REDUCTION OF HURRICANE IMPACT BY RE-CREATION OF MARSHLANDS AND BARRIER ISLANDS

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ABSTRACT

Hurricanes pose a serious threat to existence along a large part of the American coastline. The whole of the Gulf coast and the southern part of the Atlantic coast has to fear for landfall of a hurricane, almost every year several places suffer from casualties and damage. From a coastal engineering point of view and based on Dutch dredging experiences with maintaining sea defenses it seemed possible to mitigate the impact of the storm surge part of the problem. Whether Dutch experience could really be useful is depending on the match with local circumstances. A typical coastal layout is diminishing marshlands protected by shrinking barrier islands. Recreating marshlands and strengthening barrier islands both can contribute to mitigate the impact of storm surges. But a relevant reduction of dangerous storm surge heights takes immense surfaces of marshlands to recreate using vast quantities of sediment.

Recreating barrier islands to real barriers is far more promising. To demonstrate the feasibility a study area is selected: Terrebonne Bay with Port Fourchon, a stretch of coast of 65 km (40 mile), south of New Orleans. Typical cross sections are designed with narrowed channels between islands, to block the local storm surge from class 3 and class 5 hurricanes, needing an estimated 40 million m^3 (53 million cu yd). Designed slopes depend on use of coarse sand (250 micron, 0-1 phi), sufficient supplies were found at a distance of 200 - 250 km (120 - 150 Nm) in the coastal area south of Mobile at depths from 30 to 80 m (100 to 250 ft), resulting in a one day cycle time for existing jumbo hopper dredges. Access channels are foreseen to deliver the sand to pits with cutter suction dredges that pump the sediment ashore and in place over distances of 5 to 15 km (3 to 9 mile). This way of operation leads to a rough cost estimate for course sand of $ 11 / m3 ($15 / cu yd), backfill and clay from local supplies will be less expensive. Maintenance costs are not estimated; they are mainly expected to arise from erosion of island heads due to increased water velocities in narrowed channels. Estimated total costs of the whole 65 km stretch of Terrebonne Bay could amount to some 500 M$.

In this swift study lots of aspects are not taken into account, nevertheless, the combination of local circumstances with Dutch dredging experience shows that re-creating barrier islands into real barriers could very well be a solution worth looking into in a more detailed way.

Keywords: Storm surge, flood protection, jumbo hopper dredgers, wave model Mike 21, Dutch dredging experience

INTRODUCTION

The Situation to Deal With

In the morning of August 29, 2005 hurricane Katrina made landfall in coastal Louisiana, causing a tremendous amount of damage. Coastal Mississippi and Alabama were struck by an up to 10.4 meter (34 feet) high storm surge. It has become one of the deadliest hurricanes ever recorded in the US. Apart from that, Katrina has been estimated in doing $75 billions in damages and with that it is the most costly natural disaster in history of the US.

The 2005 Atlantic hurricane season has become the most active hurricane season in recorded history. Figure 1. shows the large number of 15 hurricanes recorded, far above the yearly average of 7.8 hurricanes (Blake et al. 2005). In the last century this average has risen from 5.2 to 7.8. Despite this growing hurricane threat, coastal population has grown drastically in the last decennia. This combination leads to an increased risk of new catastrophes like Katrina, a more pro-active approached might be desired to create an acceptable safety level. From Dutch experiences, a full-scale investigation, including all possible aspects inherently connected to this size of problem will take decades of multidisciplinary teams of scientists. Therefore, in this paper only existing

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regional information available from literature and public internet sites is interpreted using Dutch expertise in maintaining sea defenses, to assess whether Dutch coastal engineering solutions could be able to mitigate effects of storm surges typical for more dangerous hurricanes. It is shown that from Dutch point of view, combining coastal engineering experience with available dredging technology can lead to solutions worth looking into more closely.

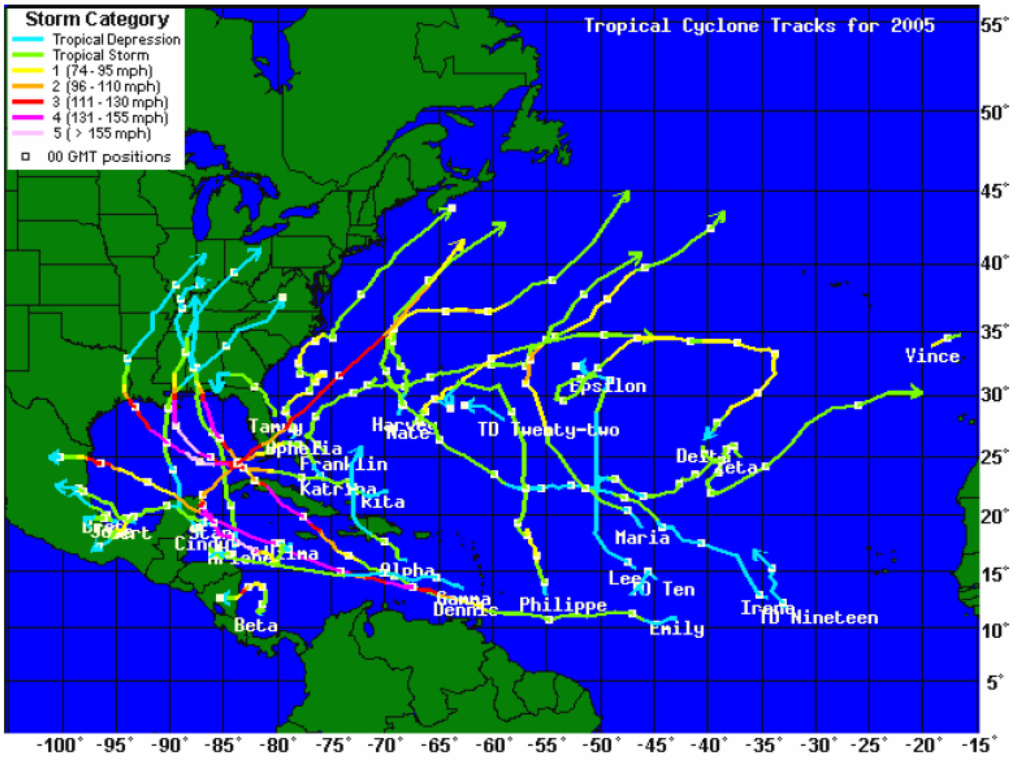

Figure 1. Paths of 2005 hurricanes. From: A New Framework for Planning the Future of Coastal Louisiana after the Hurricanes of 2005 by Working Group for Post-Hurricane Planning for the Louisiana Coast January 26, 2006. http://www.umces.edu/la-restore/New%20Framework%20Final.pdf

Damage Done by Hurricanes

Hurricanes are tropical cyclones formed in the Atlantic basin, with counter clockwise rotating surface winds of 74 mph or greater. A tropical cyclone has a much lower air pressure in its center (the eye) then in his periphery; this is what causes the strong spiraling winds towards the eye. Hurricanes develop from tropical storms as they gain strength above warm ocean water, they are classified by wind strength using the Saffir-Simpson Hurricane Scale (Table 1, ref: http://hurricanetrack.com/ncstormsurge/srginf.html#first)

Table 1. Hurricane classification.

Scale number (Category)	Winds (Mph)	Surge (Feet)	Hs (m)	Damage
1	74-95	4 to 5	4-8	Minimal
2	96-110	6 to 8	6-10	Moderate
3	111-130	9 to 12	8-12	Extensive
4	131-155	13 to 18	10-14	Extreme
5	> 155	> 18	12-17	Catastrophic

In the last century, 165 hurricanes have made landfall at the US mainland (Blake et al. 2005). Through history hurricanes caused a tremendous amount of damage in coastal areas. This damage can be divided in three main categories of origin: wind, rain and storm surge. In hurricane history large death totals are primarily a result of a 4.6 meter (15 feet), or higher, storm surge (Blake et al. 2005). Before 1970, nine out of ten deaths caused by hurricanes were due to storm surges. Today this figure is lower, as early warning systems avoid the chance of an unexpected surge and residential areas can be evacuated in time.

(http://www.cnn.com/WEATHER/9909/20/hurricane.deaths/). But early warnings cannot avoid the structural and economical damage done by a hurricane's surge. Burrus et al (2000) found that the average annual US hurricane damage for the 73 years ending in 1997 was $ 5.2 billion, much off which is attributable to storm surge. (http://www.ecu.edu/coas/floyd/papers/floyd003.pdf.) In recent years damage by a number of individual hurricanes has reached very high levels (Table 2.)

Table 2. Hurricane damage.

Most Expensive Hurricanes (Atlantic)							
Rank	Name	Year	Category	Damage (U.S.)	Land fall	Surge (ft)	Main cause damage
1	Katrina	2005	4	$80,000,000,000	LA/MS	20-30	Surge
2	Andrew	1992	5	$43.672.000.000	FL/LA	17	Wind/Surge
3	Charley	2004	4	$15,000,000,000	FL	7	Wind
4	Wilma	2005	3	$14,400,000,000	FL	-	Wind/Surge/Rain
5	Ivan	2004	3	$14,200,000,000	AL/FL	10-15	Surge/Rain
6	Hugo	1989	4	$12,500,000,000	SC	21	Surge
7	Agnes	1972	1	$11.290.000.000	FL	-	Rain
8	Betsy	1965	3	$10.800.000.000	FL/LA	10	Surge
6	Rita	2005	3	$9,400,000,000	LA	15-20	Surge
7	Frances	2004	2	$8,900,000,000	FL	6	Rain
8	Camille	1969	5	$8.889.000.000	LA/MS	24	Wind/Surge/Rain
9	Diane	1955	1	$7.000.000.000	NE US	-	Rain
10	Jeanne	2004	3	$6,900,000,000	FL	-	Rain
Note: Damages are listed in US dollars and are adjusted for inflation.							

(adjusted from: http://www.nhc.noaa.gov/pastcost2.shtml

http://www.nhc.noaa.gov/HAW2/english/history.shtml#opal and wikipedia)

From the information collected, it can be concluded that storm surge can be seen as a far greater threat than excessive wind or rainfall. Coastal engineering measures will not be able to influence damage done by wind, will hardly be able to influence damage done by rainfall, but could very well reduce damage done by its most prominent cause, storm surge.

Storm Surge Properties to Take in Account

A storm surge is a fast water level rise driven by a hurricane as it approaches the coast. Low air pressure and strong winds continually pull water up towards the centre of the storm. The height of a surge depends strongly on the bathymetry of the shore face. If the hurricane is still above deep water the surge is not able to grow very high, as the water can be dispersed down and away from the hurricane. If a hurricane passes a long shallow shore face before it reaches the shore, the water cannot escape downwards any more and the surge grows (Figure 2).

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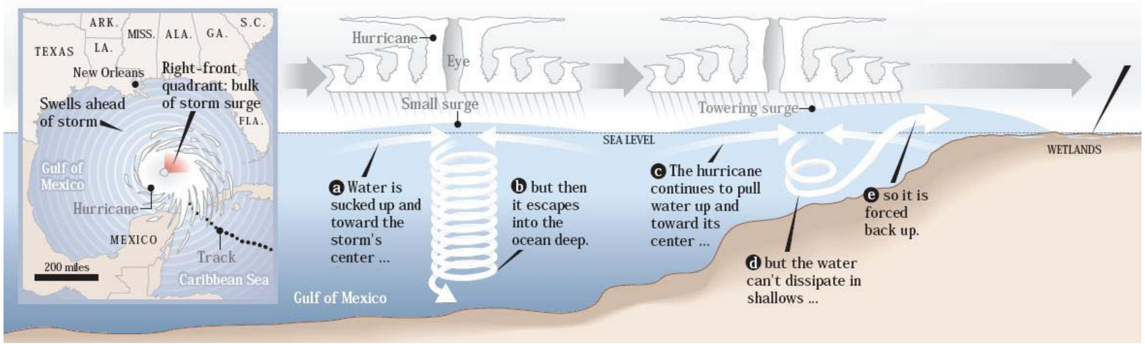

Figure 2. Creation principles of a storm surge(Adjusted from Times-Picayune, http://www.nola.com/hurricane/images/scourgeofsurge.pdf).

On a long flat continental shelf a higher surge will develop than on a short steep shelf. Instead, wave energy will have more chance to dissipate by breaking on a flat shelf than on a steep shelf, so waves might be lower. The height of a surge also depends on the magnitude, speed and path of a storm. Highest surges can be expected in the Right-Front Quadrant of the hurricane, as wind speeds are highest in this part. Also the configuration of the coastline is highly important. Like with tides the shape of the coast can have a funneling effect, leading to even higher surge heights.

Under reasonable common circumstances a surge can reach heights of over 8 m (25-feet). Katrina's highest surge elevation was measured at Bay St Louis where the surge grew to 10.5 m (34 feet). Additional are the wind-driven waves on top of the surge. A combination of surge, waves and high tide can have a devastating impact on the coast, damaging everything on its path. The amount of damage done by a storm surge depends on its height, the shape and condition of the beachfront and the possibilities to dissipate energy after crossing the beachfront. Marshlands have dissipating properties, but it takes large stretches to reduce a high storm surge to a more or less harmless level. Scientist estimates are that every 4.3 km (2.7 mile) of wetland can absorb 0.3 meter (1 feet) of storm surge (USACE 1961). High sandy dune ridges of proper sizes are very well capable in withstanding waves and surges of a storm. Some 3000 km of the US hurricane threatened coastline consists of dunes, with or without marshlands lying behind them. When not directly attached to the mainland these dunes form a line of barrier islands along the coast.

Partly due to human activities, on lots of places barrier islands and marshlands are eroding. Eroding marshlands loose their dissipating properties and eroding barrier islands can only withstand lower classed hurricanes, moreover they form a decreasing protection for erosion of their connected marshlands.

Marshland creation or re-creation is a possible way to reduce the threat of storm surges. When this can be done by restoring formerly interrupted sediment nourishing to these areas, recreation will be gradually and naturally, hardly influencing existing use and values. When it has to be done by artificial sediment supplying, it will need vast amounts of sediment and will have large-scale effects, due to the large areas needed for a relevant dissipation of surge energy. For most local circumstances this will not be the most feasible way to increase hurricane safety.

From Dutch experience with creation and maintenance of sandy sea defenses, calculated to withstand a once every 10,000-year storm, re-creation of barrier islands and dunes to effective barriers could be a very feasible way to improve the safety level. The rate of feasibility mainly depends on the match between the Dutch expertise and the local American circumstances. Very important in this respect are the natural processes that govern the existence of barrier islands and dunes; effectiveness of coastal engineering measures will be very dependant on the possibilities to 'work with nature'.

Barrier Islands

Three main theories describe barrier island formation :
(http://w3.salemstate.edu/~lhanson/gls214/gls214_barrier_isl.htm):

1. The emergence theory – This theory implies that an offshore sand shoal will continue to grow vertically, as the material on the seafloor is reworked by the waves. Eventually the accumulating bar emerges above sea level, forming a barrier island.
2. The submergence theory – The initial physical condition of this concept is a mainland with a dune complex and a low marshland separating the higher inlands from the beach ridges. In the past, rising sea levels are supposed to have flooded the marshlands, creating barrier islands, separated from the mainland by shallow lagoons.
3. The sand spit propagation theory – Growth of sand spits is due to the erosion of headlands and longshore sediment transport. Islands are formed as storms eventually breach through the elongated spits.

Schwartz (1971) concluded that barrier island formation is most probably a combination of all three theories. He only found a few barrier islands around the world, which formation could be due to only one of these theories. Most systems are much more complex, as demonstrated by the barrier islands of the Louisiana coast, which are thought to be formed by a combination of the submergence and the sand spit theory.

Many of the barrier islands along the US coast are eroding. Main causes for this erosion are a relative sea level change and a change of sediment supply (Carter 1988). A rising or falling sea level results in massive sediment transport; a stable sea level allows the beach profile to adjust and to reach an equilibrium profile. In case of a rising sea level and sufficient sediment supply the barrier should be able to adjust and retreat landward (transgression of the sea). But with too little sediment supply, the barrier might submerge and eventually disappear completely. (ref: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-1810/c-3.pdf)

Large storms will cause heavy visible instant erosion on barrier islands and dunes. When a storm surge not exceeding the dune height reaches the forefront, the steep dune profile will collapse and large quantities of sand will be deposited on the beach and foreshore. As a result the beach slope will become gentler, dissipating more wave energy, resulting in smaller waves attacking the remaining profile. Collapsing of the profile will decrease until a new equilibrium is reached; the shape of this equilibrium profile largely depends on the sediment properties, mainly the grain size distribution. If the dune ridge is wide enough to reach this stadium, or when the duration of the attack is short, it will withstand the storm. Afterwards, the local wind and wave climate will force the beach and dune back to its former equilibrium profile. This is a slow morphologic process, the dunes need time to restore, but for most existing barrier islands and dunes it is a stable system, a storm will only cause short time erosion. When barrier islands hold out, the storm surge will only enter the back barrier basin through the inlets between the islands. When these inlets are and stay relatively small compared to the basin surface, the water level rise in the back barrier basin will be substantially dampened. With the relatively short duration of the storm surge, rarely longer than 18 hours, the mainland around the basin is effectively sheltered.

Lots of barrier islands do not seem to be high and wide enough compared to storm surge heights connected to hurricanes. Once overtopped, they erode fast and loose their dampening properties in no time, especially when they consist of only fine-grained sand. Also inlets are sometimes very wide. In those cases the filling of the back barrier basin might only slightly be delayed. Enlarging the cross section of barrier islands and extending their length to narrow inlets is a feasible coastal engineering solution. Even creating completely new barrier islands is quite possible, provided that the right type of sediment can be used. Generally, it will take large amounts of sediment and constructing areas as will be shown further on, but far less than a marshland solution.

Experience with creating sandy structures like barrier islands is available. Good examples are available in the Middle and Far East. In the Palm Islands project in Dubai, four immense artificial islands are created, three in the shape of a palm tree and one like a map of the world (Figure 3). For one island, “Palm Deira”, an astonishing volume of one billion m^3 of dredged sand is needed. Another example is the offshore airport Chek Lap Kok in Hong Kong with a total of 237 million m^3 of dredging and land reclamation works.

For designing storm surge barriers based on existing barrier islands, local information is vital. Principal solutions are easy to set up, but no practical solution is possible without knowledge of at least the most decisive local circumstances, so feasibility has to be shown in a case study. For this case study, a stretch of the Louisiana Gulf Coast is chosen, for which most of the primarily necessary data was found documented on the Internet.

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Figure 3. New islands off the coast of Dubai. (http://www.iadc-dredging.com/downloads/terra/terra-et-aqua_nr92_03.pdf). (ref: http://www.iadc-dredging.com/downloads/terra/terra-et-aqua_nr92_03.pdf, http://www.sandandgravel.com/news/sponsor/jandenul/, http://www.itp.net/business/features/details.php?id=3702&category=construction)

LOUISIANA COASTAL AREA

Coastal Louisiana has one of the most significant delta areas in world. During thousands of years deposits from the Mississippi river created a large system of wetlands, barrier islands and water basins. 40% of all US wetland is situated in this area. The wetlands and barrier islands have protected coastal communities from the threat of hurricanes for centuries. The houses, businesses and infrastructure of more than 2 million people depend on the protective value of this coastal layout. Unfortunately these wetlands are disappearing at an alarming rate (Figure 4, Figure 5). Since 1930 over 900,000 acres of wetland has been lost, the current loss rate is 16,000 acres a year. If no action is taken, it will be by the year 2050 that 55 miles of hurricane protection levees, 155 miles of navigation channels and the billion-dollar oil industry will be threatened and exposed to open water conditions. Costanza (1989) has estimated that every acre of wetland has a storm protective value up to $904 per acre, this means that every year $23 million of protective value is lost.

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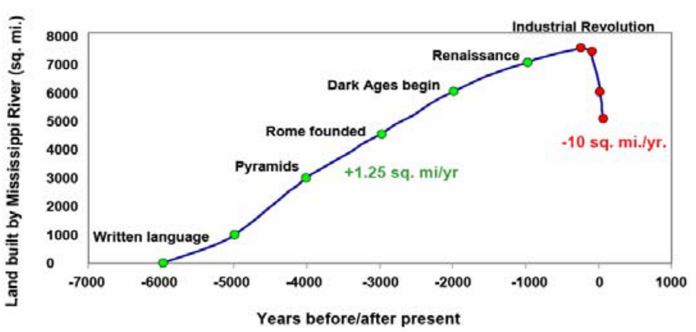


Figure 4. Creation and erosion of the Mississippi delta (http://www.umces.edu/la-restore/New%20Framework%20Final.pdf).

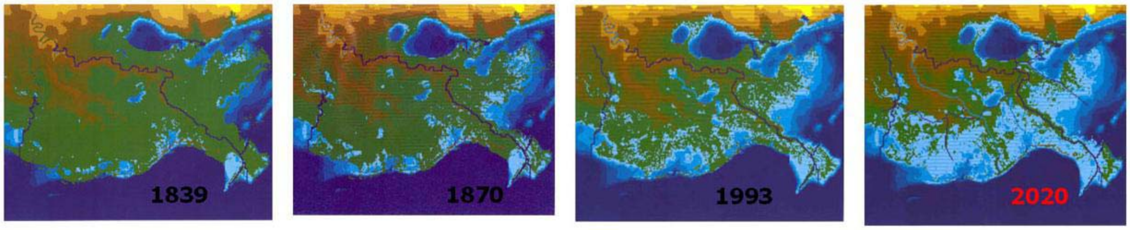


Figure 5. Loss of wetland from 1893, prediction for 2020 (www.restoreorretreat.org/coastal_erosion.html).

Besides the protective value the wetlands of coastal Louisiana have a very high economic value. The area accounts for 25 to 35 % of the national fishery catch, with a total yield of $300 million a year. Louisiana's oil and gas facilities supply almost a quarter of the countries needs, with a value of $16 billion every year. The four large ports in Louisiana together handle 20.4% of the nation's foreign waterborne commerce all using the navigation channels in the area. Besides, the total value of the coastal infrastructure is estimated at $160 billion. (http://www.coast2050.gov/lca.htm http://www.pubs.asce.org/ceonline/ceonline04/0704feat.html)

Louisiana coast has had 54 landfalls of tropical storms and hurricanes in the period 1901-1996, which comes down to once every 1.8 years (Figure 6). If the increase in occurrence expectance for the entire Atlantic basin is taken into account, Louisiana coast is expected to have a severe storm event once every 1.2 years, half of these storms are expected to be hurricanes. Two of the 54 storms that struck coastal Louisiana were a category 4 hurricane and one of the two recorded category 5 hurricanes that struck the US-coast made landfall very close to Louisiana. It can be concluded that Louisiana has a high and rising hurricane risk.

For the risk of storm surges, an important issue is that many hurricanes lose strength just before making landfall. The winds, responsible for the classification of the hurricane, subside, changing the hurricane to a lower category. But the accompanying storm surge does not dampen that quickly, it can still be a surge typical to a higher category.

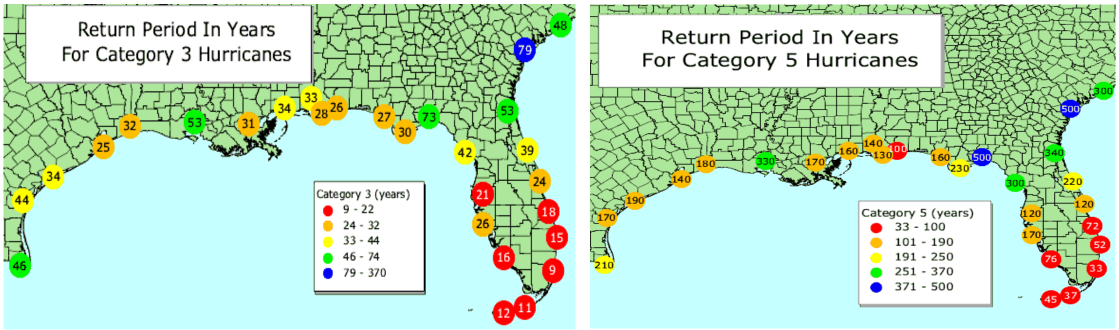
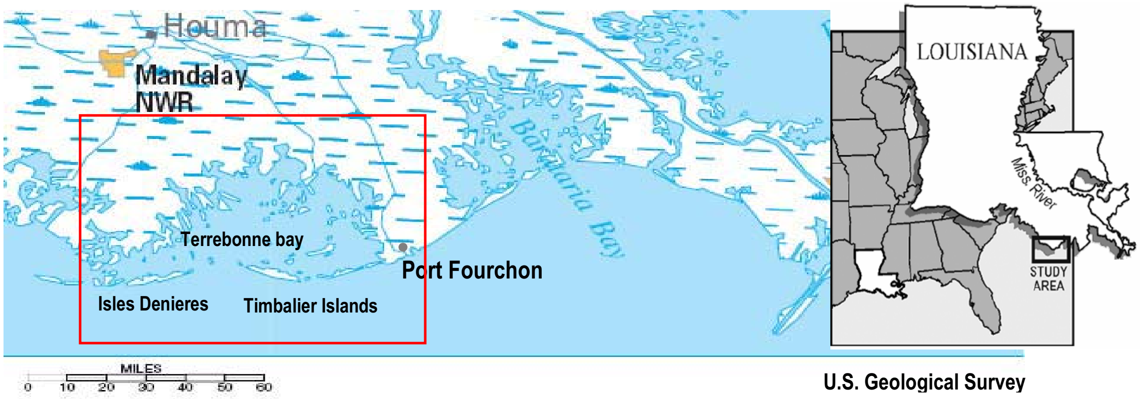


Figure 6. Return period of landfall of category 3 and 5 hurricanes.

In the last decades, calls for restoration of the Louisiana Coastal Area have grown stronger. Different organizations and institutes have presented restoration plans, all including three main engineering aspects: increase sediment supply into the area, diverse freshwater into the area in order to decrease salinity and restore barrier islands to protect against storm surges and wave attack.

So the coastal area of Louisiana gives a good opportunity to demonstrate the feasibility of coastal engineering solutions for mitigating the effect of hurricane storm surges by means of barrier island re-creation. Large areas with high human, ecological and economical values are endangered by a high and slightly increasing storm surge threat while its natural protection by marshlands and barrier islands is decreasing fast. For a basic case study the coastal area of Terrebonne Bay is selected (Figure 7), with the Isles Dernieres and Timbalier Islands as barrier islands. For the case study, Terrebonne Bay is considered to be a hydrographic unity, with no important influences from more western and eastern parts of the coast.



U.S. Geological Survey

Figure 7. Case study area barrier island re-creation (http://www.lib.utexas.edu/maps/united_states/fed_lands_2003/louisiana_2003.pdf).

BARRIER ISLAND RE-CREATION

In this part a conceptual design for large-scale restoration of the barrier islands of coastal Louisiana is presented. For this case study the shoreline of the Terrebonne bay is considered with the barrier island groups Isles Dernieres and the Timbalier Islands. (Figure 7) This area is one of the fastest eroding barrier shorelines in the US with an erosion speed exceeding 9.1 meter per year (30 feet per year) (US Army Corps of Engineers, 2004).

An important issue is the choice of acceptable risk. As the risk analyses of hurricanes is very difficult and the choice is also a political one, two designs are made. One design is based on a category 3 hurricane; the other is based on a category 5 hurricane. For the category 3 design less sand is expected necessary and therefore the construction costs will be lower. The risk of inundation however will be much higher for this design. A Cost Benefit Analyses can be made to determine the optimum in acceptable risk and construction costs.

An important aspect when considering barrier islands as a coastal protection is the design cross section. In order to protect the land behind the back barrier basin from flooding due to storm surges, the barrier island must be high enough and at the same time wide enough to avoid breaching. Furthermore, in order to properly act as a barrier against storm surges, the length of the islands and the configuration in front of the coastline are important aspects.

In order to maintain the natural appearance, it is chosen to reconstruct the barrier islands using coarse sand. As explained earlier medium or coarse sand is desired in order to construct a steep slope of the dune front, which is necessary in order to obtain the desired crest height. Further more, from Dutch dredging experiences, coarse sand is better suitable to protect the islands from erosion due to winds and currents.

Coastal Louisiana is known as a muddy area with a deficit on sand supply. There are a few offshore sandbars nearby which may be used as sand source, but these mainly contain fine to very fine sand. Coarse sand can be found further away. The deployment of jumbo hoppers makes it more cost effective to obtain high quality sand from this more distant location.

Influence of Barrier Islands

Simulation model MIKE21 (http://www.dhisoftware.com/mike21/Description/index.htm) is used to determine the effects of barrier islands on the wave- and surge heights in the back barrier basin. The simulation is performed in two steps. First a large-scale model is used to calculate the hurricane induced winds, waves and surge in front of the barrier islands; secondly a small scale (nested) model is used to calculate the flooding of the coastal area behind the barrier islands. In the nested model, setup is calculated with various barrier island configurations. The resulting surge levels of the large scale model are the boundary conditions for the nested model.

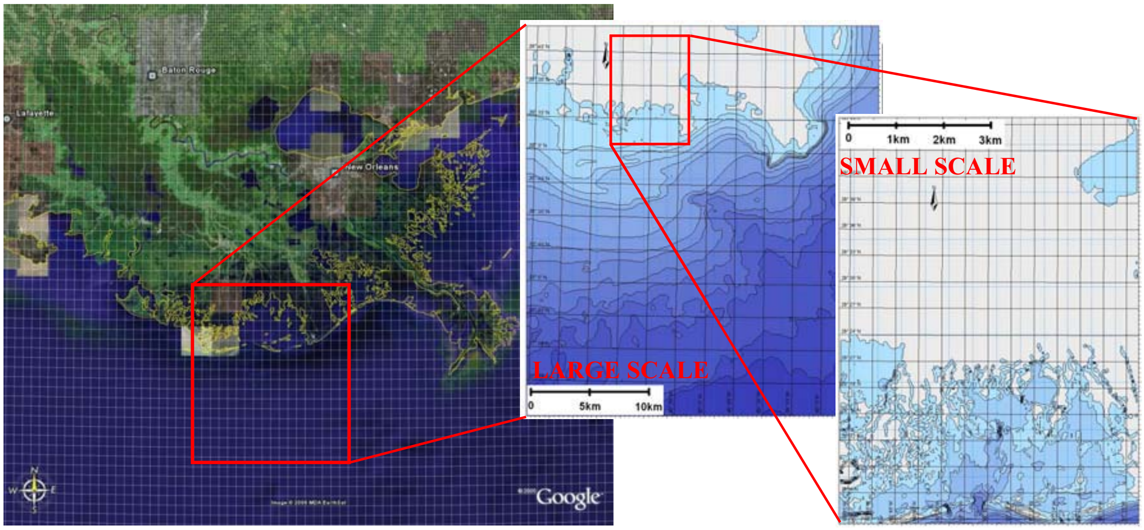


Figure 8. Model area.

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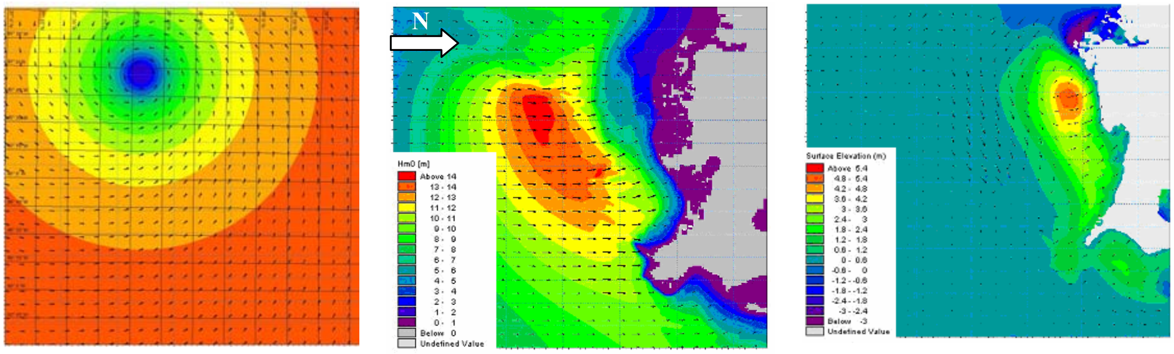
As was mentioned, two different storms are modeled, a category 3 and a category 5 hurricane. For the simulation it is assumed that the barrier islands are high and wide enough to completely resist the storm surge. Therefore the surge is only admitted through the inlets, and the dimensions of these inlets are very important for determining water levels and wave penetration inside the back barrier basin. Multiple runs with different inlet configurations are executed, in order to determine the optimum inlet sizes.

Large Scale Model:

This model encloses an area of 330 km x 300 km (205 x 186 miles), seaward of the Terrebonne bay. A hypothetical hurricane is simulated in order to determine the influence of the presence of the barrier islands on a storm surge. This hurricane travels towards the shore with a forward velocity of 20 km/h (12 miles/h, similar to hurricane Katrina) without loosing power; making landfall at 30 km west of the Terrebonne bay. This configuration leads to the largest surge heights. MIKE 21 calculates the water levels in three steps:

1. The wind fields and air pressure fields have been calculated based on the track of the hurricane and the parameters describing the hurricane (min. air pressure, max. wind speed and radius).
2. The wave fields have been calculated from the wind fields;
3. The current fields and water levels have been calculated, including wind, wave and barometric setup.



Air Pressure (colours) and wind field (vectors)

Wave heights (colours) and directions (vectors)

Water levels (colours) and current (vectors)

Figure 9. MIKE21 results large scale model: Hurricane 5 traveling towards the coast with 20 km/hr, at certain time intervals.

The large model simulation generates the development of the water level at the boundary of the nested model. In Figure 10 the water level rise in time caused by a class5 hurricane is set out. These results are used as boundary condition for the nested model.

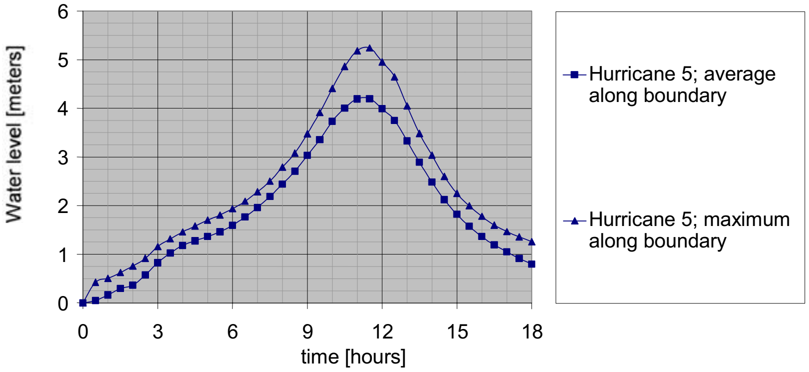


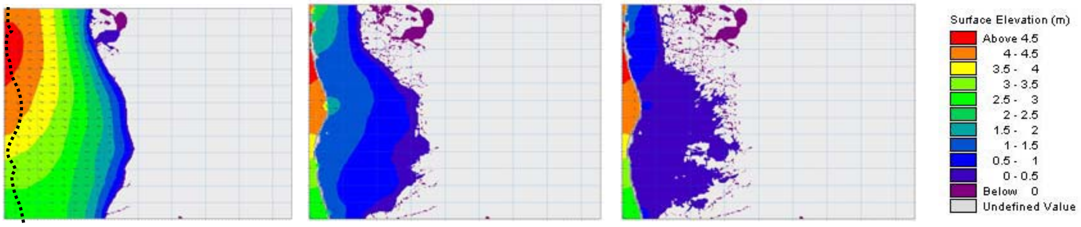
Figure 10. Development of water level at boundary of nested model during passing of hurricane 5.

Nested model

The nested model encloses an area of 86 x 63 km (53.4 mile x 39.4 mile), and includes the barrier island groups Isles Dernieres and Timbalier Islands, the Terrebonne Bay and the mainland (including the low laying wetlands). In this model the flooding of the coastal area is calculated, based on the boundary water levels derived from the large models. In the nested model (resolution 300 m), five different barrier island configurations, varying in height and inlet size, are simulated for the two hurricane categories.

1. Islands as found in original bathymetry
2. Islands at +5m and lengthened; inlet width 2 – 3 km (1.25-1.85 miles)
3. Islands at +5m and lengthened; 5 inlets, with a width of 1200 m (1098 yd)
4. Islands at +5m and lengthened; 5 inlets, with a width of 600 m (549 yd)
5. Islands at +5m and lengthened; 5 inlets, with a width of 300 m (275 yd)

The resulting plots give a water level distribution at a certain time interval.



Islands as found on original bathymetry

Islands at +5m and lengthened; 5 gaps 1200m

Islands at +5m and lengthened; 5 gaps 300m

legend

Figure 11. Water level in back barrier basin due to a hurricane 5 storm for different barrier island configurations, the black dotted line (left) represents location of original barrier islands.

The resulting maximum surge levels in these three situations are plotted over a line perpendicular to the shoreline (Figure 12).

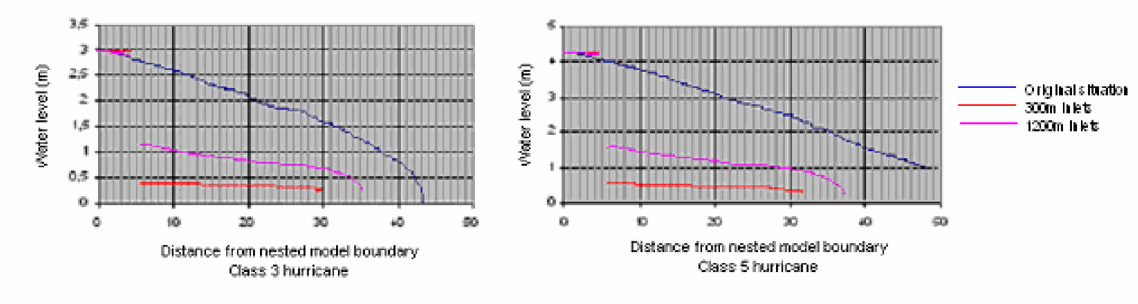


Figure 12. Maximum surge levels for a class 3 hurricane and a class 5 hurricane.

It can be seen that the restoration and recreation of the barrier islands and the narrowing of the inlets drastically reduce the surge levels in the back barrier basin and therefore the flooding hazards of the hinter laying coastline.

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Choice of inlet size

In the case study area a diurnal tide is present with a tidal range of about 1m (3 ft). This leads to tidal current velocities of approximately 0.5 m/s in the inlets. Narrowing the inlets between the islands will result in increasing tidal velocity in the inlets, as can be seen in Figure 13. These increasing velocities can result in erosion at the island tips. By using coarse sand for the restoration (especially along the island boundaries) erosion will be limited. It has to be determined to what extent erosion of the coarse sand will take place by the increasing flow velocities. Eventually an equilibrium inlet size will result, according to the Escoffier curve (Figure 14).

An inlet size of 300m is expected to be unstable due to the large flow velocities in the inlets. Therefore an inlet size of 1200m is recommended.

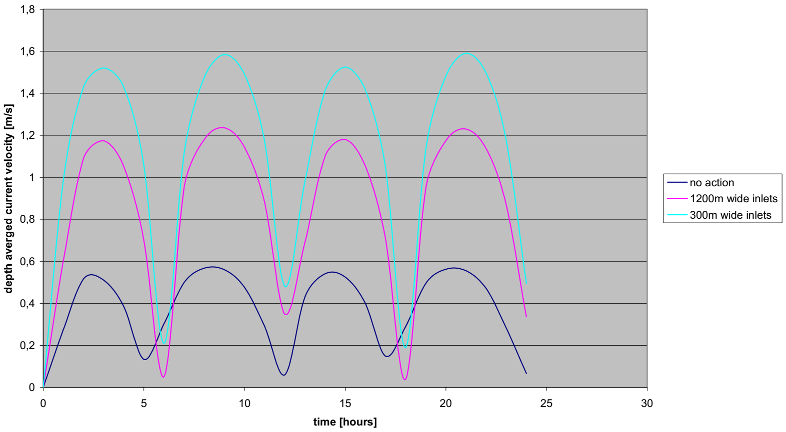


Figure 13. Regular tidal current velocities in inlets between barrier islands (tidal range 1m).

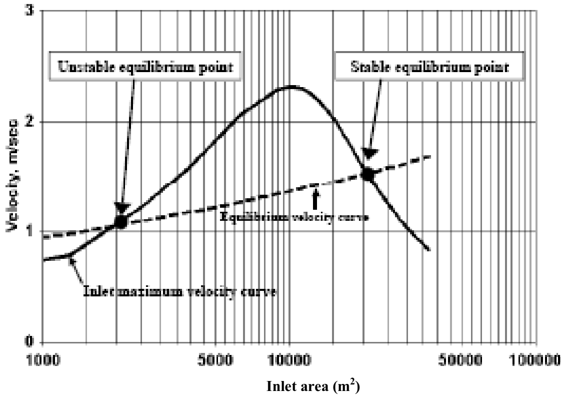


Figure 14. Escoffier curve for inlet stability.

Design of cross section re-created barrier islands

The surge heights in front of the barrier islands as resulting from the large model-simulations are 3.0 m and 4.3 m (9.8 ft and 14 ft) for respectively a category 3 and a category 5 hurricane. Most waves will break on the shallow foreshore. The maximum depth limited wave that can penetrate the back barrier basin is determined by the breaker depth criterion.

$$\gamma = \frac{H_s}{h_b}, \qquad \text{were } \gamma = 0.6 \tag{1}$$

This leads to significant wave heights of 3 m for a category 3 and 3.8 m (12.5 ft) for a category 5 hurricane. The crest height of the two alternatives is determined by limiting the overtopping volume over the crest of the barrier islands. For the "hurricane 3" alternative this results in a crest level of +4.5m (+14.8 ft) whereas the "hurricane 5" alternative requires a crest level of +8.0m (+26.2 ft). For the hurricane 3 alternative the crest and the back slope of the island must also be stable under wave attacks and significant overtopping generated by a class 4 or 5 hurricane. Therefore a 1:15 slope is applied at the rear side of the crest. For the hurricane 5 alternative limited overtopping will occur and therefore no alternate measures are taken.

From Figure 15, a beach face slope of about 1:30-1:35 is assumed to be stable for a situation with sand with a median grain size of d_{50}=0.25mm. Therefore a beach face with a slope of 1:35 is taken. The toe of the barrier islands is situated at -2m.

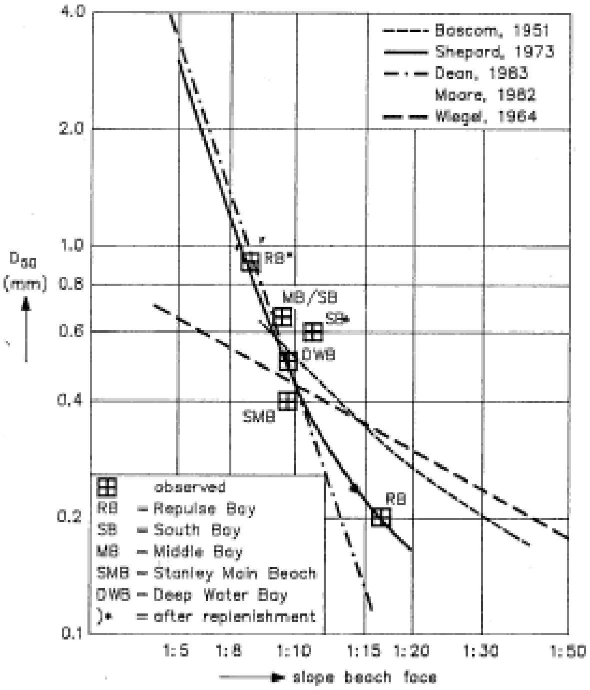


Figure 15. Stable beach face slope for various median grain sizes (Delta Marine Consultants bv in association with WL Delft Hydraulics).

The barrier island cross section that can withstand a class 3 hurricane exists of 1100 m^3/m (769 yd^3/yd) of coarse sand, and for an island to withstand a class 5 hurricane, 1360 m^3/m (951 yd^3/yd) is needed (cross sections in Figure 16).

A class 5 protection requires a slightly larger construction volume, though this leads to a considerable increase in safety against flooding. Therefore the "hurricane5" design is recommended. This design is considered in the rest of the article.

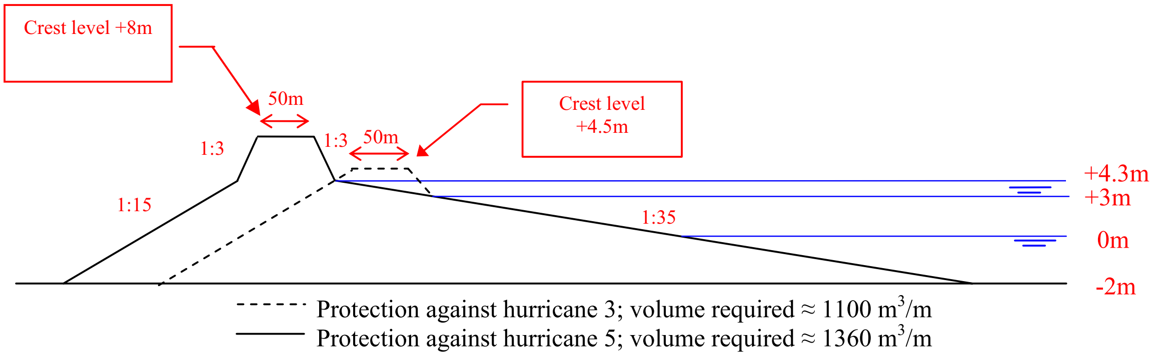


Figure 16. Desired cross section for a class 3 (top) and a class 5 (bottom) hurricane.

Length profile

From simulations it is concluded that elongation of the barrier islands significantly reduces the flooding (area and flooded depth) due to hurricanes. It is concluded that the barrier islands should be lengthened substantially as the results with inlets of more than 1200 m (0.75 miles) still show significant flooding. A situation with inlets of 1200 m width gives a satisfying result; the maximum water level rise is 0.6 m (2 ft) and the intrusion length is reduced for a category 5 hurricane. The restoration and reclamation of barrier islands in the studied area are applied over a total length of 65 km (40 miles) as shown in Figure 17.

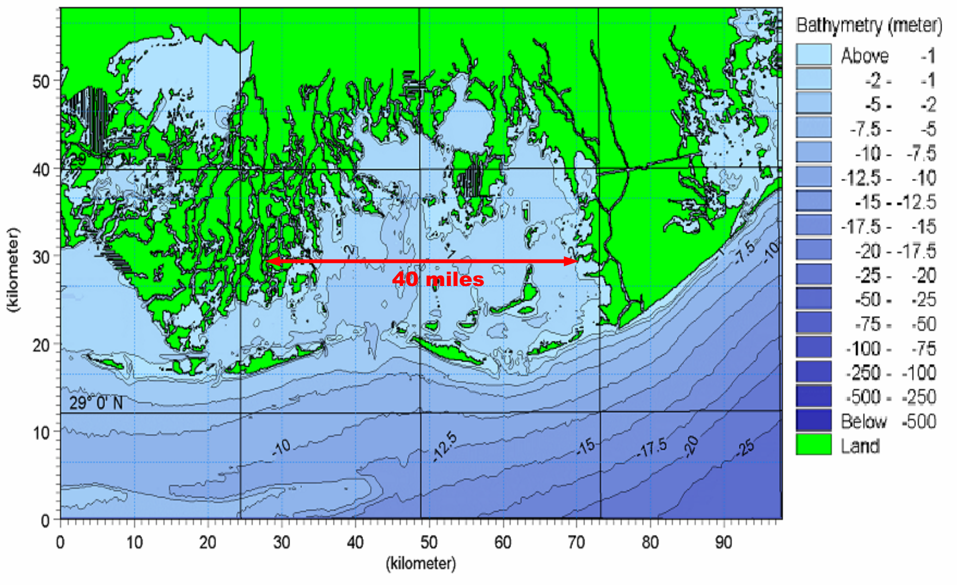
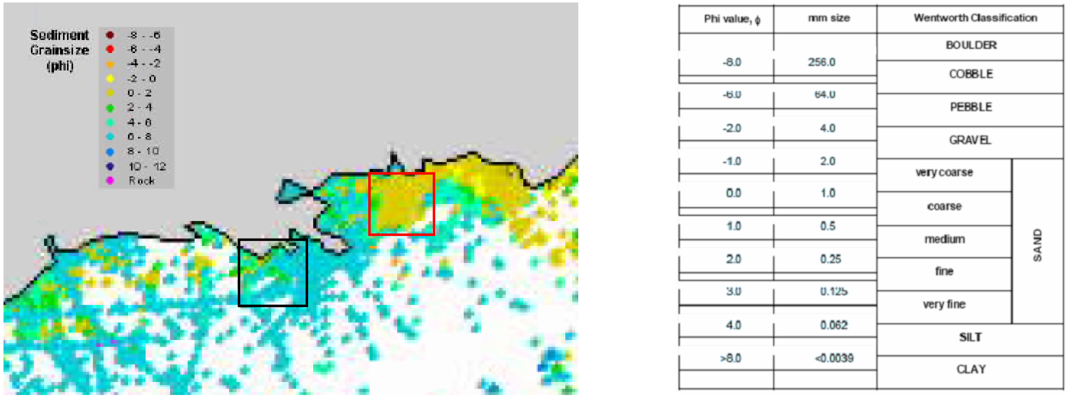


Figure 17. Current situation Louisiana coast.

It is assumed that over the total length of the restoration area, half of the volume is already in place in form of the present barrier islands. The total length of the considered shoreline is 65 km. From the calculations, five remaining inlets are assumed; each with a width of 1200 m. Therefore the total length of 60 km (37.3 miles) will have to be restored, leading to a total sand volume of: 0.5 x 60 km x 1360 m^3/m^1 = 41 million cubic meters.

Sediment source

In the direct surroundings of the site a possible source of sediment is the Ship Shoal which lies about 15 kilometers (9.3 miles) offshore from Isles Denierres, but the grain size in this shoal is no larger then 0.15 mm (Kulp et al. 2005) as the black box in Figure 18A confirms. Sand with a diameter of 0.3 mm (phi 2) or larger is desirable. It can be concluded that there is lack of coarse sediment in the direct area. From Dutch dredging experience it is known that use of coarse sand for the restoration of barrier islands is a sustainable solution. A possible sediment source is offshore Mobile Bay, see red box in Figure 18A. Here the sand is rated as 0-2 phi, which corresponds with a µ of 0.25 mm – 1 mm (Figure 18B). This area is therefore chosen as the best borrow area, even though it is 250 km away.



A.

B.

Phi value, ϕ	mm size	Wentworth Classification	
		BOULDER	
-8.0	256.0	COBBLE	
-6.0	64.0	PEBBLE	
-2.0	4.0	GRAVEL	
-1.0	2.0	very coarse	SAND
0.0	1.0	coarse	
1.0	0.5	medium	
2.0	0.25	fine	
3.0	0.125	very fine	
4.0	0.062	SILT	
>8.0	<0.0039	CLAY	

Figure 18. Sediment locations (left) and equivalence of the dimensionless phi grain size scale, metric scale and the grain size terms of the Wentworth classification scheme (right) (modified from Hobson 1979) From: http://woodshole.er.usgs.gov/project-pages/aggregates/docs/CS03_finalversion.pdf

Principle execution plan

As the sediment will have to be transported over a distance of 250 km (155 miles), from offshore Mobile to the worksite, large jumbo hoppers will be used. Self Sailing Trailing Suction Hopper will dredge the sand from the dredging area, transport it to near shore dumping pits and dump it there. Subsequently suction dredgers pump the sand via pressure pipes onto the beach. From there the sand can be distributed sideways by boosters and pipelines. Because the area is very shallow, channels will be dredged in order to allow the hopper to get to the dumping pits. The channels will be dug by smaller sized suction dredgers or cutters.

In Figure 19 the execution plan is drawn. The yellow line is the sailing route of the hoppers at sufficient depth and the red lines indicate the access channels that have to be dredged. Furthermore several connection channels (thin red lines) are needed between the dumping pits (circles). In total a length of 80 km will have to be dredged to provide sufficient access for the hoppers to the pits, resulting in about 75 million m^3 of sediment.

The sediment that is dredged for the navigation channels can, when it is useful, be used for the reconstruction of the barrier islands. The remaining sediment will be supplied behind the barrier islands and therefore will contribute to the restoration of the marsh system behind the barriers. By re-creating the barrier islands a sheltered back barrier system (under normal conditions) is created in which the marsh system will be protected from further degeneration.

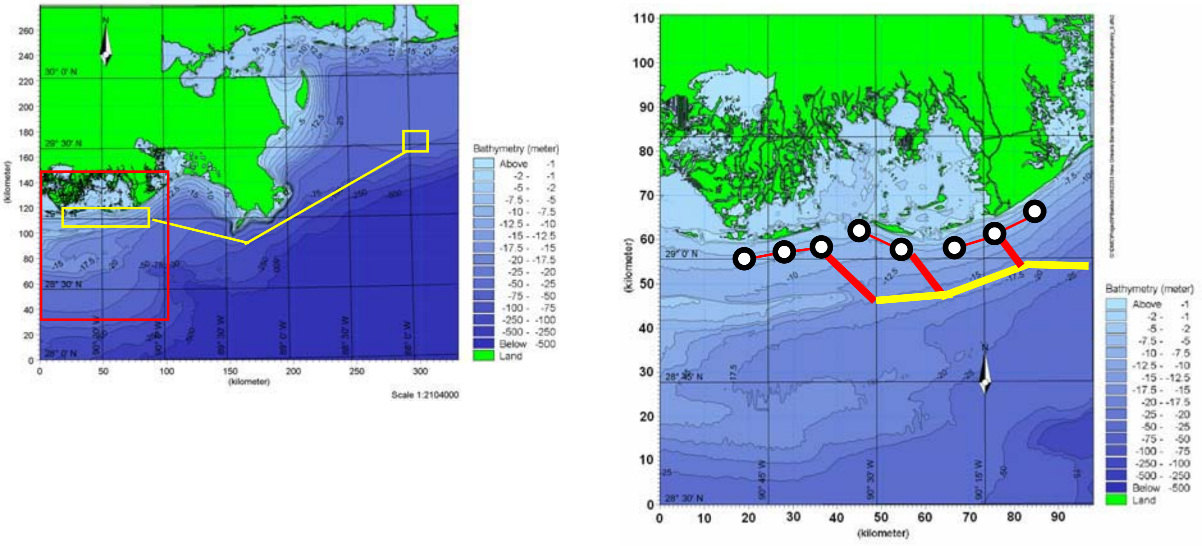


Figure 19. Execution plan barrier island restoration.

The unit price per m^3 dredged sand is determined for the execution according to the execution plan laid out above. Due to the large transport distance, the costs per m^3 will be high. Therefore the application of Jumbo Hopper Dredgers will be economical (Figure 20). The unit rate for the dredging and distribution on the site is estimated to be \$11/m^3 (based on Dutch dredgers experiences). The costs of the dredging of the channels and the disposal of material is estimated to be \$1.5/m^3. This leads to a total cost of approximately \$560 million.

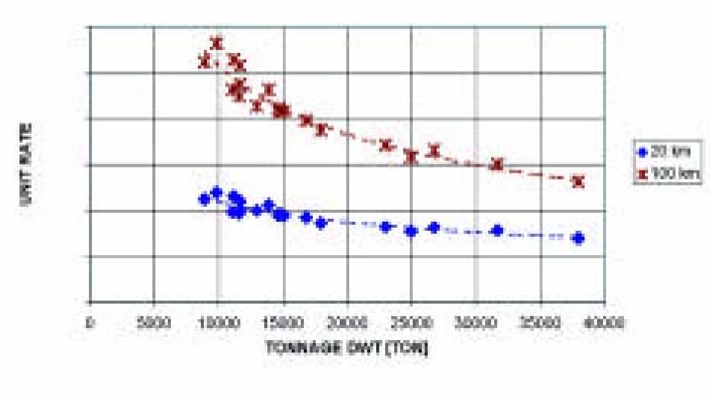


Figure 20. Unit rate vs DWT for large and shorter distance.

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CONCLUSIONS

- From the MIKE21 models it is concluded that restoring barrier islands in front of the Louisiana coast is an effective way of reducing surges due to hurricanes.
- The recommended barrier islands are designed to withstand a class 5 hurricane. This design will be only little more expensive than a class 3 design, whilst providing larger protection against flooding.
- For a design class 5 hurricane the maximum surge level just behind the barrier islands is reduced from 4.5 m (14.8 ft) in the current situation to 1.5 m (4.9 ft) after the barrier island restoration.
- An inlet size of 1200 m (1312 yd) leads to a satisfying surge height reduction behind the barrier islands.
- The restoration of the barrier islands requires a total amount of coarse sediment of 41 million cubic meters. Coarse sediment is required in order to protect the regenerated islands from erosion due to wind, waves and (tidal) currents.
- In the direct surroundings of the site no coarse sediment is available. A suitable sediment source is present offshore Mobile at a distance of 250 km (155 miles). The application of large self sailing Jumbo Hopper Dredgers is a cost effective way to obtain the suitable sediment.
- In order for the Hoppers to dump the sediment into the sandpits, 80 km of canals will have to be dredged. The dredged material from the canals is supplied into the marsh system behind the islands and therefore can put re-growth of marsh lands into motion.
- The costs for re-creation of barrier islands in front of coastal Louisiana are estimated at $560 million.
- By re-creating the barrier islands a sheltered back barrier system is created in which the marsh system will be protected from further degeneration.
- More research is necessary on the effects of the barrier islands on the sand balance in the system and the equilibrium inlet size and on all aspects not taken into account in this feasibility study.

Main conclusion: From combining Dutch dredging and sea-defense experience with local information on Louisiana circumstances, re-creation of the barrier islands in front of coastal Louisiana appears to be a good solution for reducing flooding hazards of the hinter land at relatively little costs. Additionally further marsh degeneration will probably be stopped by providing a sheltered back barrier basin in which marsh re-growth can be stimulated.

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