The Influence of Lower Plaquemines Parish Mississippi River Levees on Storm Surge in Southern Louisiana

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1. Introduction / objective

The deltaic plain of Southeastern Louisiana is a magnificent area; wetlands, channels, lakes, islands and the mighty Mississippi river curving its way towards the Gulf of Mexico. For decennia, the river spilt its water and cohesive sediment on the coastal shelf of Louisiana, developing the “Bird’s foot delta”. Nowadays, great human made levees force the water to flow quickly to the Gulf of Mexico and protect the surrounding land from flooding

During Hurricane Katrina surge that was forced by northeasterly winds was stopped by the levee system along the delta; the Lower Plaquemines Parish Mississippi levee system. This blockage caused that surge levels reached up to maximum levels of 19 ft. at the eastside of the delta. Also huge volumes of water propagated upriver towards New Orleans, causing water levels up to 13 ft. in the Mississippi River at New Orleans.

The objective of this paper is to study the influence of the Lower Plaquemines Parish Mississippi River levee system on storm surge levels during major hurricane events. A clear understanding of the process that leads to the high build-up of storm surge along the Mississippi delta during major hurricanes is necessary to understand the impact of human interference in the delta. This will provide great insight about the future course of protecting southeastern Louisiana and especially New Orleans

The levees along the Mississippi delta also influence other subjects and processes, like the declination of the wetlands, navigation, flood protection, development of the delta, etc. However, these subjects are behind the scope of this study, although these are important processes as well.

The length of the Mississippi River, measured along the thalweg, is about 80 miles from Jesuit Bend, where the rivers bends into southeastern direction, till the end of the birds-foot. An important difference exists between the west- and eastside of the river. At the eastside the levees align the river over a length of 24 miles, while on the westside the levees align the river over 57 miles. On the eastside the levees end at Pointe a la Hache, while the levees on the westside follow the river all the way to Venice.

2. The Lower Plaquemines Levee system

Human interventions, especially during the last 100 years, have changed the Mississippi River from a freely meandering alluvial river into a highly trained and confined meandering channel. Due to all the control measurements, less sediment became available to the river, decreasing the volume of suspended matter. The levees along the delta prevent the still available sediments from depositing on the deltaic plains. The levees along the Mississippi River at the lower end of the delta funnel the suspended sediments all the way up to the edge of the continental shelf, where it is dumped in the deeper oceanic currents in the Gulf.

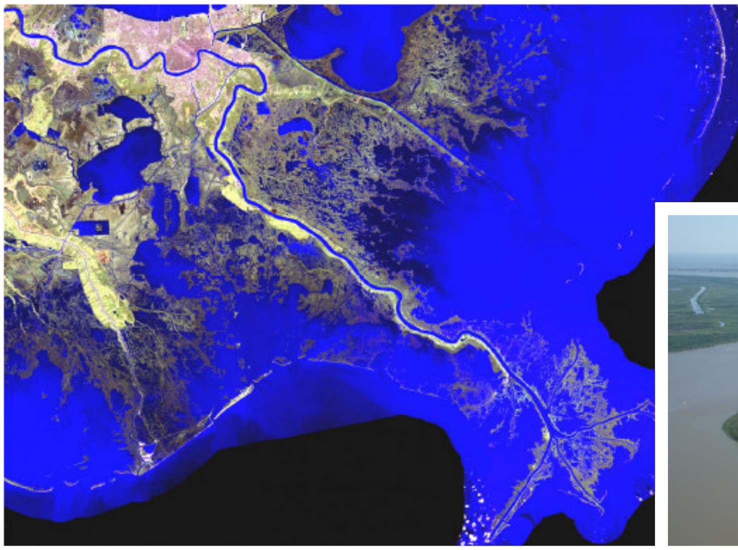

Figure 1: Satelite image of the deltaic plain of the Mississippi River

Figure 2: New constructed levees along the Mississippi River around Venice

The height of the Lower Plaquemines Parish Mississippi River levee system varies from 16 to 18 ft. The natural floodplains along the Mississippi River vary between 3.5 to 8 ft.
The delta is aligned with a stretch of wetlands. Following the river to the south, the stretch of wetlands becomes smaller, only at the birds-foot the area of wetlands becomes wider again.

3.Research Method

3.1 Computational model
The Advanced CIRCulation shallow water model (ADCIRC) has been selected to model the propagation of storm surge and to evaluate the influence of the Lower Plaquemines Parish levee system. ADCIRC is the two-dimensional depth-integrated implemenation of the ADCIRC coastal ocean model. ADCIRC utilizes the finite element method in space allowing the use of highly flexible, unstructured grids. The model has been and continues to be the standard coastal model utilized by USACE

3.2 Compuation grid
The computational grid used for this study is designated as the SL15 Grid. The SL15 unstructured computational grid contains 2,137,978 nodes and 4,184,778 elements. Grid resolution varies from approximately 12 miles in the deep Atlantic Ocean to about 100 feet in Louisiana and Mississippi.

Three different computational grids have been configured in order to simulate the impact of the levees,:

- The first grid, the base case, is defined to replicate the prevailing conditions after Hurricane Katrina.
- The second grid introduces spillways across three areas of the current levee system. The spillways should provide a hydrodynamic connection between the west- and eastside of the delta. Within the spillways, the natural floodplains are lowered, in order to improve the conveyance. The most northern spillway is located between Jesuit Bend and Naomi and has a width of about 4 miles. The second, central, spillway is located around Port Sulphur and has a width of about 4.5 miles. The most southern spillway, the third, is located around Triumph and is only 1 mile wide. The total length of the spillways is 9.5 miles, which is about 12% of the total length of the Mississippi delta.
- In the third grid the total Lower Plaquemines levee system is removed and serves as an upper limit case. The configuration represents a more natural system, where surge is stopped partly by the natural riverbanks, but were high surge levels are able to propagate across the river. The total length of the erased levee system is about 57 miles. This is about 70% of the total length of the Mississippi delta.

location of the changed geometry for each

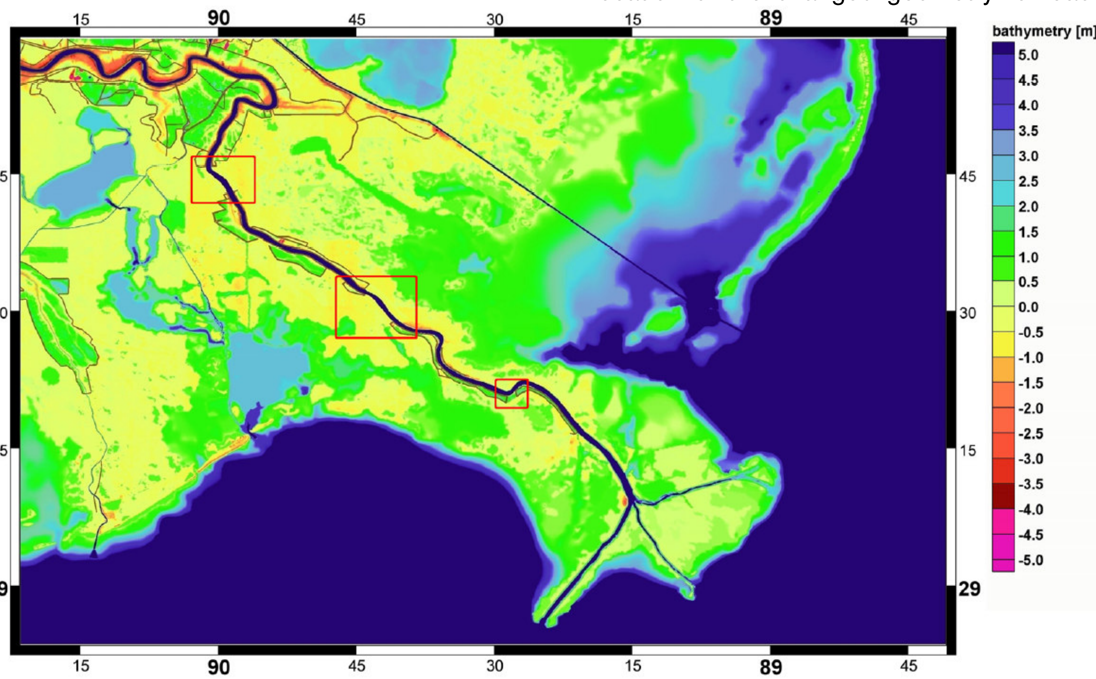

Figure 3: Topography and bathymetry 'Plaquemines Spillways'. The dark brown lines represent the raised features like levees, railroads and highways. The red boxes show the location of the three spillways. Within the spillways, the natural floodplains have been lowered

3.3 1/100 year flood levels and hypothetical storms

A suite of 152 specific hypothetical storms has been generated for the JPM-OS method. With this suite of storms stage-frequency curves are calculated and the surge levels with a 1/100 year return period determined. The JPM-OS software computes frequency of occurrence surges at specific geographic points or stations. For each of these points a surge response (value) for all computed storms is required. This response value is the maximum or peak value of the surge recorded for the entire simulation. The JPM-OS code produces a stage vs. frequency of occurrence table for all points in the input file.

In this study, the comparison of the three configurations is based on a suite of 18 storms, which is a subset of the 152 storms. The subset was created by selecting storms whose tracks and characteristics spanned the range of parameter space defined in the JPM-OS methodology. Additionally, the subset was based on the return level and the closure alternative.

Table 1 contains the characteristics of the 18 storms, concerning sustained winds, the central pressure, the scale radius of the pressure profile, the forward velocity and the track of the storm. The lower the central

Storm	**Wind**	**Pressure**	**Radius**	**Track**
	[knots]	*[mbar]*	*[miles]*	*[-]*
14	52.4	930	20.4	1
15	51.7	930	29.7	1
17	58.3	900	17.1	1
18	57.8	900	25.1	1
23	52.3	930	20.4	2
24	51.7	930	29.7	2
26	58.1	900	17.1	2
27	57.7	900	25.1	2
32	52.6	930	20.4	3
35	58.1	900	17.1	3
52	58.2	900	14.4	4
53	58	900	21.2	4
56	58	900	14.4	5
57	57.5	900	21.2	5
69	58.3	900	21.2	6
73	58.2	900	21.2	7
77	58.2	900	21.2	8
500	54.8	902	18 - 22	9

Table 1: Storm characteristics for the suite of 18 selcted storms

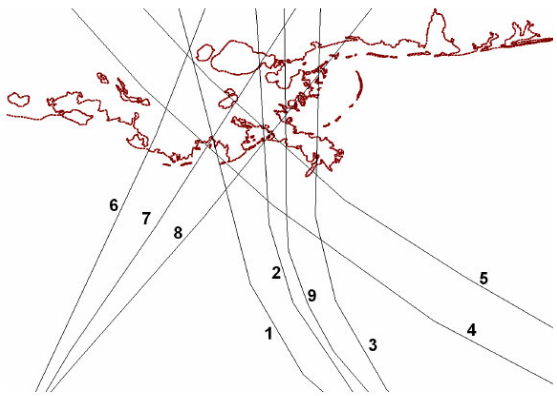

Figure 4: Schematisation of the storm tracks of the storm suite

pressure and the higher the sustained winds and diameter, the stronger the storm. Storm 18, 27 and 500 are the strongest storms under consideration. Storm 500 is not hypothetical but represents Hurricane Katrina.

4. Results reference case

4.1 Maximum surge levels

Figure 6 shows the compilation of the maximum surge levels occurring during the 18 considered storms. The figure shows the 'peak of peaks' during each storm together. The figure gives an idea about the areas that are most vulnerable for high surge levels, given the different storm tracks under consideration. The highest surge levels are found along the delta, at the Mississippi coastline and along the coastline at Houma and Morgan City.

In this paper we will focus on the surge levels along the Mississippi River. Figure 5 clearly points out that along the whole deltaic plain, surge builts up due to the hydraulic resistance of the wetlands and the blockage of the Lower Plaquemines Levee system.

4.2 surge propagation

If the storm track runs westerly from New Orleans and the delta, the highest surge levels are found around the levees of St. Bernard West, Plaquemines and Belle Chasse. Southeasterly winds push the water from the open Gulf into Breton Sound. The propagation of incoming water is slowed down by the wetlands, and stopped by the levees at St. Bernard and Plaquemines.

Track 2 runs northwards towards New Orleans East and crosses the Mississippi almost perpendicular. The surge building up on the eastside of the river is pushed on the deltaic plain by mainly easterly winds during the early stage of the storm. The highest surge levels on the deltaic plain are found around Pointe a la Hache. More to the south the surge levels get less high because the surge is drained by the Mississippi River back to the Gulf. During storm 27, when the storm is close to landfall, surge overspills the levees on the eastside of the Mississippi River. Large volumes of water get drained upriver towards New Orleans.

Track 5 runs parallel to the delta. Easterly to southeasterly winds push water against the levees of the Mississippi River. The highest surge levels occur between Pointe a la Hache and Venice, where surge is blocked by the levees on the Westside of the river.

Track 7 and 8 run form the southwest towards the northeast, crossing the delta perpendicular.

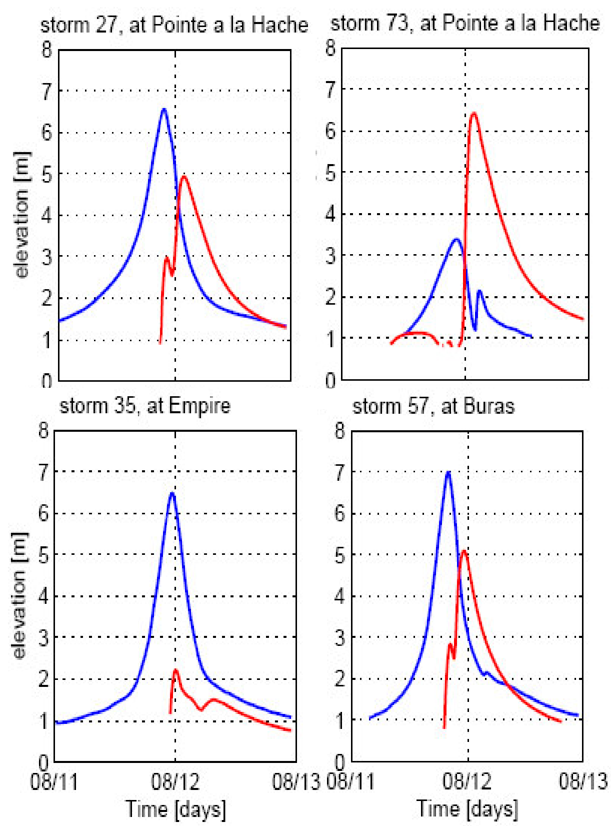

Figure 5: Difference in surge levels on the west- (red) and eastside (blue) of the Lower Palquemines levee system

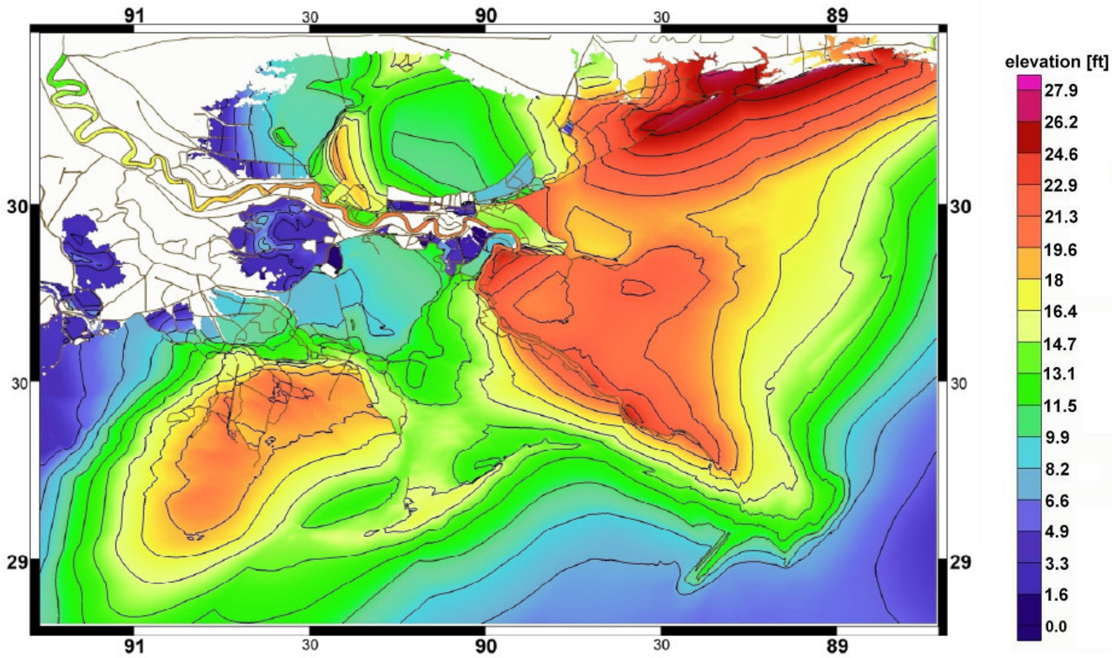

Figure 6: Maximum surge levels (ft) for the 2007 base case for a suite of 18 storms

Due to the southwesterly winds, water from the Gulf is pushed against the Mississippi River levees on the westside.

Figure 5 shows the difference in surge levels at the west- and eastside of the Lower Plaquemines levee system. At a certain moment during storm 27 the difference is up to 10 ft at Pointe a la Hache. The plots clearly indicate that the levee system separates the west- and eastside. The two sides are not hydraulic connected, which causes the huge differences between the west- and eastside. If a storm moves over the delta, wind directions can change quickly, causing, for example, first surge built up on the eastside and later on the westside.

4.3 Mississippi River

During a major hurricane, surge levels that built up on the deltaic plain tend to drain in the Mississippi River and propagate upriver. Figure 7 shows some hydrographs at the Mississippi River at downtown New Orleans for six selected storms. This surge propagation in the Mississippi River is caused by two processes:

- Overtopping of the levees between English Turn and Wills Point. During storm 18, 27, 53 and 57, the levees did overtop at this location, causing large volumes of water propagating upriver.
- At Pointe a la Hache, the place where the eastside levee ends, surge propagates into the river. Due to the difference in length between the levees on the west- and eastside of the river, surge gets captured and is funnelled by the levees in upstream direction. The drainage capacity of the Mississippi River is very large, allowing the surge to propagate upriver towards New Orleans.

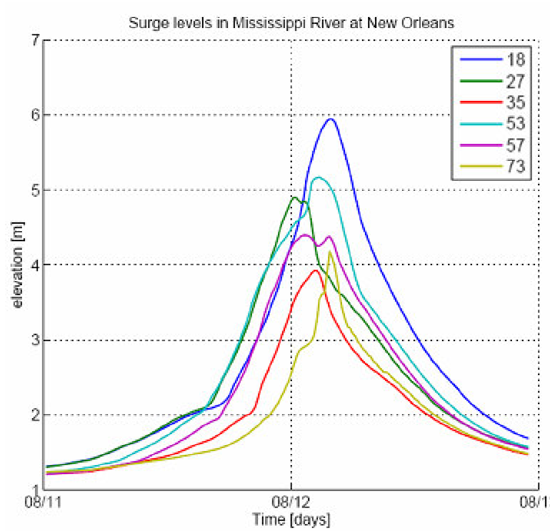

Figure 7: Surge levels at the Mississippi River at downtown New orleans during 6 selected storms

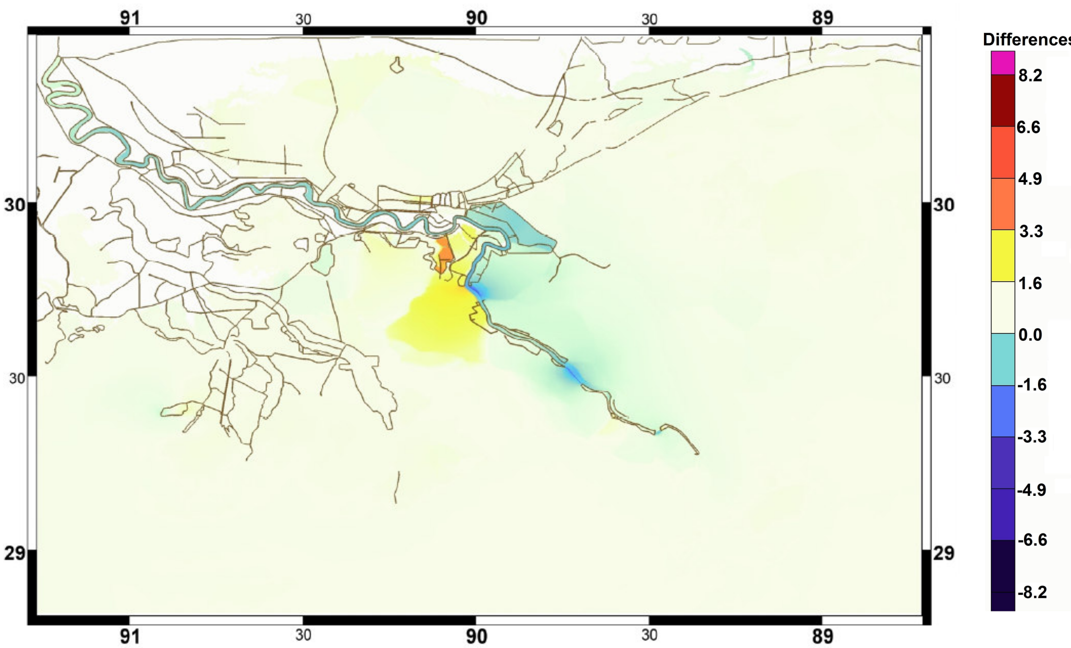

Figure 8: Difference (ft) between the maximum surge levels in the case with spillways and the base case for the 18 selected storms.

5. Results case with spillways

The purpose of the spillways is to provide a hydrodynamic connection between the west- and eastside of the delta. This should cause the surge levels on the upwind side of the delta to reduce. The spillways should be able to reduce the large difference in surge levels between the west- and eastside as shown by figure 5. The actual reduction caused by the spillways will depend on the hydraulic capacity of the spillways.

One of the main research questions of this paper is to assess the influence of three spillways on the maximum surge levels, the 1/100 year flood levels and the propagation of surge.

5.1 Maximum surge levels

Figure 8 shows the difference between the envelope of maximum surge levels in the base case and the case with spillways. The differences between the maximum surges vary between reductions of 3 ft to increases of 1.5 to 3 ft. The differences, due to the spillways, only occur along the delta, which points out that the spillways don't impact the surge levels further away. As one could expect, the largest differences are found around the spillways. At the most southern spillway (the 3^{th}), the decrease in maximum surge is in the order of 0.6 ft. At the second spillway this is order 1.5 ft. At the eastside of the most northern spillway (the 1^{st}) the decrease of the maximum surge levels is the largest, order 3 ft. just at the levees and order 0.8 ft at a distance of 0.5 mile from the levees.

On the westside of the most northern spillway, across Barataria, the maximum surge levels increase. The base case simulations already pointed out that the area enclosed by the levees of St. Bernard and Plaquemines is very vulnerable for high surge levels. The construction of a spillway at Jesuit Bend is able to drain part of these surge volumes to the westside into the area of Barataria and Turtle Bay.

5.2 Surge propagation

About the influence of the spillways on surge propagation in the area along the delta can be concluded that:

- The spillways don't influence the shape of the surge wave at the area around St. Bernard State Park and Tigers Ridge Lake. The increase of surge levels is and remains very steep, because the surge is driven into a corner at these locations. The spillways reduce the maximum surge level by an average of 0.5 – 1.0 ft. at this area.

- At the northern spillway, at Jesuit Bend, the shape of the surge propagation is affected. The surge levels on the eastside are reduced by 1.6 ft on average. Only during storm 32 and 35, the surge on the eastside increases due to the fact that surge propagates upriver and spills out again through the 1st spillway. At the westside of the spillway, the surge levels increase by 2.3 ft on average. Surge propagates trough the spillway to Barataria, decreasing the steep increase in surge on the eastside. A hydraulic connection is established.
- At Pointe a la Hache, the surge levels on the eastside reduce by 1 ft on average. The spillway is not very effective at this point, due to the fact that surge already propageted into the river at this point. The hydraulic capacity of the river is so high, that a spillway doesn't reduce the surge levels extra. However, on the westside the spillway has a larger impact. For storms that produce significant surge levels on the westside, like storm 73, 27 and 18, the surge levels decrease due to the spillway. Water is able to spill across the river towards the eastside of the delta.
- At Empire, the surge levels are not significantly affected by the spillways. The average reduction in maximum surge levels is about 0.5 ft at the eastside and 0.2 ft at the westside. Empire is probably located to far away from the second spillway and the third spillway is probably too small to make a significant impact.
- At Venice, the spillways doesn't affect the average maximum surge levels. Due to the fact that the levee system ends at Venice, a hydraulic connection between the east- and westside was already established.
- In the Mississippi River the surge levels decrease with an average of 50 cm at a location near downtown New Orleans. This difference is caused by the impact of the first spillway. Surge propagating upriver from Pointe a la Hache spills out again through the first spillway. The first spillway creates an opening from which the funnelled surge can spill out over the natural floodplains to the east- or westside of the delta.

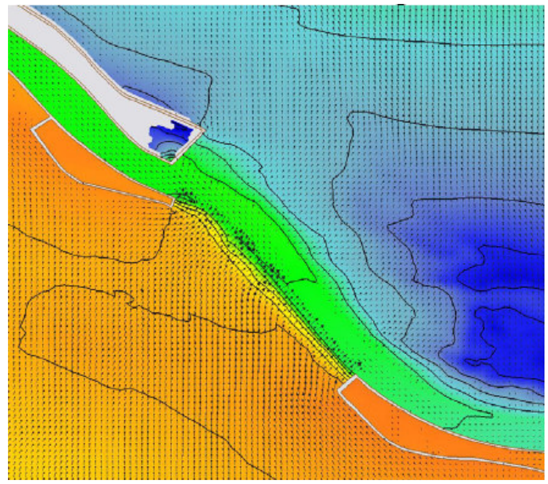

Figure 9: Surge spilling through the 2nd spillway from the west- to the eastside during storm 73.

Another important thing that was indicated by the simulations is the huge hydraulic capacity of the Mississippi River. Figure 9 shows surge propagating through the 2nd spillway from the west- to the eastside. Note the high gradients at the moment water spills over the floodplains into the river. Due to the large depth, the river is capable to drain the inflowing surge. This causes high gradients in the water level at the location where the water flows through the spillway. Part of the water that spills through the 2nd spillway is drained upriver, the other part flows to the other side of the delta.

5.3 1/100 year flood levels

Table 2 shows the flood levels with a return period of 100 years for the base case and the case with spillways. The spillways will reduce the 1/100 levels with about 1.2 to 1.6 ft in the northeastern part of the delta. At Pointe a la Hache East, at the 2nd spillway, the reduction is about 2.3 ft. But between the 1st and 2nd spillway at Nero, the reduction is only 0.4 ft. More to the south around Venice and Empire, the reduction is 0.7 ft. On the westside of the delta, the flood levels increase, with 2.3 ft at Jesuit Bend in the north, 1.4 at Pointe a la Hache and 0.1 ft. at Empire.

There are no flood levels determined for the levees along the Mississippi River at New Orleans, but based on a regression analysis the average maximum surge level will decrease with about 1.6 ft.

1/100 flood levels			
	Base Case	Case with spillways	Differences spillways – Base case
	[ft]	[ft]	[ft]
St. Bernard State Park	18.1	16.5	**-1.6**
Tigers Ridge Lake	17.8	16.4	**-1.4**
Jesuit Bend, East	17.1	15.9	**-1.2**
Jesuit Bend ,West	7.9	10.2	**2.3**
Nero	16.7	16.3	**-0.4**
Ironton	11.1	11.4	**0.3**
Pointe a la Hache, East	16.4	14.1	**-2.3**
Pointe a la Hache, West	11.4	12.8	**1.4**
Empire, East	16.2	15.5	**-0.7**
Empire, West	9.4	9.5	**0.1**
Barataria	6.0	6.3	**0.3**
Mississippi River at New Orleans, average difference in surge level			**-1.6**

Table 2: 1/100 year flood levels for the base case and case with spillways.

6. Results case without levees

The configuration without having levees along Lower Plaquemines Parish provides an upper limit in creating a hydrodynamic connection between the west- and eastside of the delta and represents a more natural system as well.

The underlying research question is to assess the influence of a more natural delta without any levees on the maximum surge levels, the 1/100 year flood levels and the propagation of surge.

6.1 Maximum surge levels

Figure 10 shows the difference between the envelope of maximum surge levels in the base case and the case without a levee system along the delta.

The differences between the maximum surges vary between reductions of 1.5 to 6.5 ft and increases in the order of 1 ft. For this case the differences are located in a much wider area around the delta. Not only the levels directly at the levees are affected, but also the levels further away from the levees. Note also the high reduction in the Mississippi River.

Although, the area of influence is more spread out then in the case with the spillways, still the area of impact occurs mainly along the delta. This points out that erasing the levees along the delta doesn't impact surge levels further away significantly. The differences show a slight increase of water levels in the area of Barataria and Turtle Bay, but this increase is smaller than the increase occurring in the case with the spillways.

6.2 surge propagation

Due to the removal of the levee system, the surge can propagate from one side of the delta to the other side. Due to the resistance it faces, the surge levels still built up along the delta. The natural floodplains, with a height of 1 to 2 meter, and the surrounding wetlands slow down the propagating surge and cause the surge levels to increase. However, the levees with a height of about 15 ft. are gone, which cause that the maximum surge levels drop with an average of 1.5 to 4.5 ft along the delta.

About the influence of the spillways on surge propagation in the area along the delta can be concluded that:

- Erasing the levees reduces the surge levels around St. Bernard State Park by an average of about 3.5 ft. For some storms, for example 26, 27 and 500, the surge would be reduced by 4.5 to 6.5 ft. The propagation of surge levels remains very steep, especially around St. Bernard State Park, because the surge is driven into a corner here. But because of the decreased surge levels all along the delta, the volume of water that is pushed towards St. Bernard and Plaquemines Parish by southwesterly winds reduces also.
- At Jesuit bend the surge levels reduce with an average of 4.5 ft at the eastside and increase with 1 ft on the westside. The increase on the westside is smaller in the case without levees than in the case with spillways. This is due to the fact that in the case without levees, the spilling water is not limited to the area of the spillway, but is able to spill over a much longer length across the river.
- At Pointe a la Hache, on the eastside of the river, the surge levels decrease with about 2.6 ft. Due to the fact that surge at this point already propagated into the river, there is almost no change in the shape of the propagation wave
- At the westside of Pointe a la Hache, the surge levels reduce with an average

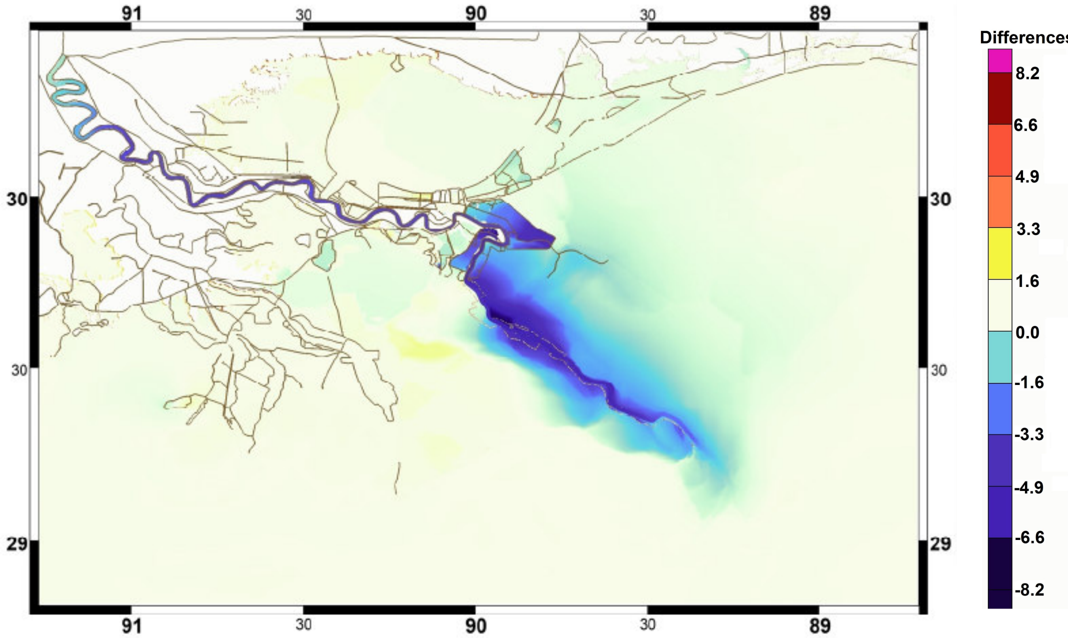

Figure 10: Difference (ft) between the maximum surge levels in the case without levees and the base case for the 18 selected storms.

of 1.3 ft. Only during storm 32, 35 and 52 the surge levels are increased due to removing the levees. Those storms tend to blow water away from the westside. Note also how the propagation of surge changes, surge is able to spill across the river instead of building up against the levees or propagating upriver.

- At Empire the maximum surge levels change with an average of 3.6 ft. on the eastside. On the westside the average reduction is 0.8 ft.
- At Venice the surge levels decrease by an average of 1.6 ft on the eastside and 2.6 ft on the westside. Although the levees end at Venice, removing the levees still has a significant impact on the surge levels at Venice.
- In the Mississippi River the average maximum surge levels decrease by 3.6 ft. Surge still propagates upriver towards New Orleans and downriver towards the Gulf. But the volumes that propagate towards New Orleans are smaller, due to the fact that, (1) the surge propagates across the delta and, (2) that propagating surge spills out of the river before reaching Jesuit Bend, from whereon it is funneled again by the levees.

Figure 11 clearly shows the capability of the Mississippi River to drain the propagating surge. Note the steep gradients along the river. If surge propagates across the river, it first builds up due to the high hydraulic resistance of the wetlands and the natural floodplains. As surge spills into the Mississippi River, the river its capability to drain the water up- and downriver causes the surge levels to drop immediately.

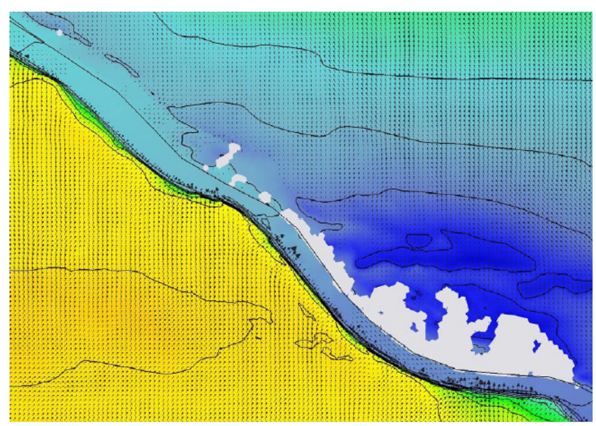

Figure 11: Surge spilling over the Mississippi River from the west- to the eastside during storm 73 in the vicinity of Pointe a la Hache. The plot shows the same moment as shown in figure 9

1/100 flood levels			
	Base Case	Case without levees	Differences No levees – base case
	[ft]	[ft]	[ft]
St. Bernard State Park	18.1	15.2	**-3.0**
Tigers Ridge Lake	17.8	15.0	**-2.8**
Jesuit Bend, East	17.1	12.7	**-4.4**
Jesuit Bend ,West	7.9	8.4	**0.5**
Nero	16.7	12.9	**-3.8**
Ironton	11.1	10.0	**-1.1**
Pointe a la Hache, East	16.4	10.9	**-5.5**
Pointe a la Hache, West	11.4	10.6	**-0.8**
Empire, East	16.2	12.6	**-3.6**
Empire, West	9.4	9.2	**-0.2**
Barataria	6.0	6.2	**0.2**
Mississippi River at New Orleans, average difference in surge level			**-3.6**

Table 3: 1/100 year flood levels for the base case and case without levees.

6.3 1/100 year flood levels

Table 3 shows the flood levels with a return period of 100 years for the base case and the case without levees. Removing the levees will reduce the 1/100 levels with about 2.8 to 4.4 ft in the northeastern part of the delta. At Nero the reduction is 3.8 ft and at Pointe a la Hache East the reduction is even more, 6.6 ft. More to the south around Empire the reduction is 3.6 ft.

On the westside of the delta, flood levels decrease at Pointe a la Hache and Empire, At Jesuit Bend and Barataria, flood levels increase with 0.2 to 0.5 ft

At the Mississippi River at New Orleans, the average flood levels decreases with 3.6 ft.

7. Comparison case spillways and the case with no levees

The results shown in Section 5 and 6 clearly point out that removing the levees has a significantly larger impact than 3 spillways. The spillways cannot prevent that huge volumes of surge build up along the wetlands on the northeast side of the delta. surge is blocked by the levees on the eastside between the first and second spillway. The capacity of the northern spillway is not enough to drain huge volumes of surge to the westside. If all the levees would be gone, the surge volumes would drain across the delta to the westside, which reduces the surge volumes on the northeast side of the delta.

Figure 12 shows the difference in maximum surge level between the case with spillways and the case without levees. All over the deltaic plain the maximum surge levels reduce if the levees are removed, compared with spillways in place. Although, one should notice that figure 12 represents the change in maximums surge levels that occur during the suite of 18 storms, the difference are quite significant.

Figure 12 provides information about areas were the levees capture a lot of surge and were relocation of a spillway may be effective. The largest differences are found between the 1st and 2nd spillway. The differences in maximum surge are 3 to 7 ft and at Nero the average difference is 4.5 ft. South of Pointe a la Hache, from where the river levee on the eastside ends, the differences decline between the two and also the width of the area, over which differences take place, declines.

Creating a 4th spillway around Nero could be quite effective. This can help to increase the spilling capacity on the northern part of the delta. At Nero the differences between the case without levees and the case with spillways are the largest. At Nero there are levees along both sides of the river, which makes the spillway even more effective. The spillway can provide extra capacity which will make the first spillway more effective also.

Another option instead of spillways is creating ring levees around the townships. Those ring levees can provide protection against storm surge for the citizens. The length of the levee system along the delta will reduce significantly and will create a situation that will act more like the case without levees than the case with spillways.

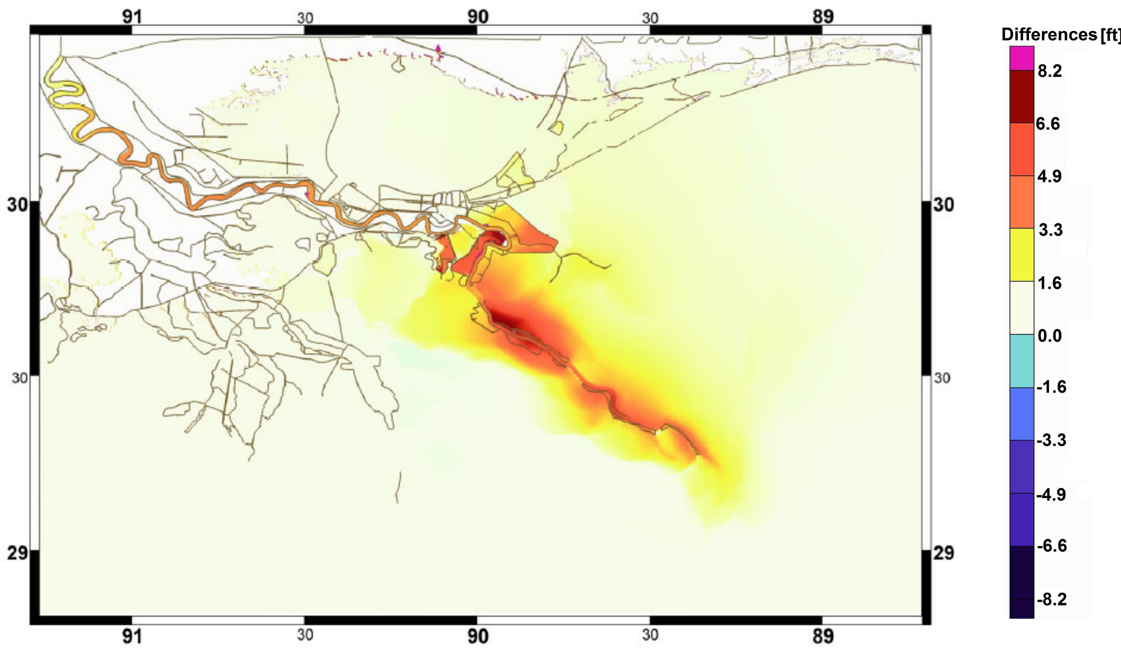

Figure 12: Difference between the maximum surge levels in the case with spillways and the case without levees. Positive values mean that the surge levels are higher in the case with spillways.

8. Conclusions and Recommendations

8.1 Conclusions

The simulation results for the base case show that:

1. Northeasterly to easterly winds push water from Breton Sound towards the delta. The propagating surge is stopped by the levees along the eastside of the Mississippi River. At the same time, water on the westside is blown away from the delta;
2. Southwesterly to southerly winds force water from the Gulf and Barataria Bay to the northeast, where it is blocked by the levees on the westside;
3. Large volumes of propagating surge are drained upriver. At Pointe a la Hache, surge propagates into the river from where it is funnelled by the levees.

From the configuration with spillways can be concluded that:

4. the spillways reduce the 1/100 year flood levels with about 1.3 to 1.6 ft on the northeastern part of the delta. At Pointe a la Hache, at the 2nd spillway, the reduction is about 2.3 ft. On the westside of the delta, at Barataria, the 1/100 year levels increase with 0.3 ft;
5. the differences, due to the spillways, only occur along the delta;
6. the spillways are not capable to reduce the surge levels in the areas between the spillways. At Nero the reduction is only 0.4 ft The capacity of the northern spillway is too small to drain the entire propagating surge to the other side of the delta;
7. surge that propagates upriver spills out again through the northern spillway, preventing part of the surge to propagate all the way to New Orleans, reducing the average maximum surge for the suite of 18 storms at New Orleans with 1.6 ft.

The configuration without levees shows that:

8. having no levees reduces the 1/100 year flood levels with 3 ft along the levees of St. Bernard. At Jesuit bend and Pointe a la Hache the reduction is even more, up to respectively 4.3 and 5.6 ft. At Nero, the reduction will be 3.9 ft. This is a difference of 3.6 ft with the spillway case. Also at Empire, the differences are significant, 3 ft. The

flood levels increase slightly at Barataria, but less than in the case with spillways;
9. the area of influence is more spread out then in the case of the spillways, but still the area of impact occurs mainly along the delta;
10. The average level for the 18 storms in the Mississippi River at New Orleans reduces with 3.6 ft.

8.2 Recommendations

Considering the differences between the base case, the case with spillways and the case without levees, it is recommended to:

1. study the impact of a 4th spillway located around Nero, between the 1st and 2nd spillway. This can help to increase the spilling capacity on the northern part of the delta. At Nero there are levees along both sides of the river, which makes the spillway probably more effective;
2. study the impact of ring levees around the townships. Those ring levees can provide protection against storm surge for the citizens. The length of the levee system along the delta will reduce significantly, which will create a situation that will act more like the configuration without levees;
3. study the impact of constructing spillways or removing (parts of the) levee system on other subjects like navigation, flood protection against high river discharges, restoration of the wetlands, etc. Those subjects are behind the scope of this study, but are important processes which need to be involved in the decision process.

Acknowledgements

I highly acknowledge the cooperation of the whole team that is involved in the LACPR project and for the cooperation to finish this study. I would like to thank Shintaro Bunya and Casey Dietrich of the university of Notre Dame, Hugh Roberts of Arcadis, John Atkinson from Ayres Associates, Kendra Dresback and Randy Kolar from the University of Oklahoma and the people from the USACE (Van Stutts, Jane Smith, Robert Jensen, Don Resio, Mary Cialoneand Alison. Sleath, Ty Wamsley, Chris Bender, Jay Ratcliff) which where involved in the LACPR project.

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