

The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana

Lake Pontchartrain Basin Foundation



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Executive Summary

The tragedies of Hurricanes Katrina and Rita in 2005 have revealed to the world the enormous challenge Louisiana now faces. South Louisiana appears to have entered a period when the convergence of two powerful forces is working against its survival. Since the 1950's, the processes driving coastal loss have continued only slightly abated.¹ Since 1990, meteorological and oceanic processes driving tropical systems have more frequently generated category 4 and 5 hurricanes.² More destructive hurricanes are predicted for coming decades.³ South Louisiana's ongoing peril is the continued overlap of weakened hurricane protection with more frequent and intense hurricanes.⁴

In light of this predicament, how can the coast and culture of south Louisiana survive? The survival of a culture and a region is at stake. Hurricanes Katrina and Rita may have narrowed the field of discussion from what Louisiana may want, down to what Louisiana absolutely needs. There is a growing consensus that what is needed is a pragmatic and effective strategy to integrate both coastal habitat restoration and engineered flood protection, such as levees.⁵ This strategy must be established soon and while under duress. The next hurricane season will always be just 180 days away.

This is a plan of how to merge coastal habitat restoration and engineered flood protection. When both are achieved, the ecology and economy of the region can continue and together they will save and sustain Louisiana's Coast for future generations. This can be achieved and this is how it may be done.

The examples shown and areas discussed in this report focus on the delta portion of the Louisiana coast; however, the same principles are applied to the entire coast of Louisiana. Maps of the chenier plain in southwestern Louisiana are under development.

The Multiple Lines of Defense Strategy proposes that two key elements of the coast be managed and perpetuated that will together sustain the coast (**Figure 1**). The two planning elements are:

- 1) Utilizing natural and manmade features which directly impede storm surge or reduce storm damage (Lines of Defense),
- 2) Establishing and sustaining the wetland habitat goals (Target Habitat Types).

These two, when integrated, can sustain the coast. This strategy is not a new restoration technology; rather, it is a new strategy to coordinate and prioritize conventional restoration methods and projects for coastal habitats.

This coastal management vision acknowledges the reality that environmental habitat restoration and engineered flood protection are not separable goals. It is unlikely that sufficient flood protection in south Louisiana can be accomplished by a "levees only" strategy. It is also true that adequate flood protection cannot be accomplished by simply restoring coastal habitats. Both habitat restoration and engineered flood protection must proceed in a coordinated plan which maximizes regional benefits and minimizes costs. Because there are substantial costs associated with both coastal habitat restoration and engineered flood protection, their financial justifications are codependent on a sustainable coastal economy.

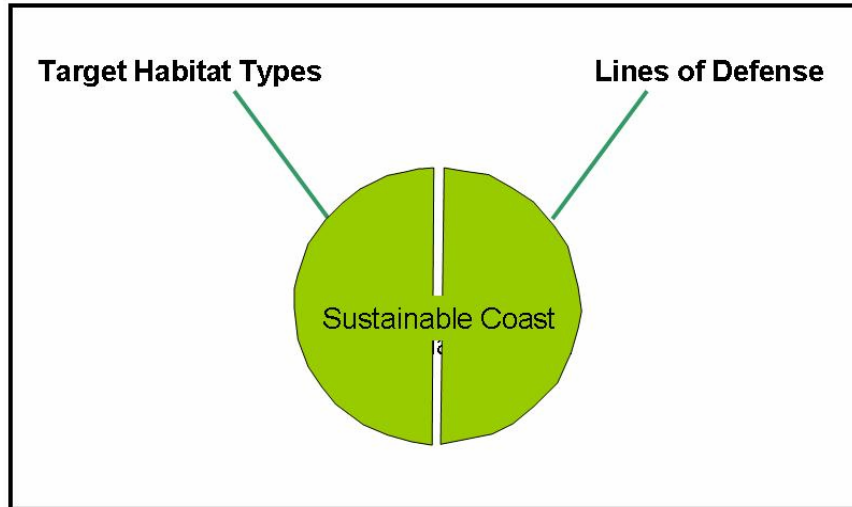


Figure 1: The Multiple Lines of Defense Strategy proposes the two essential planning elements should be defined and sustained with the result of sustaining coastal Louisiana. The Target Habitat Types defines the salinity regime and habitats for the coast. The Lines of Defense are either natural or manmade features which may reduce the impact of hurricanes to the coast.

The “Lines of Defense” include the Gulf of Mexico shelf, the barrier islands, the sounds, marsh landbridges, natural ridges, manmade ridges, flood gates, flood levees, pump stations, home & building elevations, and evacuation routes. Identification of these Lines of Defense on a map allows hydrologists, levee district managers, emergency personnel, etc. to all share a common landscape template to evaluate, abate, and monitor flood risk or other storm impacts.

The “Target Habitat Types” include swamp, fresh marsh, intermediate marsh, brackish marsh and salt marsh. Maintaining the target salinity regime and then optimally managing the habitat types, puts all the natural resources and resource managers on the same page with a unified biological and natural resource vision. Since each habitat has a differing profile of vegetation, fisheries, soils, hydrology, waterfowl, etc., it is imperative that geographic areas of each habitat be identified to optimize restoration and management for the needs for each habitat type. The establishment and maintenance of the Target Habitat Types requires a corresponding salinity gradient goal. This salinity gradient would be maintained by controlled river reintroductions and, if needed, hydrologic restoration.

Establishment of the Lines of Defense and the Target Habitat Types for coastal planning are useful separately to articulate and develop projects. However, additional value is gained by overlaying of these elements on a single map. This integrated map becomes the central coastal management planning tool since it depicts a unifying landscape vision for the coast, embracing environmental habitat restoration and engineered flood protection. The Lines of Defense define priority areas for coastal habitat restoration; that is, the “where” of restoration. The target habitats types define potential restoration methods or limitations of coastal habitat restoration; that is, the “how” of restoration. This complimentary relationship together focuses restoration funding on priority areas and guides the type of restoration possible or required. Coastal habitat restoration using traditional

restoration techniques may proceed while producing ecologic benefits and enhancing flood protection to the coastal infrastructure. The integrated map may satisfy the National Research Council's recommendation to include an explicit map of the desired future condition or goals for the coast.⁶

At least two important results of the Multiple Lines of Defense Strategy should be noted. One is that a natural ridge's ecologic function is recognized as generally being a hydrologic barrier. This makes their ecologic function compatible with using them as economic corridors. Natural ridges such as Bayou Lafourche may be leveed and still retain its ecologic function, which opens an economic corridor with flood protection. A second result is that restoration is generally focused on remaining marsh, and avoids large areas where previous heavy wetland loss has occurred. This may avoid areas with chronic causes for wetland loss that may be ongoing, such as subsidence.

In summary, the proposal described here is a unified vision for the coast which embraces environmental habitat restoration as well as engineered flood protection. Goals can be clearly articulated through maps of the Target Habitat Types and Lines of Defense. The Multiple Lines of Defense Strategy should be evaluated quickly for the entire Louisiana coast to begin implementation if it is deemed to be warranted.

Introduction

Although the rate loss of Louisiana's coastal wetlands peaked generally between 1956 and 1983, the rate is 24-square miles per year from 1990 to 2000. This represents an ongoing catastrophic habitat loss to the state and continued reduction in buffer from storm surge that coastal wetlands provide. The cumulative losses of 1900-square miles across the entire state (pre- Hurricane Katrina) have only slightly been offset by ongoing restoration.¹ Preliminary estimates of wetland loss in south Louisiana due to Hurricanes Katrina and Rita are approximately 100 square miles.⁷ A consequence of the collapsing coast has fundamentally altered the hydrology of the coast with one result being a more porous coast that is more prone to allowing the movement of Gulf waters inland. In addition, more saline habitats have generally shifted inland and salinity of coastal surface water has risen.

Numerous anecdotal reports suggests that smaller storm events, such as tropical depressions or even winter cold fronts, are more quickly and efficiently moving water inland with often negative consequences. It is significant to note that Tropical Storm Juan in 1985 slightly exceeded the prior storm surge of all hurricanes in mid-Lake Pontchartrain for the record going back to 1931. Tropical Storm Isidore nearly matched that level in 2002.⁸ With an estimated 12 feet of surge, Hurricane Katrina in 2005 probably doubled the prior mid-lake surge level for all storm events of record since 1931. In eastern Lake Pontchartrain, the surge probably exceeded 15 feet. Other areas of the coast have had significantly greater cumulative wetland loss and the vulnerability to storm surge has also increased dramatically.

The 2005 hurricane season was a record year for activity and included the following⁹:

- 27* named tropical storms for the first time since systematic record keeping began about 150 years ago (*updated by author)
- 12 hurricanes with 6 major hurricanes

- The earliest date on record by which four named tropical storms formed (Arlene, Bret, Cindy, Dennis formed before July 5)
- The earliest date on record by which two category 4 hurricanes occurred (Dennis formed July 4-7; Emily formed July 10-16)
- The most powerful hurricane ever recorded in the Atlantic basin (Wilma, central barometric pressure of 882 mBar)
- Three of the six most powerful hurricanes ever recorded in the Atlantic basin (Katrina, Rita, Wilma; This is the first time three category 5 hurricanes have ever been recorded in the same year in the Atlantic basin)
- The most destructive hurricane in US history (Katrina)

Meteorologists are suggesting a new period of increased activity may be on the horizon for the next several decades and that storms may be increasing in intensity and areal extent.^{2,3} The long-term average for Louisiana is one hurricane per 1.2 years.¹ It is reasonable to conclude that Louisiana will be struck by additional storms over the next decade as Louisiana re-establishes and improves its protection from hurricanes.

South Louisiana has many natural resources and coastal assets that together are the basis of the coastal economy. The underlying force to this economy is a culturally rich, blue-collar workforce. Flood protection and preservation of coastal habitats are the two essential features of the coast to sustain the people, natural resources and economy of south Louisiana. These two broad features of the coast can primarily be addressed by two-pronged strategy: 1) Define and sustain the Lines of Defense 2) Define and sustain the Target Habitats Types.

The Lines of Defense encompass both natural and manmade features which reduce hurricane impacts. The Target Habitat Types define a gradient of wetland habitats and a corresponding salinity regime of surface water of the coast. Planning and management of the coast should be proactive to sustain both. This is achievable since integration of the Lines of Defense and the Target Habitat Types may define the where and how of coastal restoration. Conventional methods of restoration are implemented and may include marsh creation through dedicated or beneficial fill material, river reintroductions, reef construction, rock armoring, etc. The objective of this strategy is to efficiently coordinate and prioritize these conventional methods of restoration for coastal habitats for restoration and flood protection.

Lines of Defense

It is often repeated that “barrier islands are Louisiana’s first line of defense from hurricanes”. This statement is intended to emphasize the importance of barrier islands, but is misleading because barrier islands are neither the first nor the only line of defense. This paper suggests a more inclusive and clearer definition of Lines of Defense. They are definable geographic areas where natural or manmade features are promoted, resulting in the reduction of negative impacts by tropical weather systems along the Louisiana coast (**Figure 2**).

Although estimates vary, it is sometimes suggested by coastal scientists that coastal habitats may provide a storm surge reduction of one-foot per several miles of coastal habitat.¹⁰ However, all coastal habitats types are not equally effective and their relative position also influences their potential to impede storm surge. Even if marsh were equally effective, far too much marsh has been

lost to restore all of it. It is necessary to discriminate among areas which are more valuable to restore and protect. Coastal planning must move beyond generalized guidance and actually delineate on a map the specific, critical natural landforms and engineered flood protection features.

Identification of the various natural Lines of Defense and their locations helps define their value to flood protection, but also may expose their deficiencies. The manmade engineered flood protection measures are obviously designed to be engineered Lines of Defense, but their effectiveness is influenced by the surrounding coastal habitats. Therefore, an inclusive list and map of natural and manmade features recognizes the potential role of both and is an important step toward overall mitigation of hurricane protection by managing both the existing natural landscape and engineered flood protection such as levees.

Eleven Lines of Defense are listed below in the order derived from the relative physical location to each other, moving from the Gulf of Mexico inland. The order is not intended to indicate the relative significance, just the relative physical position (**Figure 2**).

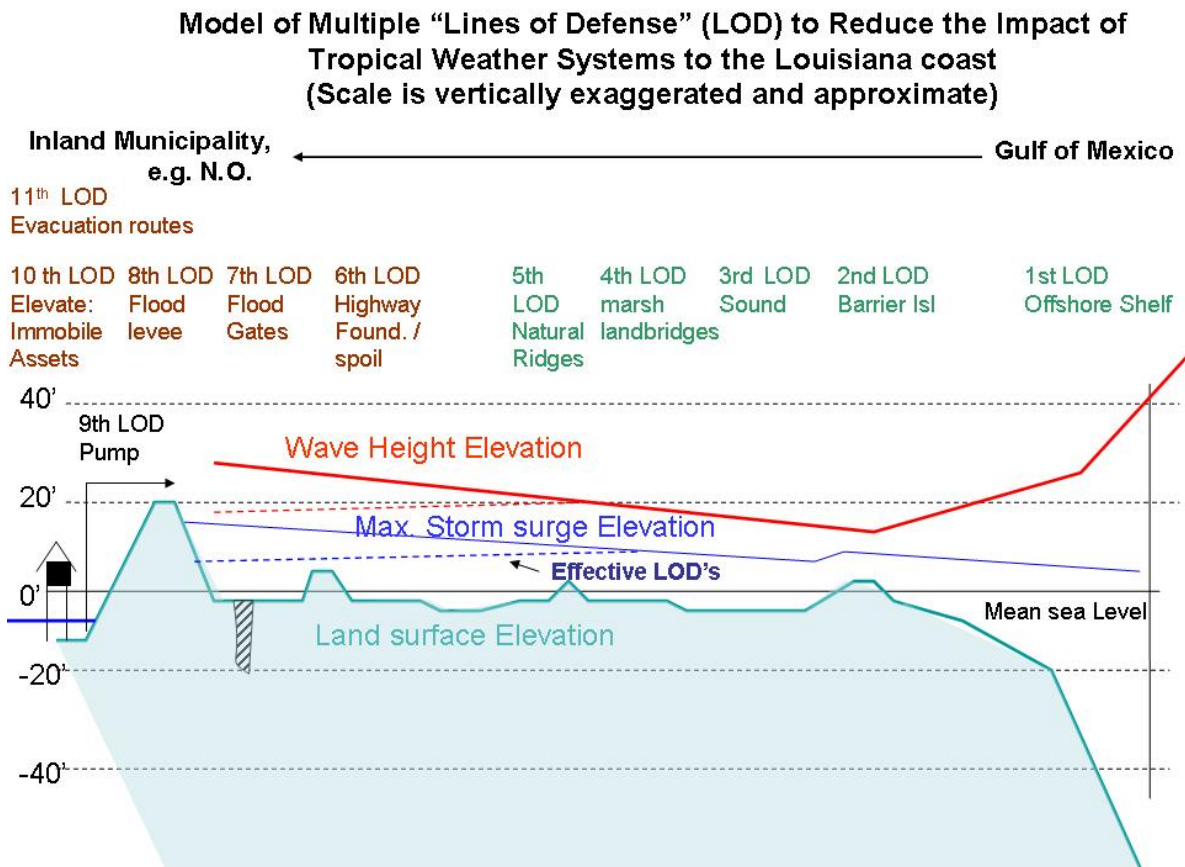


Figure 2: Diagrammatic profile of the general coast of south Louisiana indicating the eleven Lines of Defense identified. Lines of Defense are natural or manmade features that contribute to the abatement of storm damage. One through five are natural landscape Lines of Defense. Six through eleven are manmade Lines of Defense which may through design or incident provide a measure of reduction in storm damage. All eleven Lines of Defense may be influenced by human activities.

The eleven Lines of Defense are:

1st : Offshore shelf within the Gulf of Mexico

The offshore shelf ranges in depth from 300 feet at the shelf edge to zero depth at the gulf shoreline. Its width varies from a few miles to hundreds of miles. The primary benefit of the shallow shelf is to dramatically reduce wave height and wave energy from an approaching tropical system. A negative aspect of the shelf is that it will promote higher storm surges inland. The variable influences on storm surges due to the geometry of the shelf needs to be considered for storm surge analysis. Also, dredging activities on the shelf should avoid increasing shoreline erosion by wave refraction around dredge holes. The gulf fisheries and the oil and gas industry are key economic aspects of the shelf.

Examples: Narrow shelf at the mouth of Mississippi River & Wide shelf offshore from Cameron Parish

2nd : Barrier Islands

The Louisiana barrier island shoreline is characterized by fragmented barriers or shoals with low vertical profiles and low sand content. However, barrier islands provide an important wave barrier for interior sounds and coastal marsh. The primary benefits of barrier islands are the near-complete reduction in wave height and the slight reduction in storm surge further inland. A negative aspect of barrier islands is their ephemeral nature and unpredictable local impacts to them from hurricanes. Barrier islands also have significant recreational aspects such as fishing and birding.

Examples: Chandeleur Islands and Grand Isle

3rd : Sounds

The primary benefit of the sounds is to provide a relatively shallow water buffer to deep water currents. Sounds do have a negative aspect during storms by allowing waves to re-generate on the on the sound side of barrier islands. Also, sounds may cause storm surge and wave erosion on the back side of barrier islands.

4th : Marsh Landbridges

Marsh landbridges are areas of emergent marsh with relative continuity compared to adjacent bays, sounds or areas of significant marsh/land loss. Ideally, landbridges connect other elevated landforms such as natural ridges. Since some ridges are developed and have adjacent levees, marsh landbridges may also bridge adjacent levee systems and economic corridors. Marsh landbridges compose much of the residual internal framework of the coast which reduces fetch and shoreline erosion of interior marshes and lagoons. Landbridges impede storm surge movement inland and protect other emergent marsh areas that may perform the same function. Some landbridges are threatened themselves by various processes of marsh loss and need to be sustained through restoration and maintenance. The landbridges represent an increasing fraction of the remaining emergent marsh of the coast and provide typical high productivity and fishery benefits typical of coastal wetlands.

Examples: East Orleans landbridge, Biloxi Marsh landbridge, Barataria Basin landbridge, Upper Terrebonne Bay landbridge, Grand Lake-White Lake landbridge, Western Marsh Island landbridge, south Calcasieu Lake landbridge

5th : Natural Ridges

In southeast and central Louisiana, most natural ridges are the natural levees of abandoned distributary channels. These channels now act as tidal channels and are often colloquially named bayous or rivers. In southwest Louisiana, most natural ridges are cheniers running parallel to the Gulf coastline. Natural ridges may have continuous elevation of several feet and, therefore, will impede overland flow across the ridge and potentially reduce storm surge. Natural ridges often define (at least historically) the hydrologic basins of the coast. Natural ridges are most effective when they have at least 6 feet of elevation and well drained soils to maintain upland forests. Forests will also slow the movement of overland flow and may also provide a wind barrier. Natural ridges tend to be the economic corridors across the coast including primary state highways and coastal communities. These highways are also likely to be evacuation routes.

Examples: Bayou la Loutre, Bayou Lafourche

6th : Manmade Soil Foundations

Manmade soil foundations for transportation may provide incidental benefit to storm surges. Railroads, highways and spoil banks may run parallel to the coast and locally provide a manmade ridge several feet in height. These foundations may have settled and may need improvement to provide reliable transportation routes without chronic flooding. If highway improvements are contemplated, the effects on storm surge may be considered.

Examples: Highway 90, Hwy 82

7th : Flood Gates

Flood gates are typically designed to withhold flood water and, therefore, remain open under most conditions. Flood gates are generally open so as not to impede navigation or natural ebb and flow of tides and aquatic organisms. Flood gates would be closed during a threat of flooding and to reduce flood tides in channels. Because of the generally low elevation of the coast, the effectiveness of flood gates may depend on the nearby topography or constructed features such as levees or spoil banks.

Examples: Bayou Bienvenue, Bayou Dupre

8th : Flood protection levees

Flood protection levees are designed and constructed for flood protection of municipalities or other coastal infrastructure features. Levees are generally designed to be an absolute barrier defining a flood side and a protected side. The intent is to have zero storm surge flooding on the protected side, but an unintended consequence may be to increase water levels on the flood side. Levees are generally not designed to be overtopped or to withstand significant wave erosion. Exceptions include “potato levees” or other low relief levees designed to reduce flooding from non-storm tides. Typical hurricane protection levees protect limited portions of the coast with intense economic development.

Examples: St. Bernard levee, Jefferson and Orleans Parish levees on Lake Pontchartrain

9th : Flood protection pumping

Pumping stations are generally within leveed areas and are used to reduce flood risk from rainfall and are not designed to pump out flood water in the case of a levee breach. Most pumping stations are not prepared with fuel, staff or other requirements to be effective to pump

out flood water from a significant levee breach. Generally, these are large capacity pumps which displace water vertically above the water level on the flood side of the levee. Pumping stations are generally to protect areas of intense development.

Examples: Orleans and Jefferson Parish's pumping stations

10th : Elevated homes and businesses

All homes and businesses in south Louisiana are subject to being flooded if they are not elevated above the normal land elevation. Even those behind levees are not 100% safe.

Hurricanes Katrina and Rita made this painfully clear. All attempts to reduce storm surge height or its extent are limited by the intensity and attributes of particular storm events. Since there will always be the potential of a storm exceeding the limits of protection from storm surges, immovable assets such as homes and businesses should be elevated to the appropriate flood elevation risk. This is the last line of defense for immovable assets. Elevated homes also provide important side benefits such as improved protection from termites and more economic capacity to re-level or raise the houses due to settlement or increased flood risk.

Example: pre-1940 housing in New Orleans, LUMCON, Marina del Ray in Madisonville

11th : Evacuation

Evacuation routes are typically highways, but could also include other means of transportation such as railroads, air transportation, etc. Evacuation routes are the last line of defense for people or moveable assets. Evacuation routes and procedures should be established for the coast. Ideally, evacuation routes may also serve as re-entry routes for first responders and as routes to re-populate after a storm event. Evacuation routes are generally selected based on capacity to move a large number of people to safer areas as a storm approaches the coast. Some routes may be subject to flooding quickly and need to be improved.

Examples: Regional contra-flow evacuation plan for southeast Louisiana

Potential “Lines of Defense” in Southeast Louisiana

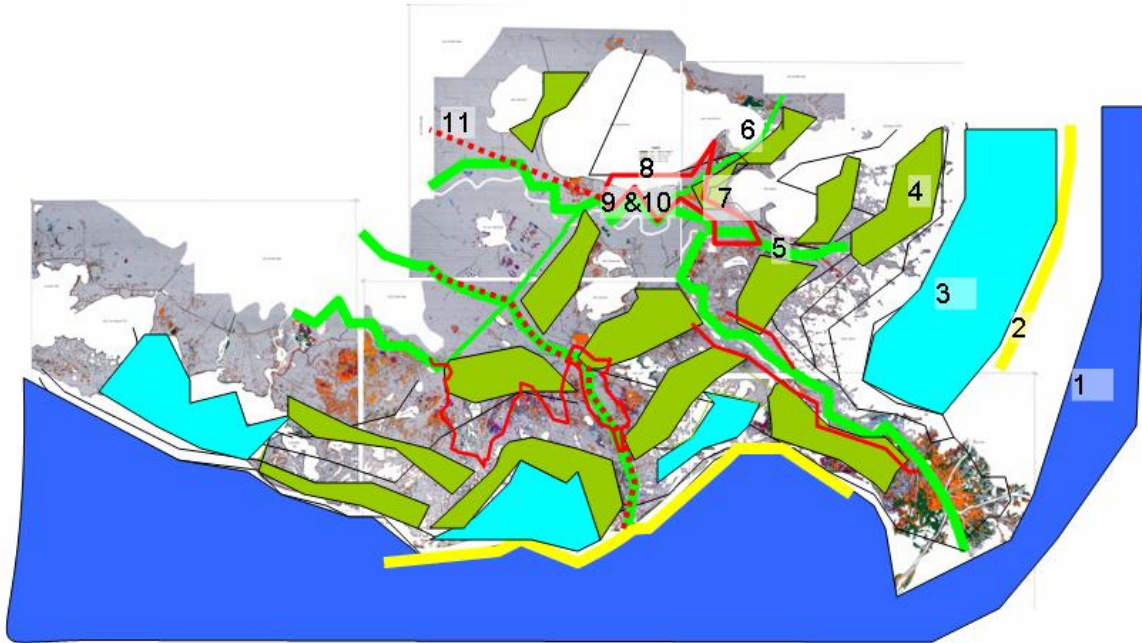


Figure 3: The proposed distribution of Lines of Defense in southeast Louisiana: 1) Gulf of Mexico shelf, 2) barrier islands, 3) sounds, 4) marsh landbridges, 5) natural ridges, 6) manmade ridges, 7) flood gates, 8) flood levees, 9) pumping stations, 10) elevated homes & buildings, and 11) evacuation routes

Figure 3 is a draft representation of potential Lines of Defense in southeast Louisiana. The map was interpreted manually from coastal information. More accurate methods using GIS and spatial analysis should be used to develop a final map representation of the Lines of Defense.

Numerous institutions have expertise or accountability in regards to these aspects of the Lines of Defense. A matrix can be used to develop management teams to address particular Line of Defense within the Multiple Lines of Defense Strategy (**Figure 4**). The goal is to reduce the exposure of homes, businesses and people to the damaging effects of flood water generated by tropical weather systems.

Accountability for Multiple Lines of Defense																					
	LOD	LPBF	CRCL	PIES	LSU Geod	UNO, SLU, LSU SC&E	N. O. Gov	DNR CRD	DNR CMD	State Police	DOTD	Parish	FEMA	MMS	COE	USFW	NMFS	NRCS	EPA	USGS	# of Accn'ble Parties
Offshore Shelf	1			1		1			1					1	1	1	1		1	1	9
Barr Islands	2	1	1	1		1		1	1			1			1	1	1	1	1	1	13
Sounds	3	1	1	1	1	1		1	1			1			1	1	1	1	1	1	14
Marsh Fringe	4	1	1	1	1	1	1	1	1			1			1	1	1	1	1	1	15
Natural Ridge	5	1	1	1	1	1		1	1			1			1	1		1	1	1	13
Manmade Ridge	6				1		1		1	1	1				1				1	1	9
Flood Gates	7	1	1				1	1	1			1			1	1	1		1		11
Levees	8				1	1	1	1	1			1			1				1		9
Pumps	9				1		1					1			1						5
Elevate	10				1		1					1			1						5
Evacuation	11				1		1			1	1	1			1						7

Figure 4: Matrix with Lines of Defense (LOD) listed vertically (numbers under LOD refer to Figure 2). Some typical institutions with a presence in the Louisiana coast listed horizontally. “1” in the matrix indicates the institution has significant expertise or accountability regarding a specific Line of Defense.

LPBF= Lake Pontchartrain Basin Foundation;
TNC = The Nature Conservancy;
BTNEP= Barataria-Terrebonne National Estuary Program;
CRCL = Coalition to Restore Coastal Louisiana;
PIES = Pontchartrain Institute for Environmental Sciences;
LSU SRC = LSU Spatial Reference Center;
LSU SC&E = LSU School of the Coast and the Environment;
N.O. Gov = New Orleans City Government;
DNR CMD = Department of Natural Resources – Coastal Management Division;
DNR CRD = Department of Natural Resources – Coastal Restoration Division;

State Police = LA State Police;
DOTD = LA Department of Transportation and Development;
Parish = any LA coastal parish government;
FEMA = Federal Emergency Management Agency;
MMS = Mineral Management Service;
COE = US Army Corps of Engineers;
USFWS = US Fish and Wildlife Service;
NMFS = National Marine Fisheries Service;
NRCS = Natural Resource Conservation Service;
EPA = Environmental Protection Agency;
USGS = US Geological Survey.

Target Habitat Types

The Target Habitat Types span from Fresh to Saline habitats and together represent a gradient of habitat types from inland areas to the Gulf of Mexico. Related to the habitat gradient, salinity also varies across the estuary from fresh to seawater. More than any other variable, salinity determines the basic wetland habitat type in south Louisiana (Fresh, Intermediate, Brackish or Saline). The habitat type determines the vegetation, animal and other life present and, therefore, defines the natural resources of the landscape including much of its economic potential. Since the biological resources can be strongly influenced by salinity, and salinity can be manipulated, the control of the estuarine salinity gradient of the coast should be a primary management goal and not a random result nor simply the result of a restoration project.

Therefore, one of only two essential planning elements is a map of the Target Habitat Types distribution for restoration and management. This map defines the distribution of five basic coastal habitats and, therefore, potentially defines the natural resource goals for the coast. Everyone on the coast from fisheries managers, to biologists evaluating regulatory compliance, to recreational fishers will potentially understand the target habitats, species composition and natural resources of the coast. The map of Target Habitat Types is analogous to architectural plans for a house. With a house plan, everyone involved with construction such as plumbers, carpenters, etc. understands where the kitchen, bathrooms, etc. are going to be located. As well, the occupants of the house will be rewarded with a functional house, just as coastal communities will anticipate and rely on a functional coast with pre-defined resources. However, contrary to a rigid house, it is understood that salinity will always have desired, seasonal movement. Therefore, the map represents an average, long-term salinity target around normal seasonal variation.

Regardless of coastal habitat restoration or other interventions by man, the future salinity of the coast will primarily define the future natural resources. It is proposed here that, in the future, salinity goals, restoration projects, fisheries management, resource conservation and exploitation of coastal resources, in general, be managed using the accepted Target Habitat Type distribution for the coast. Coastal salinity should be managed to prevent damaging, extreme salinity events rather than being determined by hurricanes, droughts, floods or the retreat of the coast. Natural resources management will be improved since all stakeholders understand the intended distribution of the natural resources.

The habitat types also influence one other extremely important element of coastal planning. They limit the tools available for restoration and, therefore, define what restoration projects are possible. For example, a freshwater diversion will predominately build fresh or intermediate habitat, and has little capacity to create brackish or saline marsh. Conversely, the armoring potential of oyster reefs (brackish habitat) generally provides little direct protection to a fresh swamp. However, it is possible - and desirable - that a fresh water diversion can manage salinity over all the habitats within the area of influence of the diversion including a brackish marsh. A freshwater diversion may not build a brackish marsh but it may be designed to manage salinity so that the brackish marsh can still be enhanced through marsh creation, barrier reef development, rock armoring or other sustaining techniques. Long-term stabilization of the salinity also generates a more consistent and predictable natural resource, which promotes economic and responsible commerce. The enhanced oyster production due to salinity management by the Caernarvon freshwater diversion is a good example of the benefits of salinity management by a freshwater diversion.¹¹

The basic coastal wetland habitats in south Louisiana are typically described as Swamp, Fresh marsh, Intermediate, Brackish and Saline.^{12,13} These habitats are strongly influenced by the salinity regime of the surface water. Historically, the habitats were maintained by freshwater introduced through rivers such as the Mississippi River and other natural water sources and there was an absence of manmade canals. The construction of flood protection levees limits freshwater into the marsh and the construction of canals allows additional saltwater into the estuary.¹⁴ These and other changes have resulted in the unnatural shift of habitats inland.

The five Target Habitat Types are:

Swamp (0-3 ppt salinity)

Forested coastal wetlands in south Louisiana are dominated by bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*), which have re-generated since extensive logging of virgin forest more than 70 years ago. The Louisiana swamps generally lack a mature canopy as was present in pre-existing forests and have lower productivity where isolated from riverine influences.¹⁵ The greatest potential to restore and sustain coastal forests is near the Mississippi and Atchafalaya Rivers where freshwater reintroductions may be implemented. Other local sources of freshwater may be municipal wastewater or storm water. Potentially sustainable economic natural resources include fisheries of catfish, crawfish, etc. and logging of wetland forests.

Fresh Marsh (0-3 ppt salinity)

Fresh marsh has the highest plant diversity of all the coastal habitat types including as many as 93 species. Productivity is higher in fresh marsh than swamp. Floating aquatic and submerged plants are common and are significant for waterfowl. Soils may be highly organic and prone to settlement. The greatest potential to restore and sustain fresh marsh is near the Mississippi and Atchafalaya Rivers where freshwater reintroductions may be implemented. Other sources of freshwater may include municipal wastewater. Economic natural resources include fisheries of crawfish (*Procambarus clarkii*), blue catfish (*Ictalurus furcatus*), and channel catfish (*Ictalurus punctatus*). Duck hunting and bass fishing are important recreational industries.

Intermediate Marsh (2-8 ppt salinity)

Intermediate marsh has lower species diversity than fresh marsh, but may have higher productivity. This habitat provides important nurseries for brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), blue crab (*Callinectes sapidus*), and Gulf menhaden or pogy (*Brevoortia patronus*),. Soils may be very poor due to very high organic content. Important species are Rangia clams (*Rangia cuneata*) and Roseau cane (*Phragmites australis*). Clams are important for filtration and may compose a significant portion of the biomass in lakes or bays. Roseau cane is an aggressive and highly tolerant plant. Its root system is dense and resists shoreline erosion. Submerged aquatic vegetation within lakes and bays are vital to secondary productivity. Economic natural resources include fisheries of blue crab, shrimp, catfish and drum. Duck hunting and recreational fishing are important recreational industries.

Brackish Marsh (4-18 ppt salinity)

Brackish marsh has the low plant diversity, but may be the most productive. The dominant species is emergent marsh grass. Oysters (*Crassostrea virginica*) are exceptionally significant due to filtration, biomass, reef building, and commerciality. Historically, natural reefs had more vertical structure and were larger than managed oyster beds. Natural reefs have generally been lost due to mining or salinity increases. Presently, oysters are located further inland and generally have little vertical reef due to harvesting practices. Oyster management should be directed toward expanding oyster extent within the targeted brackish habitat and enhancing critical functions of oysters including oyster reefs as barriers. Oyster shell material also helps stabilize shorelines. Economic natural resources are fisheries (shrimp, blue crab, oyster, drum, mullet, Gulf menhaden, and others). Duck hunting and recreational fishing are important recreational industries. Speckled trout, redfish and flounder are typical sport fish.

Salt Marsh & Barrier Islands (8-29 ppt salinity)

Salt Marsh and Barrier Islands have high overall species diversity due to plants and animals (primarily waterfowl). In addition to its special ecologic value, this habitat has high aesthetic and recreational value. Bird rookeries are important and include threatened or endangered species. Nesting for sea turtles occurs on some islands. Some islands also have true seagrasses on their bay side lagoons and provide habitat for the endangered West Indian manatee (*Trichechus manatus*) during migration.

It is recommended, but not required, that the distribution of the Target Habitat Types is primarily based on consideration of an historical baseline and what is biologically and physically achievable with restoration, considering the already collapsed condition of the Louisiana coast. The overriding goal of development of the Target Habitat Types is stabilization and sustainability of the regional estuaries which compose coastal Louisiana and the estuarine functions. Ultimately, this may only be economically feasible through high organic productivity and efficient riverine sediment importation, which suggests allowing the estuaries to function as naturally as possible.

Because of the great need to allow the rivers to introduce sediment and nutrients to the coast, displacement of current fisheries is required to achieve sustainability of the coast. However, it must be noted that all five coastal habitats do have commercial fisheries and so all regions of the coast will still have commercial fishing. Nevertheless, it is not known if a sustainable condition will be the most commercially viable in the short-term, but the only viable long-term economic prospect for a commercial fishery is a sustainable coast.

The Lines of Defense include natural landscape features, which are the offshore shelf, barrier islands, sounds, marsh landbridges, and natural ridges. Their capacity to reduce storm impacts is a service naturally provided by the indigenous characteristics of these coastal habitats. Future restoration and management of these natural Lines of Defense should expand or accentuate this service, naturally and without compromising other services typically provided by these habitats. One exception may be natural ridges designated as an economic corridor. In general, restoration and management of the natural Lines of Defense represent an opportunity to greatly expand the physical and biological services provided by Target Habitat Types located on a Line of Defense.

Figure 5 is the proposed Target Habitat Types map for the Louisiana coast. This map is a reconstruction of habitats based on historical habitat data circa 1900 to 1932. The distribution

reflects a more natural influence of overbank discharge the by the Atchafalaya and Mississippi Rivers, resulting in the rivers being enveloped by dominantly fresh habitat. The intervening areas of Terrebonne Bay and St. Bernard have more saline habitats consistent with the historically inactive deltaic influence and less riverine influence. These habitat distributions are indicated by historical maps of oyster reefs and of forest types of coastal Louisiana.^{16,17}

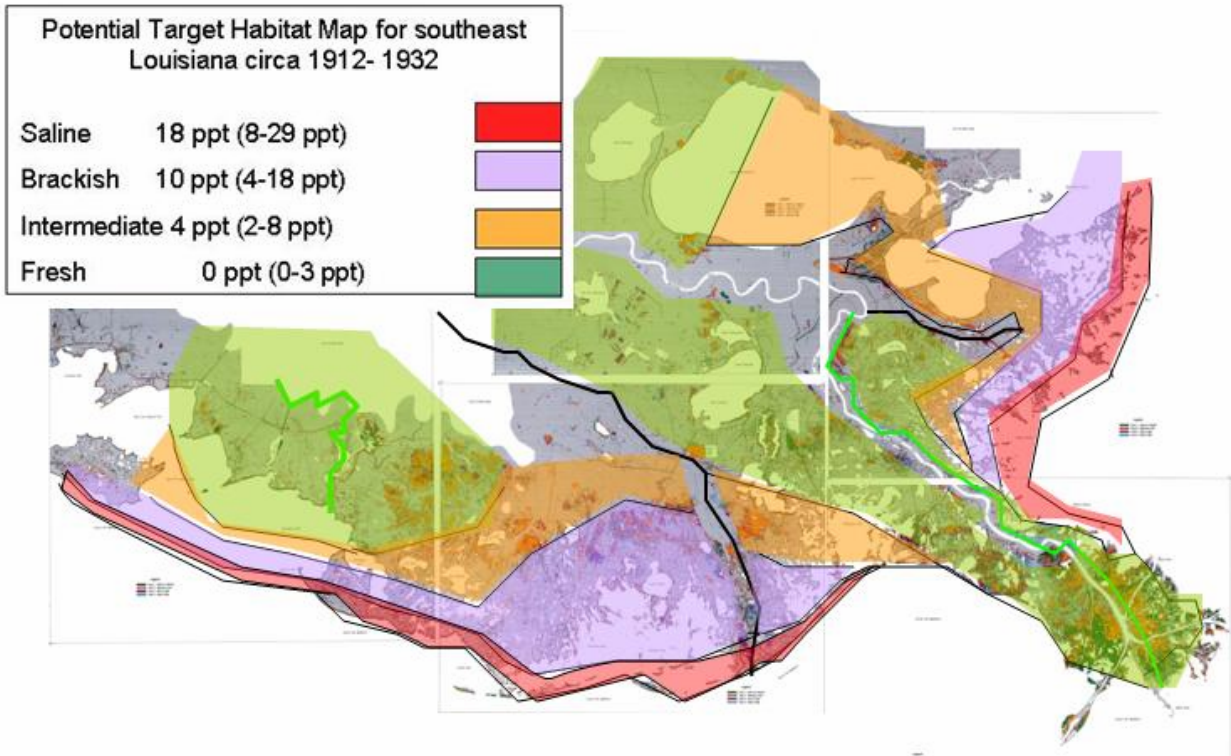


Figure 5: Potential baseline distribution of Target Habitat Types for southeast Louisiana. Map is primarily based on historic maps indicating the distribution of natural oyster reefs and wetland forests, circa 1900- 1932. The goal of this proposal is to have an accepted map of the Target Habitats Types, but it is not required that is this particular baseline reconstruction be accepted.

An essential restoration strategy is to maintain a salinity regime for the Target Habitat Types and to promote the general health of the habitats including high productivity and appropriate diversity. Once the habitat distribution is established and mutually accepted, a multitude of resources can focus on each of the habitat types, including both public and private restoration efforts and fisheries management. Greater diligence to habitats is devoted to those which are also an identified Line of Defense

Integration of Lines of Defense and the Target Habitat Types

The strength of the Multiple Lines of Defense Strategy is the ability to integrate of the Lines of Defense with the Target Habitat Type maps. The combination of these data sets has the potential to be a powerful management tool, which may articulate the goals of coastal habitat restoration, flood protection and potential economic development.

Simply overlaying the two data sets with GIS mapping allows combining the two data sets to be used for coastal management decisions. **Figure 6** is an overlay of the Target Habitat Types (from Figure 5) distribution over the Lines of Defense (from Figure 3).

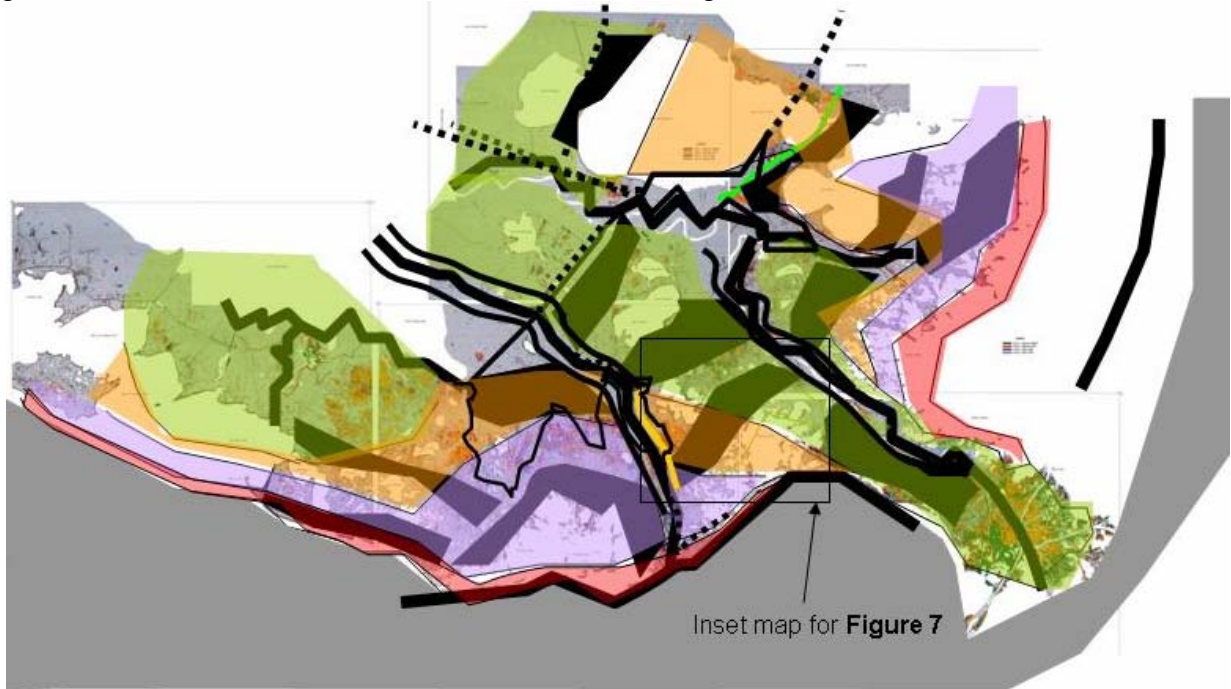


Figure 6: Overlay of the Target Habitat Types (Color) over the Lines of Defense (black overlain in color). The Lines of Defense indicate priority areas for restoration or preservation of coastal habitats. The Target Habitat Types indicates the type of restoration that may be feasible or desired.

The Lines of Defense map indicates where it is a priority to maintain or restore coastal features (manmade or natural). The Target Habitat Type map indicates the type of restoration needed or available to sustain that area of the coast. Any Line of Defense has a corresponding Target Habitat Type mapped. The combination of maps guides the where and how of coastal management and restoration.

Consider an example of a marsh landbridge identified as a Line of Defense in the Barataria Basin, such as between Barataria Bay and Little Lake (**Figure 7**). The landbridge on the east end would be near the Mississippi River where the target habitat is fresh indicating river reintroductions would be appropriate to restore or maintain that portion of the landbridge. Further away from the river, long-distance pipeline pumping of sediment may be appropriate beyond the reach of natural land building. Even further from the Mississippi River, the Target Habitat Type would be brackish, which suggests a robust oyster reef barrier habitat and fisheries should be maintained. This area may also require dedicated dredging for marsh creation if it is beyond the reach of long-distance pumping of sediment from the Mississippi River. The combination of these conventional restoration projects on this single landbridge would restore and sustain the landbridge. These restoration projects provide predictable ecologic and fishery benefits articulated by the Target Habitat Type map. Through the same investment of restoration projects, the entire integrity of the landbridge is maintained providing predictable flood protection benefits.

Consider a second example of an engineered Line of Defense, such as levee construction. The levee performance would be based on socially defined flood risk goals e.g. “Category 3 flood protection”. To achieve a given performance level, future storm surge elevation would be predicted to physically design the levee height and other design parameters. This would need to consider the future natural landscape of the coast that the surge water would travel across. If the natural landscape has clearly defined restoration goals which themselves have an element of flood protection, much of the potential uncertainty will be removed from future predictions of storm surge. The Multiple Lines of Defense Strategy proposes that the natural Lines of Defense are restored and sustained in perpetuity just as levees are maintained and managed in perpetuity. Ultimately a better fit will be defined for the levee because there is a commitment to maintain certain elements of the landscape identified as Lines of Defense including both natural and engineered elements.

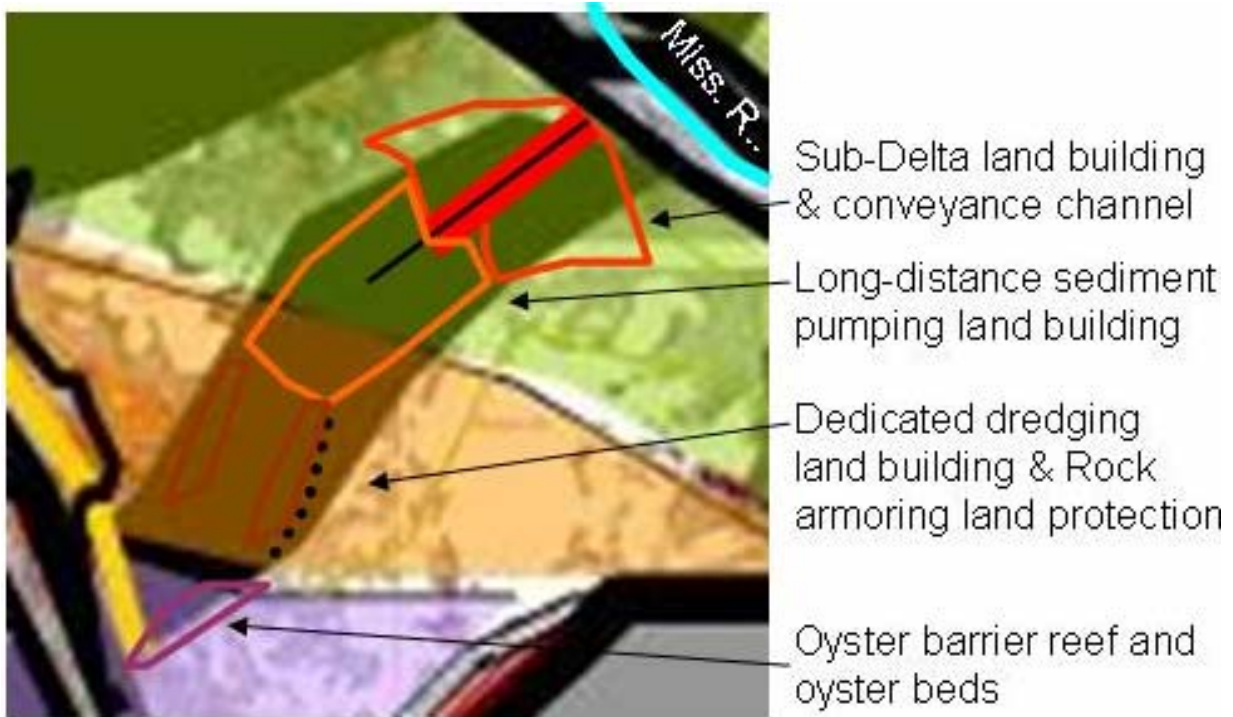


Figure 7: Example of landbridge restoration located between Barataria Bay and Little Lake (see Figure 6 for location). The Target Habitat Type of the landbridge is fresh (near river in green) to brackish (near gulf in purple). Restoration projects vary across the landbridge due to the habitat distribution, i.e. the Target Habitat Types.

On the integrated map, the Lines of Defense suggest where the restoration should be a priority and the Target Habitat Types indicate what type of restoration or estuarine management is appropriate. The overlap of a restoration project on a Line of Defense is where flood protection benefits are produced and anticipated, while also allowing effective restoration and management of coastal habitats.

Discussion and Conclusion

The Multiple Lines of Defense Strategy differs from prior coastal planning efforts in several ways, including:

- 1) The National Research Council's assessment of Louisiana coastal restoration states:

“An explicit map of the desired future landscape of coastal Louisiana should be developed as soon as possible to guide the selection of more-integrated restoration projects in the future”

The integrated mapping of the Target Habitat Types and the Lines of Defense may provide at least one regional map of consistent goals and may address deficiencies recognized by the National Research Council.

- 2) Most coastal restoration programs do not officially place a priority on flood protection. CWPPRA and LCA place highest priority on the maximum areal extent of emergent vegetation. The Multiple Lines of Defense Strategy clearly puts priority on flood protection. If followed strictly, the strategy would only invest in projects that provide some measure of flood protection either through engineered flood protection or coastal habitat restoration. If followed strictly, the only coastal restoration would be on an identified Line of Defense.
- 3) Most prior coastal restoration programs have incremental project approval processes which, in the absence of long-term goals, tends to be influenced by transient perceptions. This may lead to reactionary decision making. The Target Habitat Type map clarifies the long-term natural resource base of the coast and guides projects to be designed within this unified biological template. This should promote pro-active project development by all stakeholders even with an incremental approval process. No former restoration program in the Louisiana coast appears to have proposed the obvious: what are the basic habitat goals, i.e. the Target Habitat Type map.^{1,18} This document is not attempting to dictate exactly what the habitat distribution should be, but it is stating that it is necessary to agree on the basic habitat distribution for the coast. This does not need to occur simultaneously across the coast. Each hydrologic basin has some latitude to define the Target Habitat Types. For example the habitats east of the Mississippi River are basically independent of those habitats west of the Mississippi River.
- 4) The basic ecologic function of abandoned distributaries is considered a hydrologic barrier rather than a hydrologic channel. This has large implications since economic development is centered on these ridges. Under the proposal, economic development is compatible with coastal habitat restoration, since levees along the ridges may enhance the ecologic function as a barrier. This also eliminates the need to utilize these channels as major conveyance canals for large river reintroductions. It is questionable if these abandoned channels have the discharge capacity adequate for significant land-building. In addition, local residential and commercial development further limits the potential for conveyance. Because abandoned distributaries are not required to be utilized for conveyance and are instead hydrologic barriers, prominent features such as Bayou Lafourche and Bayou la Loutre can be identified as commercial corridors compatible with a long term vision for habitat

restoration and engineered flood protection (**Figure 8**). This does not preclude modest introductions into distributaries such as Bayou Lafourche that are compatible with local development. These small scale freshwater diversions may play a significant role in providing municipal water supply and nurturing marshes that its discharge affects.

- 5) Because existing marsh landbridges are identified as a Line of Defense and, therefore, a priority for preservation or restoration, this places priority on existing marsh remnants. Areas of very heavy loss are generally avoided. This may be critical since these areas of marsh loss may be inherently less stable due to other coastal processes of marsh loss such as subsidence¹⁹, faulting²⁰ or fluid withdrawal²¹.

Integration of Development Corridors Routes into the LOD's

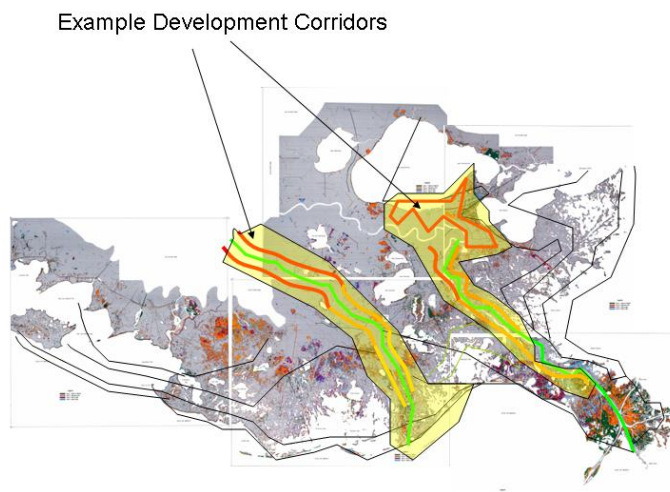


Figure 8: Example of Economic Corridors (yellow), which are compatible with coast habitat restoration within the Multiple Lines of Defense Strategy.

In summary, the proposal described here is a unified vision for the coast which embraces environmental habitat restoration as well as engineered flood protection. Goals can be clearly articulated through maps of the Target Habitat Types and Lines of Defense. The Multiple Lines of Defense Strategy should be evaluated quickly so that implementation can begin, if it is deemed to be warranted. The paramount product of this effort should be a single map indicating the desired future elements of the coast that provide essential ecologic services and adequate flood protection to perpetuate the economy of the region.

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