted line in parts A and B.

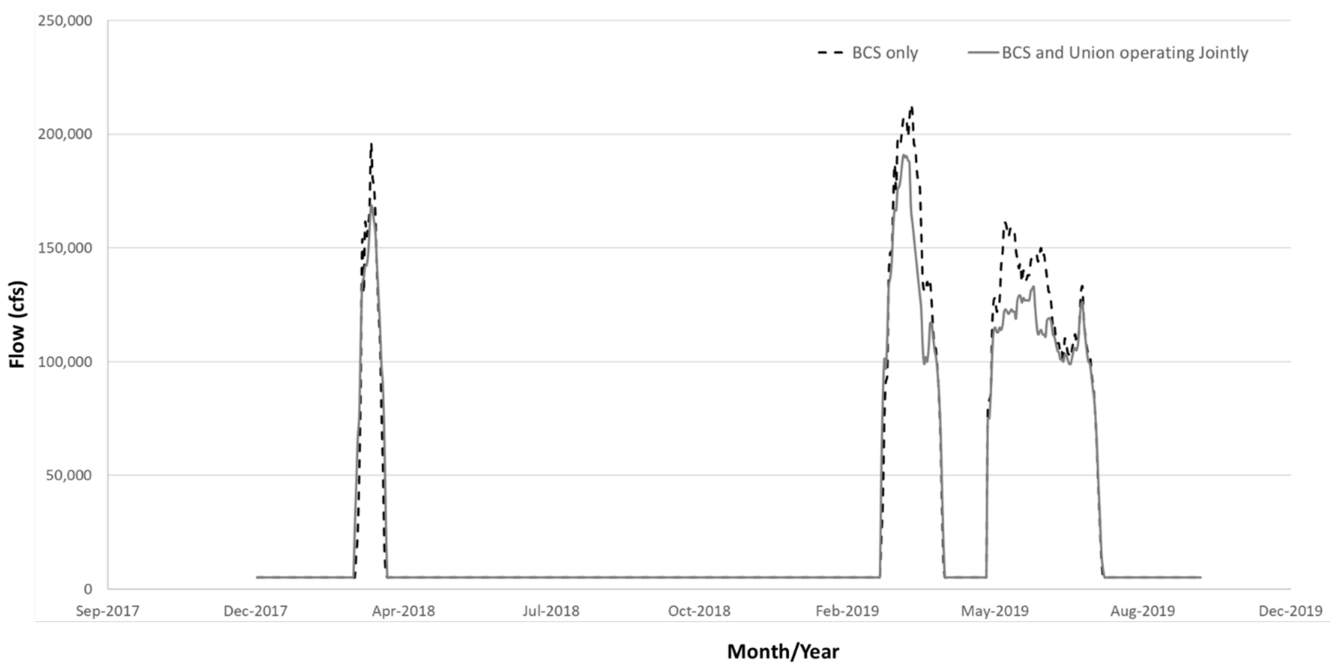


Figure 15. Results for the Union diversion augmenting the BCS as a flood control outlet.

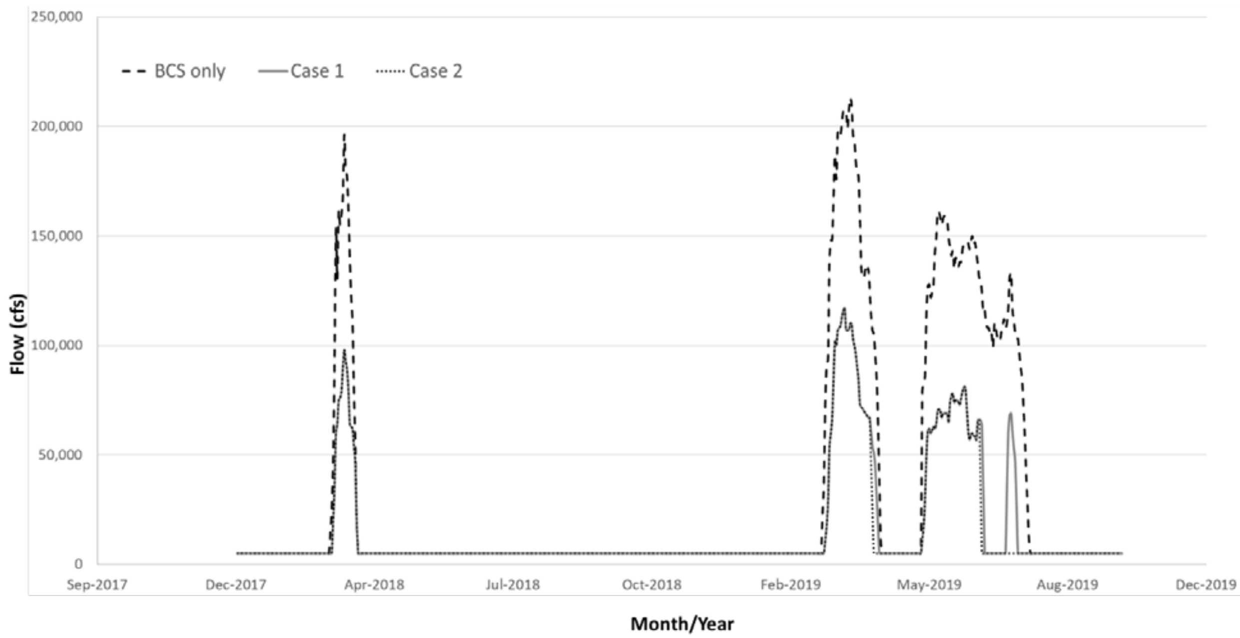


Figure 16. Results for the Union and Ama North diversions jointly augmenting the BCS as flood control outlets. Case 1: Union is operated when the river exceeds 1,250,000 cfs; and Case 2: when the river exceeds 1,000,000 cfs.

Table 12. Summary of potential reduction to the duration or magnitude of the BCS pulse through operating the upper river diversions.

	BCS (Existing Conditions)	**Ama North + BCS**	**Union + BCS**	**Ama North + Union + BCS (Case 1)**	**Ama North + Union + BCS (Case 2)**
Duration (days)	143	129	143	110	96
Diverted Water Volume ($10^6 \times ft^3$)	17.9	9.3	16.5	7.6	7.0
Water Volume Reduction Percentage	-	48%	8%	57%	61%

4. Conclusions

This study explores the effectiveness of utilizing upper river diversions as flood control outlets to supplement the BCS. For the analysis, we used riverside unsteady HEC-RAS model from Baton Rouge-Gulf. The model simulated the Ama North, Union, and River Reintroduction into Maurepas diversions as possible flood control outlets. Due to its small size, Maurepas, resulted in a marginal difference in the operation of the BCS. Ama North and Union (individually and jointly) resulted in noticeable reduction to the magnitude of the BCS pulse. They also reduced the duration of the pulse but not substantially. Specifically, when the Ama North and Union diversions are operated jointly, the reduction in the flow volume released through the BCS ranged between 57% and 61% depending on the operation plan of the Union diversion.

Environmental challenges resulting from the recent and frequent need to operate the BCS to protect against river floods illuminated the urgency of identifying alternatives to reduce the magnitude and duration of the freshwater pulses from the BCS. In a future phase of this study, basin-side analysis will be performed to capture and quantify the other potential benefits of utilizing the upper river diversions as flood control outlets. The goal of such analysis would be to examine water quality impacts, including the possible reduction in the likelihood of algae bloom formation, salinity changes and the potential environmental benefits to the receiving wetlands and estuarine systems such as nutrient uptake and building and sustaining wetlands.

Acknowledgment

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