Sensitivity Analysis of Relative Sea Level Rise on Gate Closure Frequency for Lake Pontchartrain and Vicinity (LPV)/ West Bank and Vicinity (WBV) 1% Hurricane and Storm Damage Risk Reduction System (HSDRRS)

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1. Executive Summary

This document presents the findings of a sensitivity analysis of gate closure frequency due to Relative Sea Level Rise (RSLR) for the Lake Pontchartrain and Vicinity and West Bank and Vicinity 1% Hurricane and Storm Damage Risk Reduction System (LPV/WBV 1% HSDRRS). Relative sea level rise includes the effects of eustatic sea level rise and land subsidence. Both of these hazards will have an increasing effect on LPV/WBV 1% HSDRRS over the 50-year project life.

The LPV/WBV 1% HSDRRS has a total of 501 openings that can be closed during tropical and riverine flood events. As sea level rises and land subsides, the frequency of gate closure will continue to increase to alleviate internal flooding. The purpose of this analysis is to estimate how the frequency of closure will change throughout the project life for three different RSLR scenarios. The analysis includes the effects of tides, high wind events, sea level rise, subsidence, seasonal water level variation, and storm surge events.

As sea level rises, some gates will be forced to close more often to reduce the risk of interior flooding. In some cases, the gate might be forced to remain closed indefinitely unless interior top of wall elevations are raised. In these scenarios, interior drainage modifications including pump stations might be necessary to remove rainfall and seepage inflows.

This analysis assumes each gate is closed when the water level (stage) reaches a given trigger height relative to the structure or its controlling gage, and opened when the water level recedes past the same trigger. In reality, each gate is operated according to a more complex set of opening and closing criteria. This analysis also assumes that stages will exceed their triggers more often in the future due to both the eustatic rise of the sea itself plus subsidence of the structure/gage (together known as RSLR). Water control manuals for some structures dictate that gates can close only when a tropical event is forecast or occurring. In this analysis, gates are assumed to close during any condition that produces a stage exceeding the trigger. As a result, this analysis may be conservative in the sense that future gate closures may not be as frequent as this analysis indicates.

The analysis provides estimates of gate closure frequency and percent of year closed for a range of hypothetical RSLR scenarios and gate closure triggers. In this analysis, the metrics are defined here:

Gate closure frequency = the number of closures per year. A closure is triggered when the exterior water elevation reaches the trigger elevation.

Percent of year closed = the total amount of time in hours the exterior water level is greater than the trigger elevation divided by the total number of hours in one year.

As expected, the results show that gates with lower trigger elevations will be affected earlier than gates with higher trigger elevations. The analysis provides estimates of the

year in which a gate will require chronic operation or permanent closure. These estimates are important, because they demonstrate the possible future need for permanent gate closure along with modified interior drainage with additional pumping capacity, or other modifications. For example, the Bayou Segnette complex on the WBV 1% HSDRRS requires a 2.0 ft NAVD88 closure elevation with a maximum interior water surface elevation of 2.4 ft NAVD88. For the low RSLR scenario, this gate is estimated to have chronic operation or closure by 2027. For gates facing similar conditions, some possible modifications to alleviate the interior flooding include:

- Permanent closure and installation of permanent pump station
- Raising internal line of risk reduction elevations to allow gates to remain open
- Buy out/retreat (areas that become subject to flooding during non-tropical events could be abandoned)
- Raising of flood-prone structures and infrastructure
- Modification of operating procedures to reduce the risk of internal flooding.

2. Introduction and Background

The LPV/WBV 1% HSDRRS has a total of 501 openings that can be operated during high surge and riverine flood events to reduce interior flooding risk. There are 10 navigable openings, 144 roadway openings, 45 railroad openings, 136 access openings, and 160 drainage openings. Figure 1 displays the location and gate type for these LPV/WBV 1% HSDRRS gates. Additionally, there are 6 openings currently under construction as part of the WBV-Mississippi River Levee (MRL) co-located levees which extend from River Mile 70-85.5 on the west bank (these openings are not shown in Figure 1. The gates under construction along the WBV-MRL will only close during storm or riverine flood events even with the effects of RSLR considered, as the gate sills are above the MR&T flowline elevation. A subset of major navigable openings and drainage structures is labeled in Figure 1. The major navigation openings/drainage structures are the subset of openings that the Emergency Operations Center (EOC) primarily focus on during storm events. Table 1 displays pertinent information for a sub-set of major openings including the closure triggers for storm conditions and the top of interior wall elevations. The information in Table 1 was developed by the district's EOC, since the EOC is most familiar with the intricacies and constraints of the gates concerning closure of the system during tropical and riverine flood events. In Table 1, green cells are components of the WBV, while purple cells are part of the LPV.

During extreme surge events, many openings must be closed in a complex and coordinated effort involving Federal and local authorities. Some gates must be closed during high tide or high wind events, because the interior top of wall elevation is relatively low. For example, flooding will begin when the interior water level reached 2.4 ft NAVD88 at the Bayou Segnette Complex. On the east bank, interior flooding will begin at 2.9 ft NAVD88 at the Caernarvon Sector gate. As sea level rises, these gates will be forced to close more often to reduce the risk of interior flooding. In some cases, the gate might be forced to remain closed indefinitely unless interior top of wall elevations are raised or other measures are taken to reduce the interior water levels. In

these scenarios, interior drainage modifications including pump stations might be necessary to remove rainfall and seepage inflows.

The purpose of this analysis is to determine the impacts to gate operations due to RSLR. The analysis predicts future condition water levels using a random sampling of historical water level data and then determines the number of closures per year and the percent of year closed for a range of different closure elevations.

Structure	Closing Elevation (ft. NAVD88)	Structure Elevation (ft. NAVD88)	Top of Interior Wall Elevation (ft. NAVD88)	Maximum Operating Elevation (ft. NAVD88)	Top of Interior Wall Elevation Note
Harvey Sector Gate	2.0 ft and rising	10.7 ft	N/A	2.3 ft	Limited storage capacity.
Bayou Segnette Complex	2.0 ft	16 ft	4 ft	2.4 ft	Wave action will splash at ~El+2.4.
Sellers Canal Complex	2.0 ft	16 ft	N/A	5 ft	Hwy 90 floods when prot side is El+5. No pumps.
West Closure Complex	No later than 4 ft - See WCM	16 ft	8.5 ft	4.0 ft / 5.8 ft	Max on Harvey is El+4.
Hero Canal Stoplogs	2.0 ft	14 ft	N/A	3.5 ft	Pump turns on at El+2, off at El 0.
Caernarvon Sector Gate	2.5 ft	26.0 ft	2.9 ft	5.0 ft – 6.5 ft	The point where water would begin to flow over Hwy 39 into the populated areas of St. Bernard
Bayou Bienvenue Sector Gate	2.0 ft	N/A	10.0 ft	5.0 ft – 6.5 ft	The local operator closes at approximately 2.0ft to reduce flooding at Paris road
Bayou Dupre Sector Gate	2.0 ft	31.0 ft	10.0 ft	5.0 ft – 6.5 ft	The elevation of the non-Federal back levee
Lake Borgne Surge Barrier	Between 1.5 and 4.0 ft	25.0 ft – 26.0 ft	11.0 ft	5.0 ft – 10.0 ft	The elevation of the lowest floodwall in the IHNC corridor
Seabrook Structure	Close after Surge Barrier when water equalizes	16.0 ft	11.0 ft	6.0 ft – 7.0 ft	The elevation of the lowest floodwall in the IHNC corridor
17th St Canal ICS	3.0 ft and rising	16.0 ft	8.7 ft	6.0 ft	West road ramp located just south of the interim control structure
Orleans Ave Canal ICS	5.0 ft and rising	16.0 ft	9.5 ft	8.0 ft	East levee section without wall at south end near OP#7 pump station
London Ave Canal ICS	2.5 ft and rising	16.0 ft	7.8 ft	5.0 ft	East floodwall at Robert E. Lee Blvd crossing
* All elevations are referenced to NAVD88 2004.65 datum					

Table 1 Subset of Navigable Gates Closure Triggers and Top of Interior Wall Elevations. N/A means not available.

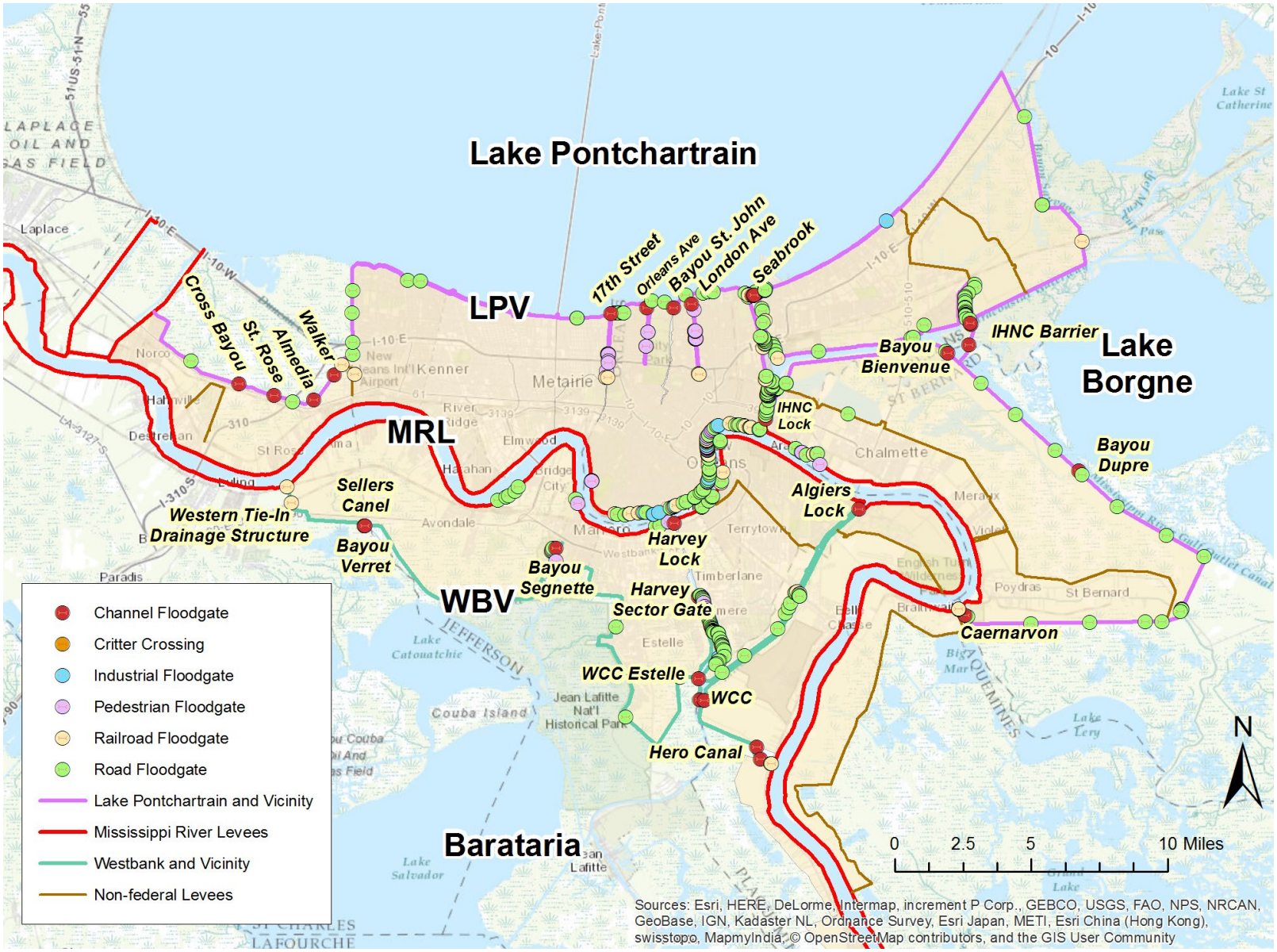


Figure 1 LPV/WBV 1% HSDRRS Flood Gates

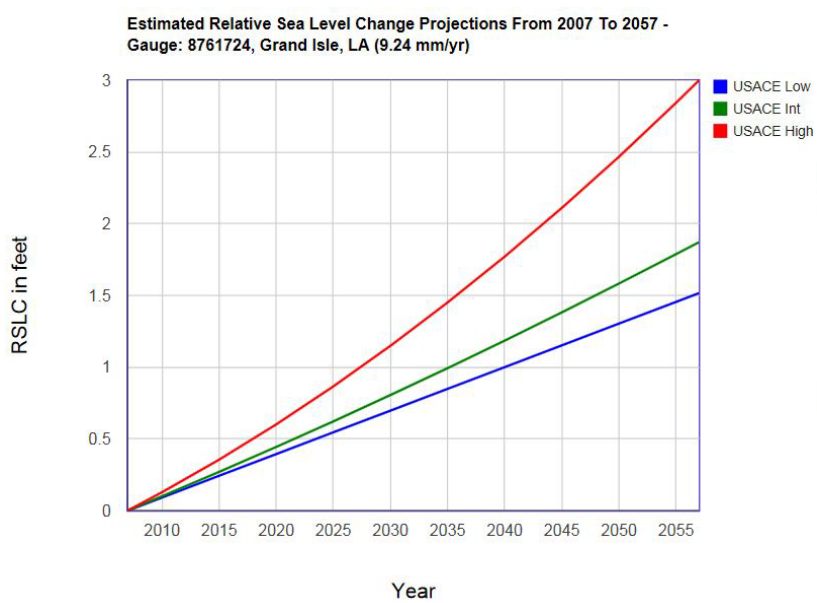
3. Methodology

3.1 ER 8162 and Relative Sea Level Rise Scenarios

Engineering Regulation (ER) 8162, *Incorporating Sea Level Change in Civil Works Programs*, dated December 31, 2013 is a policy document concerning incorporation of sea level change in civil works programs. The policy describes how projects must consider three possible RSLR projections including a low, intermediate and high RSLR. For this analysis, the Corps climate change website, which automatically calculates sea level change estimates based on the methodology outlined in ER 8162, was used to determine the three rates at the Grand Isle, LA gage.

http://corpsclimate.us/ccaceslcurves.cfm

Figure 2 displays the low, intermediate and high RSLR projections based historical water level gage records at Grand Isle, LA. The gage records indicate a long term RSLR rate of 9.24 mm/yr, which is one of the highest observed rates for the region. The project start year is 2007 and the project end year is 2057. The highest estimate of projected RSLR is 3.0ft NAVD88 in 2057. In this analysis, the Grand Isle RSLR projections were used as a representative curve for the entire region. Since Grand Isle has one of the higher RSLR projects, the decision to use the gage for the entire region is slightly conservative.



Estimated Relative Sea Level Change from 2007 To 2057
8761724, Grand Isle, LA
NOAA's Published Rate: 0.03031 feet/yr
All values are expressed in feet

Year	USACE Low	USACE Int	USACE High
2007	0.00	0.00	0.00
2010	0.09	0.10	0.13
2015	0.24	0.27	0.36
2020	0.39	0.44	0.60
2025	0.55	0.62	0.87
2030	0.70	0.81	1.15
2035	0.85	0.99	1.45
2040	1.00	1.19	1.77
2045	1.15	1.38	2.11
2050	1.30	1.58	2.47
2055	1.46	1.79	2.84
2057	1.52	1.87	3.00

Figure 2 Low, intermediate and high RSLR projections for 2007 to 2057 at Grand Isle, LA (9.24 mm/yr) based on data available at http://corpsclimate.us/ccaceslcurves.cfm

3.2 Water Level & Closure Analysis

Historical water level time-series are analyzed at three locations including Shell Beach, Grand Isle, and New Canal. The Shell Beach gage is in the open water of Lake Borgne.

The Grand Isle gage is located at the coast at the entrance to the Barataria Basin. The New Canal gage is located on the south shore of Lake Pontchartrain. These three gages were selected because each is representative of a distinct basin surrounding the HDSRRS. With RSLR and the loss of frictional resistance associated with wetlands, the connectivity between the Gulf of Mexico and the interior basins is expected to increase. Therefore, using the Grand Isle gage to represent the Barataria Basin in the future condition is a reasonable assumption, in the absence of more refined data. Figure 3 displays the location of the Shell Beach, New Canal, and Grande Isle gages.

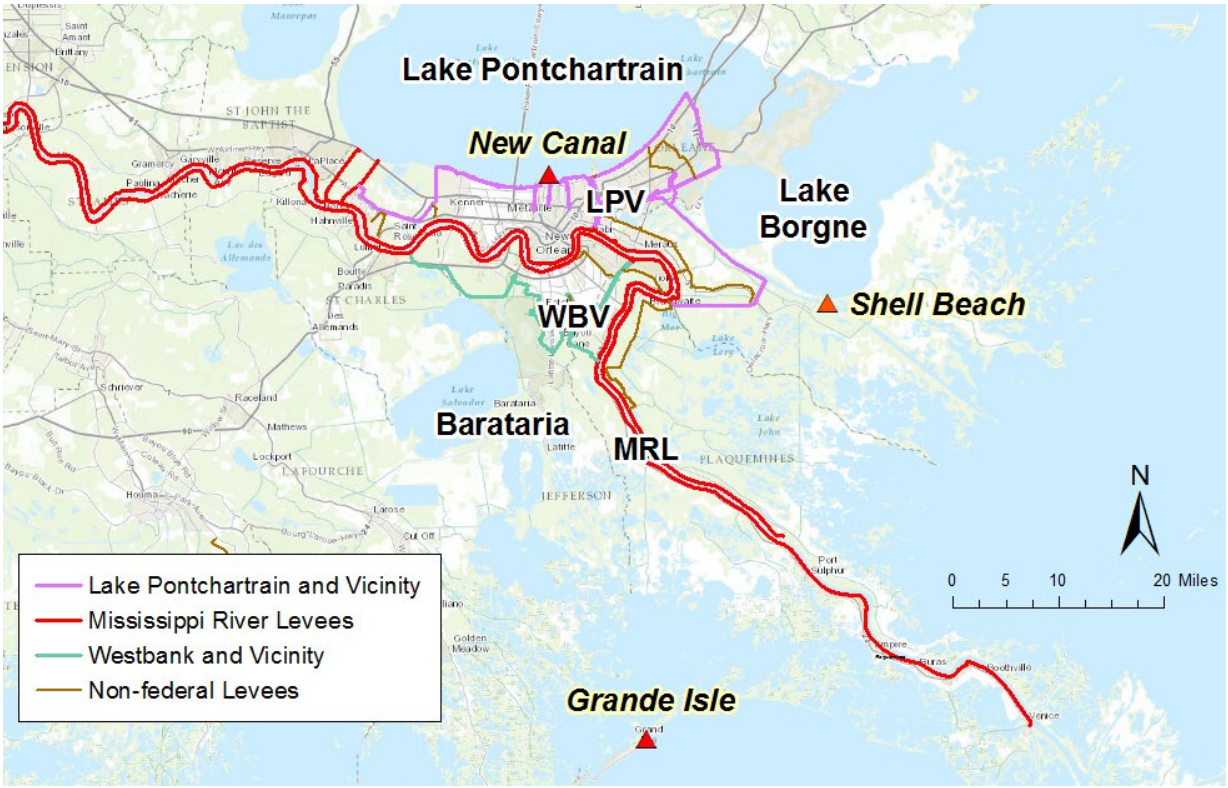


Figure 3 Location of Shell Beach, New Canal, and Grande Isle gages

Figure 4 displays the historical water levels at Shell Beach, Grand Isle and New Canal. All three time series include the highly active 2008 hurricane season which included Hurricanes Gustav and Ike, and the 2012 season, which included Hurricane Isaac.

At any given time, the water level elevation is a function of tides, wind, rainfall, and seasonal steric adjustments. Steric adjustments to water level result from seasonal differences in temperature and salinity. The variation in water level can be seen in Figure 4. In the recent past, water levels typically range from around -1.5 to 2.0 ft NAVD88, although some extreme tides and surge events can push water levels lower or higher. The time-series includes the surges produced by major storms as labeled in Figure 4.

To develop future condition time-series, the historical water levels were randomly sampled on a month by month basis and adjusted to include the effects of RSLR. A

Matlab script was developed to randomly sample and process the historical water level data. For example, the script begins with the month of January in 2007. The script first needs to populate hourly water level time-series from 1/1/2007 00:00 to 1/31/2007 23:00. Instead of using the actual data from January 2007, the program randomly samples another month of January, possibly from a different year, and then adjusts this sampled data based on the 2007 RSLR projection (the 2007 RSLR is zero, so no adjustment is made). The program loops through month to month and populates the needed water level values. As the program gets to the final block of data need (12/1/2057 00:00 to 12/31/2057 23:00) the script will randomly sample an entire block of December data from the observed datasets and adjust the data based on the 2057 RSLR projection (the 2057 high estimate of RSLR is 3.0 ft, so 3.0 ft will be added to the sampled data). To estimate future condition time-series, the RSLR amount is added linearly to the sampled water levels. The script does not make any adjustments to the observed data to baseline it back to 2007 conditions before projecting it to the future condition, since a very small amount of RSLR can be measured from 2005 to 2015.

Figure 5 displays the predicted hourly water levels from 2007 to 2057 at the Grand Isle gage for the high RSLR scenario. Each distinct color represents a different month of sampled data. Similar time-series were developed for the low and intermediate RSLR scenarios for all three gages employed for the analysis.

Once the future condition time-series were developed, a separate Matlab script processes the data to determine the number of closures per year and the percent of the year closed. The closure trigger level varies from 1.0 to 5.0 ft NAVD88, a range which is reflective of actual structures presented in Table 1.

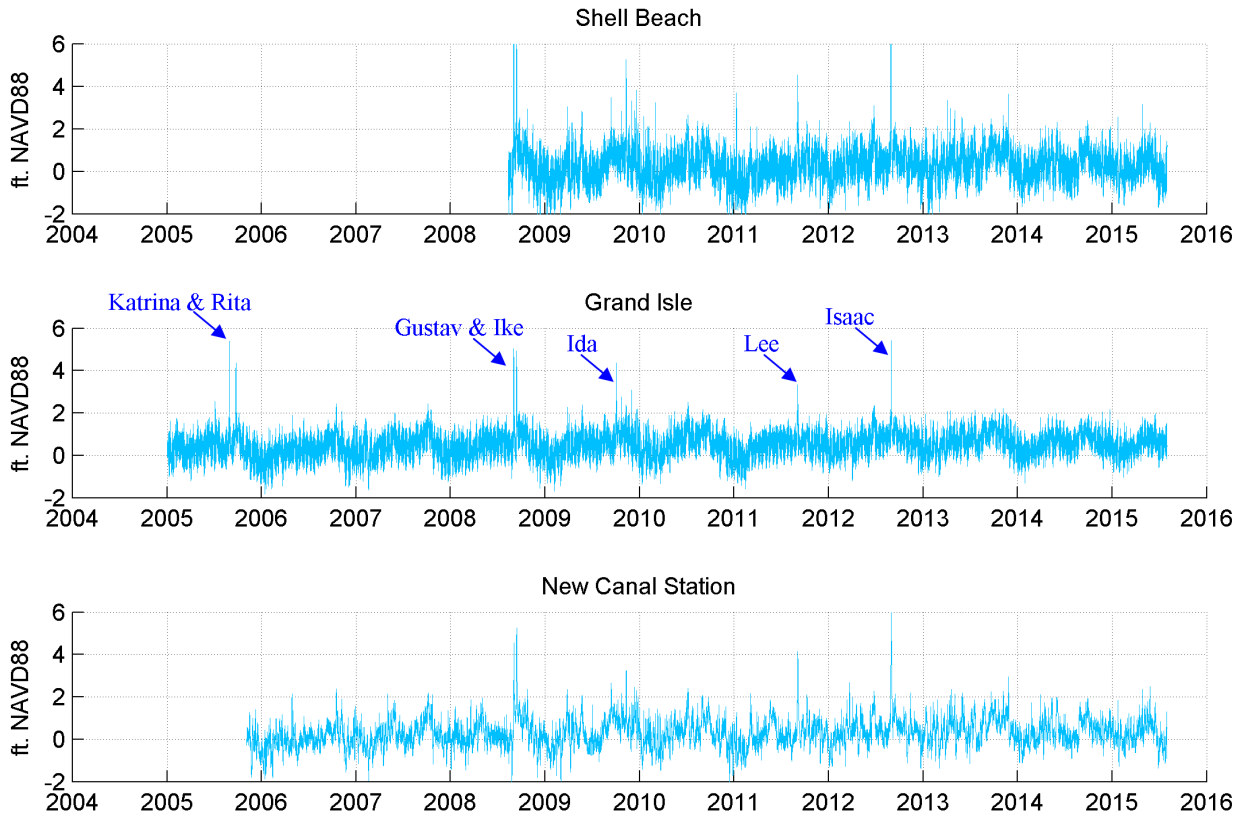


Figure 4 Historical observed water levels at Shell Beach, Grand Isle, and New Canal Station.

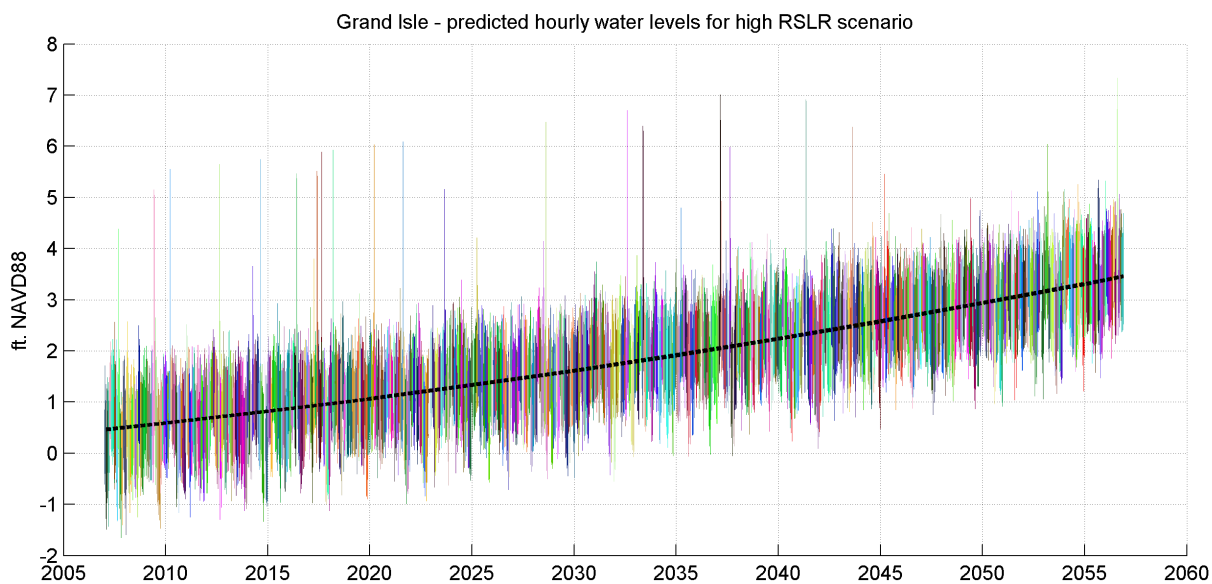


Figure 5 Predicted hourly water levels for the high RSLR scenario using random sampling and adjustment of historical water level data at Grand Isle, LA

3.3 Limitations and Assumptions

The predicted water levels assume the tidal amplitude at the three gages will not change in the future condition. In reality, the loss of wetlands and other changes in the hydrodynamics of the Gulf of Mexico might change the tidal amplitude. In an attempt to address this issue, gages were selected in open water, where the effects of the marshes are minimal. Additional tidal modeling of the Gulf for future conditions can provide better estimates of future scenario water levels. However, using exposed gages and linearly adding the RSLR amount to the sampled water levels gives a reasonable first estimate of a possible future condition, in the absence of more refined data.

The analysis provides future condition water level time-series at only three locations. Each location is assumed to represent a unique area of the LPV/WBV 1% HSDRRS. More gages could be added to the analysis to better estimate gate closure frequency to specific areas. However, the water levels at the three gages do an adequate job of representing each basin around HSDRRS since each gage is located in an exposed area, subject to the full tidal range of the Gulf. The gages were selected in open water since the analysis focuses on the future conditions (+50 years) when the effects of the marsh on tides will be diminished if land-loss and subsidence continue.

The analysis considers simplified gates with closure triggers based on water level only. In reality, the closure trigger for many gates is not based solely on water level. The closure is also based on wind speed, navigation interests, and other factors.

This analysis only considers a small subset of LPV/WBV 1% HSDRRS gates, with some gates more vulnerable than others to the effects of RSLR. Specifically 6 gates listed in Table 1 have closing elevations around 2 ft NGVD88. There is a possibility that more gates (out of approximately 500 total) will be impacted by the effects of RSLR. However, the results of this analysis can be applied to other gates, as long as the trigger elevation, which is usually lower than maximum allowable interior water level, can be determined.

The analysis uses RSLR trends at Grand Isle to represent RSLR for all of LPV/WBV 1% HSDRRS. In reality, each location experiences a different amount of RSLR. Although the RSLR experienced at Grand Isle is high relative to most locations, therefore making the results conservative.

Another limitation is the fact that only one future with a low, medium and high RSLR rate was considered. A single future time series was created for each gage and each RSLR scenario, which of course is highly uncertain. A more rigorous approach would be to look at multiple (up to hundreds or thousands) of plausible future water level time series. However the future condition considered was a reasonable average of several predicted future conditions or was a worst case scenario or add some language justifying why we used just one scenario. Trying to not get hammered with comments from agencies that review the CED Phase II when they ask why we didn't do more analysis/future scenarios. Max, do you remember the specific comment from NMFS on the CED Phase I that spurred this analysis and maybe we should insert that comment here.

4. Results

4.1 Closure Frequency and Percentage of Year Closed for Low, Intermediate and High RSLR

The analysis provides estimates of gate closure frequency and percent of year closed for a range of hypothetical RSLR scenarios and gate closure triggers. In this analysis, the metrics are defined below:

> ***Gate closure frequency*** = the number of closures per year. A closure is triggered when the exterior water elevation reaches the trigger elevation.
>
> ***Percent of year closed*** = the total amount of time in hours the exterior water level is greater than the trigger elevation divided by the total number of hours in one year.

The results presented in this section are estimates based on a single future condition time-series which is developed using predicted low, medium, and high RSLR and observed water level time-series. There is considerable uncertainty in the results provided. The analysis is only meant to provide a general idea of what can possibly occur in the future. (Please see Limitations and Assumptions section).

Figure 6 displays some results of the closure frequency analysis for the Lake Borgne region for a trigger elevation of 2.0 ft NAVD88. The results from this plot represent any gate within the Lake Borgne Basin, with a trigger elevation of 2.0 ft NAVD88. The Bayou Bienvenue gate would be an example of a gate that is currently operated with a 2.0ft trigger elevation. The top portion of Figure 6 shows the predicted water levels for the low, intermediate and high RSLR trends. The data from the high RSLR water is visually covering the data from the low and intermediate RSLR time series. The middle plot of Figure 6 contains the calculated number of closures per year considering the 2.0 ft NAVD88 trigger elevation for all three RSLR scenarios. The bottom portion of the plot shows the percent of year closed for all three RSLR scenarios. As expected, both the number of closures per year and percent of year closed increase as the project ages. For the high RSLR projection, the number of closures actually starts to decrease around the year 2040, because by this time, the mean exterior water level is higher than 2ft, and the structure remains closed for a large percentage of the year.

For the sake of consistency, the tables in the results section have been color coded to represent the metrics in the following way. Blue numbers represent less than 10 closures per year with the gate closed 0 to 1% of the entire year. This classification more or less represents gate operations in the existing 2007 to 2015 timeframe, where gates are typically closed for low-frequency surge or high tide events only. Green numbers represent between 10 and 20 closures per year with the gate closed between 1 and 2% of the year. This number of closures represents a condition where the gate is operated frequency due to high tide events and the occasional surge event. Green numbers more of less represent a tipping point of when the gate will be operated from frequently to chronically. Red numbers represent greater than 20 closures per year with

the gate closed between 2 and 100% of the year. In this scenario, the gate will be operated chronically to reduce the risk of interior flooding. For some specific locations, it might make more sense to seal the gate permanently and modify the internal drainage with additional pumping capacity.

Table 2 contains results for the low RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The table shows that any gate with a 1.0 ft NAVD88 trigger elevation (although there are no LPV/WBV 1% HSDRRS gates with this operating criteria) requires chronic operation or permanent closure. Although there were no LPV/WBV 1% HSDRRS gates with a criteria of 1.0 ft NAVD88 (the lowest trigger is 2.0 ft NAVD88), this was analyzed to show closure impacts at 1 ft intervals. For example, in the year 2007, a gate with a 1.0 ft NAVD88 trigger elevation in the Lake Borgne basin (if there were any with this trigger elevation), would be required to close 191 times per year, and remained closed for 18% of the year. Gates with a trigger elevation of 2.0 ft NAVD88 are operated frequently in 2007 to 2027, however by the year 2037, gates with this operating criteria require chronic operation or permanent closure. Gates with a 3.0 ft NAVD88 trigger elevation require infrequent to frequent operation for most of the project life, depending on location. In the latter half of the project life, gates with a 3.0 ft NAVD88 trigger elevation will require chronic operation or permanent closure. For the low RSLR estimate, gates with a 4.0 to 5.0 trigger elevation will only require infrequent operation to reduce interior flooding.

Table 3 contains results for the intermediate RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The results for the intermediate RSLR conditions are similar to the low RSLR results, although frequent and chronic operation are required a few years sooner than the low RSLR scenario. This is expected since the RSLR trends for the low and intermediate scenario are very similar (see Figure 2)

Table 4 contains results for the high RSLR scenario for Lake Borgne, Lake Pontchartrain and the Barataria Basin for years 2007 to 2057 for 1.0 ft to 5.0 ft NAVD88 trigger elevations. The results show that gates with a 3.0 ft NAVD88 trigger elevation will require chronic operation or permanent closure by year 2037. Gates with a 4.0 ft NAVD88 trigger elevation require chronic operation or permanent closure near year 2047. Gates with a 5.0 ft NAVD88 trigger elevation are infrequently operated at the end of the project life.

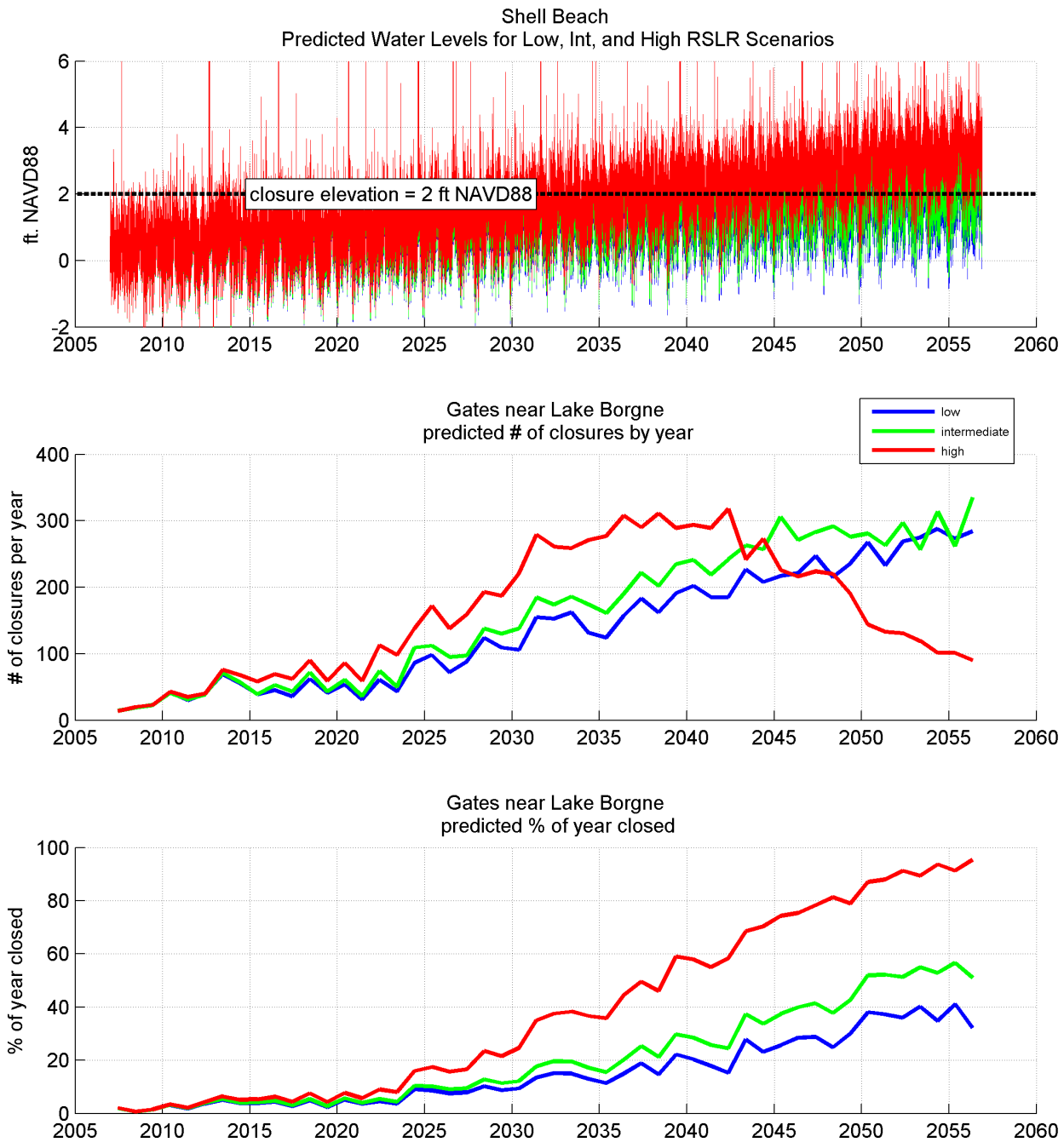


Figure 6 Predicted water levels and closure statistics at Shell Beach gage for a trigger elevation of 2.0 ft NAVD88 for low, intermediate and high RSLR

		Trigger Elevation (ft NAVD88)				
location	year	1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	191 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	267 (29%)	36 (3%)	6 (0%)	3 (0%)	0 (0%)
	2027	296 (43%)	88 (8%)	6 (1%)	1 (0%)	1 (0%)
	2037	265 (65%)	183 (19%)	30 (2%)	3 (0%)	0 (0%)
	2047	230 (76%)	247 (29%)	26 (2%)	2 (0%)	0 (0%)
	2057	210 (83%)	284 (32%)	46 (4%)	5 (1%)	2 (0%)
Barataria Basin	2007	172 (14%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	243 (29%)	15 (1%)	0 (0%)	0 (0%)	0 (0%)
	2027	300 (61%)	81 (5%)	1 (0%)	0 (0%)	0 (0%)
	2037	192 (81%)	212 (21%)	2 (0%)	0 (0%)	0 (0%)
	2047	120 (90%)	291 (37%)	20 (1%)	0 (0%)	0 (0%)
	2057	70 (95%)	272 (53%)	65 (4%)	0 (0%)	0 (0%)
Lake Pontchartrain	2007	91 (9%)	9 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	136 (22%)	11 (1%)	2 (0%)	0 (0%)	0 (0%)
	2027	210 (39%)	43 (3%)	0 (0%)	0 (0%)	0 (0%)
	2037	175 (59%)	55 (9%)	4 (1%)	2 (1%)	1 (0%)
	2047	146 (78%)	89 (12%)	7 (1%)	1 (0%)	0 (0%)
	2057	68 (92%)	160 (31%)	33 (2%)	2 (0%)	0 (0%)

Table 2 Summary of number of closure per year and % of year closed for low RSLR

		Trigger Elevation (ft NAVD88)				
location	year	1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	192 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	286 (31%)	43 (3%)	6 (0%)	3 (0%)	0 (0%)
	2027	293 (47%)	97 (9%)	8 (1%)	1 (0%)	1 (0%)
	2037	251 (72%)	222 (25%)	40 (3%)	3 (0%)	0 (0%)
	2047	175 (85%)	283 (41%)	62 (4%)	4 (0%)	1 (0%)
	2057	116 (93%)	335 (51%)	88 (9%)	6 (1%)	3 (0%)
Barataria Basin	2007	173 (14%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	248 (31%)	18 (1%)	0 (0%)	0 (0%)	0 (0%)
	2027	279 (67%)	101 (8%)	1 (0%)	0 (0%)	0 (0%)
	2037	147 (87%)	272 (31%)	6 (0%)	0 (0%)	0 (0%)
	2047	67 (95%)	279 (54%)	63 (4%)	0 (0%)	0 (0%)
	2057	25 (99%)	225 (73%)	147 (13%)	1 (0%)	0 (0%)
Lake Pontchartrain	2007	90 (9%)	9 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	149 (24%)	16 (1%)	1 (0%)	0 (0%)	0 (0%)
	2027	220 (46%)	42 (5%)	0 (0%)	0 (0%)	0 (0%)
	2037	174 (70%)	85 (13%)	11 (1%)	2 (1%)	3 (0%)
	2047	74 (91%)	156 (23%)	13 (2%)	2 (0%)	0 (0%)
	2057	17 (98%)	187 (56%)	62 (7%)	2 (0%)	1 (0%)

Table 3 Summary of number of closure per year and % of year closed for intermediate RSLR

		Trigger Elevation (ft NAVD88)				
location	year	1.0	2.0	3.0	4.0	5.0
Lake Borgne	2007	193 (18%)	14 (2%)	8 (1%)	2 (0%)	0 (0%)
	2017	307 (38%)	62 (4%)	6 (1%)	2 (0%)	1 (0%)
	2027	292 (61%)	159 (17%)	22 (2%)	5 (1%)	1 (0%)
	2037	138 (89%)	290 (50%)	102 (10%)	12 (1%)	1 (0%)
	2047	21 (99%)	224 (78%)	255 (32%)	36 (2%)	2 (0%)
	2057	2 (100%)	90 (95%)	328 (57%)	115 (11%)	8 (1%)
Barataria Basin	2007	175 (15%)	11 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	268 (38%)	28 (1%)	1 (0%)	0 (0%)	0 (0%)
	2027	200 (83%)	201 (19%)	2 (0%)	0 (0%)	0 (0%)
	2037	29 (99%)	266 (65%)	105 (7%)	0 (0%)	0 (0%)
	2047	10 (100%)	102 (91%)	280 (42%)	27 (2%)	0 (0%)
	2057	0 (100%)	19 (99%)	192 (80%)	186 (19%)	2 (0%)
Lake Pontchartrain	2007	91 (10%)	8 (1%)	0 (0%)	0 (0%)	0 (0%)
	2017	176 (31%)	22 (2%)	2 (0%)	0 (0%)	0 (0%)
	2027	209 (69%)	75 (10%)	2 (0%)	0 (0%)	0 (0%)
	2037	64 (90%)	173 (37%)	35 (4%)	1 (1%)	4 (0%)
	2047	1 (100%)	131 (81%)	107 (15%)	8 (1%)	1 (0%)
	2057	1 (100%)	7 (99%)	200 (64%)	76 (9%)	4 (0%)

Table 4 Summary of number of closures per year and % of year closed for high RSLR

5. Conclusions and Discussion

The analysis provides estimates of gate closure frequency and percentage of year closed for a range of hypothetical RSLR scenarios, five different trigger elevations, and three different regions. As expected, the results show that gates with lower trigger elevations will be affected earlier than gates with higher trigger elevations. The analysis provides estimates of the year in which a gate will require chronic operation or permanent closure. These estimates are important, because they demonstrate the possible future need for permanent gate closure along with modified interior drainage with additional pumping capacity, or other modifications. For example, the Bayou Segnette complex on the WBV 1% HSDRRS requires a 2.0 ft NAVD88 closure elevation with a maximum interior water surface elevation of 2.4 ft NAVD88. For the low RSLR scenario, this gate is estimated to have chronic operation or closure by 2027. For gates facing similar conditions, some possible modifications to alleviate the interior flooding include:

- Permanent closure and installation of permanent pump station

- Raising internal line of risk reduction elevations to allow gates to remain open
- Buy out/retreat (areas that become subject to flooding during non-tropical events could be abandoned)
- Raising of flood-prone structures and infrastructure
- Modification of operating procedures to reduce the risk of internal flooding.

This analysis assumes each gate is closed when the water level (stage) reaches a given trigger height relative to the structure or its controlling gage, and opened when the water level recedes past the same trigger. In reality, each gate is operated according to a more complex set of opening and closing criteria. This analysis also assumes that stages will exceed their triggers more often in the future due to both the eustatic rise of the sea itself plus subsidence of the structure/gage (together known as RSLR). Water control manuals for some structures dictate that gates can close only when a tropical event is forecast or occurring. In this analysis, gates are assumed to close during any condition that produces a stage exceeding the trigger. As a result, this analysis may be conservative in the sense that future gate closures may not be as frequent as this analysis indicates.