Gaining Ground

Wetlands, Hurricanes and the Economy: The Value of Restoring the Mississippi River Delta

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Executive Summary

> ***"As the great Mississippi River Delta disappears, so do the ecosystems, economies and people that it holds. The Mississippi River is the solution. It has the water, sediment and energy to rebuild land, defend against hurricanes and again provide habitat, safety, livelihood, and prosperity. We must look to the natural functioning of the delta to guide us in restoration."***
>
> ***John Day, 2007***

Economies need nature. Natural systems provide foundational economic goods and services including oxygen, water, land, food, climate stability, storm and flood protection, recreation, aesthetic value, raw materials, minerals, and energy. All "built capital" is made of natural capital, including cars, buildings and food. An economy also requires hurricane protection, a stable climate, waste assimilation and other natural services. No economy can function without nature's provision of economic goods and services. This is most apparent in North America's largest river delta.

The Mississippi River Delta ecosystems provide at least $12-47 billion in benefits to people every year. If this natural capital were treated as an economic asset, **the delta's minimum asset value would be $330 billion to $1.3 trillion** (3.5% discount rate)**.** This study is the most comprehensive measure of the economic value of Mississippi River Delta natural systems to date. Marine waters, wetlands, swamps, agricultural lands and forests provide natural goods and services. The goods and ecosystem services valued in this study include hurricane and flood protection, water supply, water quality, recreation and fisheries. The Mississippi River Delta is a vast natural asset, a basis for national employment and economic productivity. It was built by literally gaining ground: building land with sediment, fresh water and the energy of the Mississippi River.

Yet, this vast national economic asset is being squandered at tremendous cost. The Mississippi Delta lost over 1.2 million acres of land in the last 80 years. In some areas, the coastline has retreated by as much as 30 miles. The lower Mississippi River has been constricted by levees since the 1930s, resulting in billions of tons of valuable sediment and trillions of gallons of valuable freshwater being channeled into deep water off the edge of the continental shelf. The Mississippi's energy to move vast amounts of sediment and water could have built additional land and provided hurricane protection and other economic benefits at no significant cost.

Without the input of sediment and water, wetland systems collapse. Land is lost to the waters of the Gulf of Mexico causing tremendous economic and human cost. Wetlands provide vital protection against hurricanes. When land disappears, so do the economies, homes and communities that depend on it. Solving this problem requires an accounting of and investment in the economic assets of nature – natural capital – as an integral component of hurricane damage prevention and as a critical foundation for healthy communities and economies.

Is this national investment worthwhile during a period of financial crisis? The results of this report point to an unequivocal "yes." Seventy years ago, investments in roads yielded high economic returns because the U.S. was transitioning from a horse and wagon road system to a motorized system. Today, roads are neither scarce nor a barrier for economic recovery. Hurricane protection is scarce and hurricanes hamper national economic productivity; the disruption of oil and gas supplies alone cost U.S. citizens dearly. Today, a major investment in natural capital is required for economic development. An investment in restoring the Mississippi River Delta is both a local and national investment that realizes local and national economic benefits.

This report discusses the value of investing in the restoration of the Mississippi River Delta. Part I introduces a new view on the value of natural capital as a critical and large part of the economy. It also introduces ecosystem services and goods that directly benefit people but have historically been overlooked. Part II presents a valuation of ecosystem services in the Mississippi Delta, calculates their present value to assess the flow of value over time. Part III of this study examines the dramatic dynamic physical changes affecting the Mississippi River Delta and the profound economic implications for the region and our nation. Part IV examines three investment/restoration scenarios for the Mississippi Delta.

The first scenario involves doing nothing new: invest nothing in natural capital and keep building costly levees that are repeatedly damaged by storms while land continues to wash away. Practiced for 80 years, this option has proven to be very costly. It results in a retreating coastline in the Mississippi Delta, causing a retreat of people, communities, industry, built capital and the economy. This report estimates losses associated with this option at $41 billion. This does not include estimates of damage from another major hurricane, which is certain to happen. Considering that Katrina caused $200 billion in damage and that with further land loss future damage may greatly increase, this is a significant underestimate. The nation breathed a sigh of relief when Hurricane Gustav's glancing blow did not destroy New Orleans in 2008. Had the hurricane struck slightly to the east, the impact could have been more damaging. Hurricane Ike was perhaps more powerful than hurricane Katrina. The resulting devastation along the Texas coast demonstrated that the entire U.S. Gulf Coast and Eastern Seaboard are now vulnerable to hurricanes and storm surges of increasing power. The contribution of natural capital in protecting people and economic assets need to be considered throughout the Gulf of Mexico and Southern Atlantic seaboard. Hurricanes Gustav and Ike caused tens of billions of dollars in damage, much of which would have been reduced had larger barrier islands and a greater wetland buffer been in place. This first scenario continues the path of reducing natural hurricane buffering. The less nature does its work, the more FEMA will be needed.

The second scenario covers a suite of projects that aim to maintain the current amount of land across the delta so as to "hold the line" and prevent net land loss. The U.S. Army Corps of Engineers adopted this scenario in the 2008 Louisiana Coastal Protection Technical Report (LACPTR). Holding the line provides greater benefits than the first do nothing new, let-it-deteriorate scenario. This option prevents further collapse of the Mississippi Delta and the loss of at least $41 billion in ecosystem services. However, it does not significantly secure greater natural hurricane buffering than what was available the day Hurricane Katrina hit. It will leave New Orleans and other populated areas no better protected by natural systems. This scenario depends on larger and more expensive levees that actually require wetlands as buffers. Hurricanes Katrina, Rita, Gustav and Ike provided an important lesson, recognized by the U.S. Army Corps of Engineers, that levees protected by wetlands perform better and fail less than levees directly exposed to hurricane storm surges. Although this scenario takes into account some lessons from recent hurricanes, it does not grapple with the scale of the problem and potential for success. Deltas on the scale of the Mississippi River Delta are tremendously dynamic, either expanding or shrinking depending on the allocation of vast quantities of water and sediment. Attempting to "hold the line" is not realistic in a deltaic system of this scale. It is more difficult and more costly than actually re-establishing deltaic processes and using the energy and water of the Mississippi River on a larger scale to reap far greater benefits. The “hold the line” scenario is a better strategy than doing nothing but it is not systemic and provides too little investment in the Mississippi Delta. It does not solve the problem at the needed delta-wide scale.

The final scenario, sustainable restoration, implements large-scale, controlled diversions of water and sediment from the Mississippi River to reconnect it to the delta. This will gain ground, restore deltaic processes at the scale that the delta requires to stop land loss and maintain a net expansion of land. It will build a larger natural asset base and yearly provide greater ecosystem services, such as, fisheries production and direct expansion of hurricane buffering before hurricanes hit the levees and inhabited areas. Studies show that diversions and plant growth are sufficient to outpace the expected sea level rise that the Intergovernmental Panel on Climate Change has predicted. This scenario offers the best economic investment in terms of producing the greatest benefits in safety, economic viability and habitability of the Mississippi River Delta. It is also the most resilient option to uncertainty in natural systems, such as climate change and economic uncertainty. Initial investments in diversion structures utilize the energy of the Mississippi River and are inexpensive to operate over the long run.

The lands gained from this scenario will avoid the $41 billion in damage under scenario 1 and produce benefits with an estimated present value of at least $21 billion, bringing in an annual net benefit of $62 billion. This includes partial values of 11 ecosystem services. It does not include the value of increased protection for levees, or avoided catastrophic impacts such as levee breaching. It does not include the benefit of reduced displacement of residents, reduced FEMA, relief and recovery costs, lower insurance rates, lower national oil and gas prices, less litigation, or the benefits of an expanding coastal economy, greater employment, and stability gained for existing communities and residents.

A comparison of the three scenarios - with 27 other criteria including contribution to coastal stability, capacity to expand economic development and protection of water quality and energy infrastructure - show scenario 3 to have the highest ranking by far.

With an expanded Mississippi Delta, prevention of damage from levee failure or the protection of an existing levee infrastructure can provide benefits on the level of tens of billions of dollars in a single hurricane event. These values are difficult to estimate. However, it is clear that a strategy of gaining ground will provide critical natural goods and services such as public safety, storm protection, oil and gas and thereby expand the economic base of the Mississippi Delta and the nation. This is not a cut-the-river-loose scenario, but a managed system of diversions to use sediment and water to provide for public safety and economic benefits.

The economics is clear: invest in the Mississippi River rebuilding the delta to gain ground, physically and economically. On the other hand, ground loss results in loss of nature’s services, causing a hurricane-driven disorderly retreat inland and damaging people and businesses. This analysis strengthens ongoing planning by providing the economic justification for large-scale restoration. It complements efforts such as the State of Louisiana’s Comprehensive Master Plan for a Sustainable Coast and the Multiple Lines of Defense strategy developed by the Lake Pontchartrain Basin Foundation and Coalition to Restore Coastal Louisiana.

Academics, non-profit organizations, state officials, residents and just about every person who studied this issue carefully support the restoration of the Mississippi Delta. Gaining ground provides economic benefits by:

1. Rebuilding land with more than half of the Mississippi River's peak flow water and sediment;
2. Adding economic value including hurricane protection and protection of existing levees;
3. Spurring wetland plant growth soaking up carbon, increasing fisheries production and other benefits;
4. Building land with plant growth that beats sea level rise and land subsidence;
5. Helping stabilize barrier islands increases hurricane protection and coastal stability;
6. Reducing the "dead zone" in the Gulf of Mexico which will increase fisheries and other benefits;
7. Yielding greater ecosystem services for better water quality, wildlife habitat and hurricane protection;
8. Securing the nation's energy infrastructure and inhabitable area of the Mississippi River Delta;
9. Providing a more sustainable, vibrant economy with a higher quality of life; and
10. Setting an example for the nation, Gulf Coast and Eastern Seaboard in natural hurricane buffering.

The use of diversions for restoration is a proven strategy, not an experimental approach. Over 30 years of experience in water and sediment diversion shows that this strategy is successful in building land area and restoring wetlands. The Old River Control Structure diverts water and sediment down the Atchafalaya River; this results in the formation of new deltas in Wax Lake. The diversion at Caernavon is another success for rapid wetland expansion. These examples can be replicated on a much broader scale.

With such a wide range of economic benefits, this report provides a starting point to inform investments in levees, restoration, land use, and economic development in the Mississippi River Delta. This study provides the most comprehensive valuation of natural capital assets in the Mississippi River Delta to date; however, it is still a partial valuation and an underestimate of the delta's total potential economic value. This valuation does not include economically valuable benefits such as navigation, protection of oil and gas infrastructure, and aesthetic value. Even with a wide range of estimates, it points to critical tools that can better inform investments in levees, restoration, land use and economic development in the Mississippi River Delta.

This report shows conclusively that physical sustainability and delta expansion secures vast economic benefits locally and nationally. Within the context of the current financial crisis, investment in restoration secures short-term benefits of employment, income generation, greater ecosystem services and other economic benefits, and the long term goals of increased storm protection, greater oil and gas supply reliability and other economic benefits. A sustainable restoration of the Mississippi River Delta is a good investment with a high rate of return. Gaining ground is the most successful economic strategy for securing hurricane defenses and economic development.

Main Points

1. Mississippi River Delta ecosystems provide economically valuable services including hurricane storm protection, water supply, climate stability, food, furs, habitat, waste treatment, and other benefits worth at least $12-47 billion/year. These annual benefits provide a vast amount of value to people across time.
2. Estimates of the present value of the benefits from 11 Mississippi Delta ecosystem goods and services are between $330 billion and $1.3 trillion (3.5% discount rate).
3. Wetlands – a product of Mississippi River deltaic processes – which include freshwater, saltwater, estuaries, tidal bays, and cypress swamps account for more than 90% of the estimated total value of ecosystem services provided in the Mississippi Delta.
4. Large-scale physical changes are affecting the Mississippi River Delta. These are known facts: hurricanes have become larger and more frequent in the last 30 years, sea level has risen, atmospheric temperatures have risen, and the delta is subsiding and has lost over 1.2 million acres of land since 1930.
5. Three scenarios show that a "do-nothing" approach will cost at least $41 billion in damages. A "hold the line" scenario avoids the $41 billion, without additional benefits. A third "sustainable restoration" option will avoid $41 billion in losses and secure $21 billion in benefits, providing $62 billion in present value.
6. Science has established that large diversions of water and sediment from the Mississippi River are required to rebuild the Mississippi Delta and secure economic benefits.
7. Many ecosystem services with clear economic value could not be estimated in this study. Work is critically needed to further understand the benefits that investments in diversions, levees, or other structures produce.
8. Restoration of the Mississippi River deltaic processes requires a major investment to maintain or expand the vast value of this natural asset. The movement of water and sediment and the maintenance and expansion of land underlies the production of many economic benefits, including protection against hurricanes. Without this investment, people and economic assets will be forced to retreat from the coast.
9. Delta restoration must be based on ecological engineering. High and rising energy costs will erode the economics of energy intensive options such as levees and sediment pumping. Water and sediment diversions utilize the Mississippi River's energy and can easily be maintained throughout many decades.
10. Within the context of the current financial crisis, investment in the restoration of the Mississippi River Delta provides high short and long-term returns. The Army Corps of Engineers, Federal, State and local governments should dramatically increase expenditures for the restoration of the Mississippi Delta.

List of Abbreviations

AC	Avoided Cost
CPRA	Coastal Protection and Restoration Authority
CV	Contingent Valuation
ESV	Ecosystem Services Valuation
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GNP	Gross National Product
GV	Group Value
HP	Hedonic Pricing
IPCC	Intergovernmental Panel on Climate Change
LCA	Louisiana Coastal Area
LSU	Louisiana State University
MRGO	Mississippi River Gulf Outlet
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value
PV	Present Value
RC	Replacement Cost
TC	Travel Cost
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

Introduction

"We are living in a historic moment, one that presents us with a stark choice: either make the bold and difficult decisions that will preserve our state's future, or cling to the status quo and allow coastal Louisiana to wash away before our eyes. There is no longer any time to waste. We must act now or forfeit the possibility that our children and grandchildren will be able to share the life, culture, and resources that are so precious to us and so important to the nation."

Coastal Protection and Restoration Authority of Louisiana, May 2007

A Rich and Enriching Delta

Landscapes, rivers and ecosystems are integral natural capital assets that influence, house, build and shape economies. The greatest concentrations of people and economic productivity have thrived along rivers, especially by coastlines and river deltas. Practically all major US cities have settled by rivers. Mississippi River, the longest in North America, has a basin that comprises 41% of the continental United States covering 1.2 million square miles. The water and soil of the Mississippi Basin flow, as they have for millennia, to the Mississippi River Delta[1] and into the Gulf of Mexico. Engineering on the Mississippi River over the years has removed sediment and water which once expanded the Mississippi River Delta. This has degraded vast areas of the delta and resulted in massive land loss.

The 9,600 square-mile Mississippi River Delta, one of the most productive and expansive river deltas in the world, is an invaluable part of America. Over 2.2 million people live in the delta.[2] The history, music, literature, cuisine, Cajun and Creole culture, and folk songs and stories of the Mississippi River Delta form part of the heart and soul of our nation.

The geology, climate, biological systems, and movement of water and sediment within the Mississippi River Delta sustain its economy and communities. The Mississippi River Delta has 40% of the United States coastal wetlands. It has provided the US and the world a vital navigation route to the mid-western states, oil and gas resources, pipelines, refineries, chemical and fertilizer industries, fisheries, forestry and agricultural production.

Healthy communities and economies need a well-functioning "natural capital", the stock of natural and ecological systems that yield a flow of ecological services and natural resources that benefit people.[3] River deltas shaped the world's first economies. Economies on river deltas expand or shrink with the delta.

Understanding the economic importance of natural capital in the Mississippi Delta requires an assessment of its economic productivity. More importantly, decisions that impact the delta's viability require measurement of the

[1] Reference to the Mississippi River Delta in this report includes the Mississippi River deltaic and Chenier plains.
[2] U.S. Census, 2004
[3] Daly & Farley, 2004

value and benefits that this natural feature provides, such as storm protection, fisheries production, drinking water, recreation, wildlife habitat, and flood protection.

For the past eight decades, management of the Mississippi River Delta has had the primary goal of promoting shipping and the secondary goal of preventing flooding and storm damage. Today, an understanding of nature's contribution to the economy is fast emerging. A healthy economy requires the contributions that natural ecosystems provide, including oxygenated air, the protective ozone layer, a stable climate, clean water, land that does not sink, and protection from flood and storm. Forests, oceans, rivers, and land provide a vast array of benefits that are economically valuable assets.

Eighty years ago, the natural capital and benefits provided by the Mississippi River wetlands and barrier islands were so plentiful that they were viewed as limitless and deemed to be largely without value. Economic goals focused on the expansion of built capital, including roads, houses and levees. Today, built capital is abundant and more people have settled in coastal areas even as protective coastal features, such as wetlands and barrier islands have shrunk and hurricanes have grown stronger. Natural capital providing goods (fish, water) and services (storm protection, recreation) is now scarce and more valuable. The need to protect people and property against the destructive power of hurricanes, while increasing the stock of natural capital, has become more critical.

The barrier islands, coastal wetlands, swamps and uplands all provide buffering against hurricanes. Studies show that wetlands significantly reduce hurricane storm surge.[4] This and the value of other ecosystem services have not been counted as economic benefits. Neither were they included in flood and storm protection analyses that valued only built structures like levees. Valuable natural capital was then squandered. Land, barrier islands and wetlands were needlessly lost – as were the substantial benefits that these ecosystems provide, including hurricane protection.

The loss of valuable natural capital is a national trend, but change is afoot as new analyses and solutions are developed and applied. New Jersey became the first U.S. state to actually conduct a full economic analysis of its natural capital assets.[5] The Puget Sound basin was the first region with a valuation of 12 ecosystem services setting out a new vision of a local economy which includes the economic value of healthy natural systems.[6] On a local scale Earth Economics' recent study on the valuation of ecosystem services demonstrated that salmon restoration along the Green River in Puget Sound provides other ecosystem services, such as recreation and flood protection.[7] Six cities in the U.S., including Seattle, San Francisco and New York, filter drinking water through natural watersheds at costs that are far lower than what water filtration plants require. Most services that healthy ecosystems provide can be secured at far less cost compared to replacing these natural systems with built capital by incorporating these services (for instance, clean water or flood protection) in the management of utilities.[8] This study provides state of the art valuation methods to inform investment decisions.

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[4] Boesch et al. 2006, Day et al. 2007
[5] New Jersey Department of Environment Protection, 2007
[6] Batker et al. 2008
[7] Earth Economics, 2006
[8] Earth Economics, 2006

Knowledge of the Mississippi River Delta's economy is incomplete without measuring the economic productivity of the natural systems (natural capital) in providing hurricane storm protection, fisheries production, drinking water, recreation, wildlife habitat, flood protection and other benefits. Hurricanes Katrina and Rita demonstrated that natural, social and human capital have been undervalued in the decision making process and are now needed for economic analysis and for generating pragmatic and effective solutions.

Eyeing the Storms

Katrina first struck the U.S. near Florida's Broward/Miami-Dade County line as a category 1 hurricane on August 24, 2005. Fueled by the Gulf of Mexico's hot water, it quickly powered up into a massive category 5 hurricane. As Katrina moved inland, it crossed wetlands which then put more physical drag on the storm, slowed its progress, lowered the storm surge and reduced fetch (the area of open water where waves can gain in size and momentum). Figure 1 shows that as the hurricane hit the coastline, it quickly weakened to category 4 and then category 3 by the time it struck the Mississippi-Louisiana border on August 29, 2005 with sustained winds of 125 mph. The hurricane generated a storm surge that exceeded 30 ft along the Mississippi coast.[9] New Orleans experienced storm surges from 14-18 ft.

Figure 1. The track of Hurricane Katrina Showing Changes in Storm Intensity and Spatial Extent

Track of Hurricane Katrina, August 23-29, 2005, showing spatial extent and storm intensity along is path.

Source: NOAA

[9] NOAA, 2005; USACE, 2007

The hurricane storm surge flooding was most severe along the Mississippi coastline and in Louisiana communities where levees and floodwalls failed and wetland buffers had disappeared. Hurricane Katrina directly pummeled the Mississippi River Delta, affecting an area of over 90,000 square miles and over two million people. The communities most impacted include the Birdfoot Delta of the Mississippi River, the Mississippi coast, Slidell and surrounding areas, St. Bernard and Plaquemines parishes and New Orleans.[10]

Wetlands reduce hurricane impact. Hurricanes Katrina and Rita passed through areas of the Mississippi River Delta that had the greatest wetland loss between 1932 and 1990. This includes the Birdfoot Delta of the Mississippi River which lost 50% of its land area, St. Bernard Parish wetlands lost 17.0%, Plaquemines Parish lost 12.0% and the East Orleans land bridge lost 17.6%.[11] If the original wetlands still existed, they would have buffered the storm surge and both hurricanes would have caused far less damage.

Three weeks after Hurricane Katrina struck, category 5 Hurricane Rita cut a far larger swath of destruction, running parallel to the Gulf Coast stretching from Florida to Texas and again flooding parts of New Orleans. It made landfall near Sabine Pass at the Louisiana-Texas border with sustained wind speeds of 120 mph and a storm surge of at least 20 ft. Hurricane Rita's southeasterly approach resulted in a storm surge of at least nine ft that swept through the entire Louisiana coast.

In the 2008 hurricane season, Hurricane Gustav's faster speed in crossing the Gulf of Mexico fortunately prevented the storm from building up a larger storm surge. Had it moved more slowly, it would have generated and hauled a much larger storm surge across the gulf. Striking to the west of New Orleans, the storm surge of Hurricane Gustav was reduced by wetlands in its path. Gustav caused significant damage and again clearly demonstrated the importance of wetlands as barriers to hurricane storm surges.

The severity of hurricane damages in recent years have spurred a lively debate on the full impact of levees and built structures on storm surges. The Army Corps of Engineers now recognizes that the configuration of canals and levees can increase the damage caused by hurricane storm surges. For instance, the Mississippi River Gulf Outlet Canal (MRGO), dredged to provide an extra shipping canal for New Orleans, created a v-shaped funnel as wetlands in the center of the v-shape were lost due to salt water intrusion. Had these wetlands been intact, there would have been less flooding in southeastern New Orleans and St. Bernard Parish and the levee may have held and not been breached. However, as the storm surge waters of Katrina progressed from the wide-open mouth of the v-shape to its closed point, the levees constricted the storm surge waters and increased their height and destructive power. This flushed the storm surge's full force right into New Orleans, overtopping and demolishing the protective levees. This led the Louisiana Legislature and the U.S. Congress to order the permanent closure of the Mississippi River Gulf Outlet Canal. Plans to close the MRGO canal at the Bayou La Loutre ridge have been set.

Wetlands in the "land bridge" once provided a physical barrier to hurricane storm surge waters from the Gulf of Mexico entering Lake Pontchartrain. However, with the severe degradation of these wetlands, the storm surge

[10] Cole, 2005
[11] USGS, 2002

of Hurricanes Katrina and Rita engorged Lake Pontchartrain, levees and sea walls failed below their rating, causing catastrophic flooding and killing people.

Levees can reflect and amplify storm surge waves, unlike wetlands that absorb and resist storm waters without amplifying wave action. The levee along the Birdfoot portion of the Mississippi River may have actually reflected Katrina's storm surge back to the Mississippi coastline, creating an additive effect and increasing the size and power of storm surge waves that struck the coast. The Army Corps of Engineers initially contested this view but accepted it as true after studying the similar effects from Hurricane Gustav.[12]

It is a clear fact that intact natural wetland ecosystems and other natural features provide hurricane protection. It is undeniable that the loss of barrier islands, wetlands, and land over the past several decades has made coastal residents far more vulnerable to hurricanes and storm surge damage. Louisiana lost over 1,875 square miles of wetlands and many of its barrier islands between 1932 and 2000.[13] After the hurricane season of 2005, this number rose to over 2,000 square miles or about 25% of total wetland area that existed at the turn of the century.

Public investment in the restoration of the Mississippi River can restore natural processes which generate real economic value in the form of hurricane protection, recreation, safe land for housing and industry and other benefits. Ignoring the degradation of the Mississippi Delta entails tremendous economic, ecological and social costs.

The Hurricanes' Economic Impact

Hurricanes Katrina, Rita, Gustav and Ike wrought heavy havoc along the U.S. Gulf Coast. Although the damage to built capital can be monetized, the human cost is incalculable. Hurricanes Katrina and Rita alone caused 1,815 deaths in Louisiana and Mississippi[14] with 705 people still deemed missing.[15] FEMA estimated the displaced people at two million in January 2006.[16] The hurricanes exposed the harsh reality of poverty and racism.[17] Neighborhoods and communities that were poor or African American or both still lie in ruin. Some coastal towns remain virtually abandoned. Hundreds of thousands of people remain displaced. The social fabric of the Gulf Coast is yet reeling from the storms' effects. Impeded by physical, legal and economic obstacles, full recovery has been slow to come.

Hurricane Katrina, the most costly natural disaster in U.S. history, caused $200 billion in property damages and economic losses.[18] Both hurricanes damaged 150 miles of levees to the point of requiring reconstruction; wrecked 360,000 homes, 504 schools, 97 hospitals, 570,000 cars, and 70,000 boats;[19] destroyed roads, bridges,

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[12] USACE, 2007
[13] USGS, 2003, also Boesch et al. 2006, Day et al. 2007
[14] Louisiana Department of Health and Hospitals, 2006
[15] Krupa, 2006
[16] Hsu, 2006
[17] Brown University, 2006
[18] U.S. Government Accountability Office, 2006
[19] FEMA, 2006

electric posts, telecommunications, water supply, sewerage, industrial areas, and playgrounds; caused 99% mortality in oyster beds with $1.1 billion in fisheries losses;[20] damaged 365,000 acres in 16 federal wildlife refuges, $1 billion in cropland losses;[21] and spilled 6.5 million gallons of oil.[22]

Property prices fell across the U.S. Gulf of Mexico while insurance rates rose.[23] Katrina shut down over 95% of offshore gulf crude oil production, roughly 27 % of total U.S. crude oil production. It broke pipelines and forced the shutdown of nearly a dozen refineries in eastern Louisiana, Mississippi and Alabama. Hurricane Rita forced the closure of 20 Texas and Louisiana refineries, accounting for more than four million barrels a day or more than 26% of U.S. refining capacity.[24] The disruption of oil and gas pipelines and oil refining in Louisiana caused a spike in the prices of natural gas, gasoline and other petroleum product throughout the U.S. Americans had to pay for the increase in the transportation costs of goods and people.

The increase in construction in Louisiana increased the cost of labor and materials by 20-40 % of the pre-2005 hurricane season; the nationwide increase was 5-10%. This dramatically increased the cost of recovery for insurers and owners across the Gulf Coast.[25] It also increased the price of building materials throughout the South. The legal aftermath of Hurricane Katrina promises to be as costly as the hurricane damage. Katrina produced an unprecedented number of lawsuits involving, among others, FEMA, the U.S. Army Corps of Engineers, levee boards, States, local governments, insurance companies, banks and homeowners.

While experts expect the damage from hurricanes to increase in the coming years, they also agree that this can be mitigated. The costliest hurricanes in history offer lessons we need to heed, the most important of which is the need to rebuild the delta at the scale that significantly reverses land loss.

Restoration Plans and Recent Legislation in Louisiana

Louisiana has developed restoration plans for the Mississippi River Delta. However, Hurricanes Katrina and Rita revealed that because of their limited goals for halting land loss, restoration plans such as the 1998 Coast 2050 Plan and the 2004 Louisiana Coastal Area Plan did not meet the scale of the problem. The Mississippi Delta is dynamic. It has consistently swung between gaining and losing land, but not to the extent of the net land loss in the past century. Meeting the goal of stopping land loss cannot be accomplished through levees and small projects. It requires a fundamental shift toward large diversions – moving vast quantities of water and sediment into the delta and out of the Mississippi River where it would be dumped off the continental shelf. Models and analyses of the impacts of wetlands and Hurricanes Katrina and Rita on flooding and storm surges now stress the need[26] to build land, sequester carbon and secure hurricane buffering and other services.

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[20] Gaddis et al., 2005
[21] Center for the Study of Rural America, 2005
[22] EPA 2005
[23] Fletcher, 2005
[24] Federal Trade Commission, 2006
[25] McCormack, 2006
[26] Farley, Batker, & Pittman, 2006

In recognition of this weakness and in response to the 2005 storms, the Louisiana Legislature approved Act 8 creating the Louisiana Coastal Protection and Restoration Authority (CPRA) to develop and implement a comprehensive and integrated plan to restore the coastal wetlands and barrier islands. CPRA produced a master plan with the core objective to "Promote a sustainable coastal ecosystem by harnessing the processes of the natural system."[27] This plan outlines the need for a large-scale restoration of the Mississippi River Delta.

This objective includes the use of the Mississippi River's water and sediment to reestablish water flow and sediment delivery.[28] This comprehensive approach will provide a full basket of ecosystem service benefits including hurricane protection and flood protection, internationally significant fish and wildlife habitat, water quality, regionally and nationally important port facilities, navigable waterways, fuel processing capacity and the unique culture of the area.[29] Effective coastal restoration calls for a recognition of how the economy is dependent on a stable, healthy and expanding Mississippi Delta.

The State of Louisiana is moving forward with a new vision of restoration in the Mississippi Delta. In addition, citizen's organizations such as the Lake Pontchartrain Basin Foundation and Coalition to Restore Coastal Louisiana have outlined a Multiple Lines of Defense strategy, which also restores basic deltaic processes and is integrated with levees and built structures to provide effective hurricane protection.[30] However, the investment resources for implementing a comprehensive restoration are lacking. Understanding the importance of natural capital to the local and national economy is a relatively new revelation in economics. It provides a new view of the economy and a better insight into the local and national value of investing in natural capital.

Part I: A New View of Value in the Mississippi River Delta

The field of economics has advanced significantly in recent years improving our ability to quantify the value of goods and services provided by nature. These advances include new concepts and techniques such as "natural capital" and ecosystem service valuation. The sophistication and applicability of ecosystem service valuation has also rapidly expanded.[31] This section provides basic concepts and methods used for assessing the value of ecosystem services in the Mississippi River Delta.

Natural Capital

Natural Capital and Asset Management

In the 1930s, human-built capital was scarce; the expansive wetlands of the Mississippi River Delta were considered a wasteland. Natural goods sourced in the wetlands such as timber, fish and oil were viewed as limitless. Economic development was seen as the conversion of otherwise untapped natural resources into built capital or useful marketable goods. However, natural systems produce benefits and public goods – such as

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[27]Coastal Protection and Restoration Authority, 2007a
[28] CPRA 2007a
[29] CPRA 2007a
[30] Lake Pontchartrain Basin Foundation, 2008
[31] Limburg, O'Neill, Costanza, & Farber, 2002

breathable air and hurricane protection – without human labor, fees or restriction (everyone can breathe the air and everyone living behind wetlands receives storm protection). Because these "public goods" cost nothing and could not be privatized or traded in markets, they were deemed to have no economic value. Today, however, markets produce a vast abundance of goods such as cloths, toys, asphalt and food for a lower real cost while nature's goods and services have become relatively scarcer and increasingly valuable. Given the loss of healthy ecosystems, the valuation of natural capital helps decision makers identify costs and benefits, evaluate alternatives and make effective and efficient management decisions. Excluding natural capital in investment decisions or asset management can result in significant losses, increased costs (public and private) and decreases in efficiency and community benefit.

Understanding Natural Capital

Natural capital is comprised of the geology, nutrient and water flows, native plants and animals, and the network of natural processes that yield a continuing return of valuable benefits.[32] It contributes to our economy and quality of life in many ways that are not currently included in market transactions or policies. In fact, most decision makers and the citizens are not aware of the full economic value of natural systems. Natural capital contributes to the provision of water, natural water filtration, energy production, flood control, recreation, natural storm water management, biodiversity, discovery of new medicines, and education. Ecosystems are defined as all the interacting living and nonliving elements of an area of land or water. Ecosystem functions refer to the processes of transformation of matter and energy in ecosystems. Ecosystem goods and services are the benefits that humans directly and indirectly derive from naturally functioning ecological systems.[33] They are the flux of value provided from intact natural capital to people. For something to be classified as an ecosystem good or service, it must benefit people.

The Economics of Natural Capital

Healthy ecosystems are self-maintaining. They have the potential to appreciate in value over time and to provide an ongoing output of valuable goods and services in perpetuity. In contrast, built structures and other man-made capital depreciate in value over time and require capital investment, operations and maintenance. The provision and filtration of water is a good example.

The city of New York requires a daily supply of more than one billion gallons of water. Facing degraded drinking water quality, New York City weighed its options between building a water filtration plant costing over $6 billion and that of investing $1.5 billion to restore the health of the watershed thereby allowing natural processes to filter the water and meet drinking water standards. The city decided to invest in the watershed. Investment in restoration has proved to bring a far higher rate of return; it is less costly and less risky for meeting standards. The cities of Seattle, Tacoma, Portland and San Francisco have maintained forested watersheds that supply water at above drinking water standards. With forests filtering water for drinking, the cities of Seattle and Tacoma have avoided capital construction for water filtration plants that would have cost $250 million and $150 million respectively. In addition, filtration plants would require maintenance and replacement while the forest is essentially a self-maintaining water supply and filtration system. If the value of

[32] Daly & Farley, 2004
[33] Costanza et al., 1997; Daily, 1997; De Groot et al., 2002; Wilson, Troy & Costanza, 2004

these ecosystems is not recognized and they are degraded, we may well lose these critical benefits and be forced to replace least-cost natural systems with more costly built capital replacements.

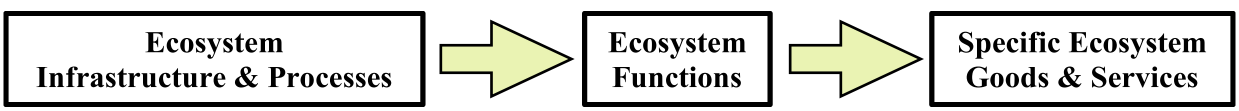
Ecosystems and Value

Ecosystems and Value Production

Ecosystems are comprised of structural components (trees, wetland plants, soil, hill slopes, etc.) and dynamic processes (water flows, nutrient cycling, animal life cycles, etc.) that create functions (water catchment, soil accumulation, habitat creation, reduced fetch, obstructions to hurricane storm surges, etc.) that generate ecological goods (fish, timber, water, oxygen) and services (hurricane and flood protection, water filtration, recreation, aesthetic value, etc.). Figure 2 below summarizes these relationships in a simplified diagram.

Ecosystem infrastructure has particular physical components such as the salt, brackish, intermediate and fresh marshes and swamps of the Mississippi Delta. The infrastructure itself is dynamic; biotic structures migrate and abiotic components flow through the delta, often via air or water. For example, the lobes of the Mississippi River Delta show great dynamism in the deposition of historical sediments. These functions vary widely in spatial boundaries (oxygen migrates globally while shrimp spawning and production are confined locally). Thus ecosystems may provide benefits that extend globally (carbon sequestration) or locally (drinking water production). These structures, processes and functions combine to produce economically valuable goods and services.

Figure 2. Relationship of Ecosystems to the Goods and Services Produced



Valuation of Ecosystem Services

Ecosystem service valuation assigns a dollar value to goods and services provided by a given ecosystem. This allows for proposed management policies to be considered in terms of their ability to improve ecological processes that produce the full diversity of valuable ecosystem goods and services. This study will provide the low and high value estimates for some of the goods and services provided in the Mississippi River Delta.

Ecosystem Goods and Their Valuation

Most goods that the Mississippi River Delta provides – such as water, timber, fish, and furs – are excludable. If one individual owns or uses a particular good, that individual can exclude others from owning or using the same. For instance, if one person eats an apple, another person cannot eat that same apple. Excludable goods can be traded and valued in markets.

The production of goods can be measured by the physical quantity produced by an ecosystem through time. This is known as a flow of benefits; for instance, the volume of water production per second, the board feet of timber production in a 40-year rotation, or the weight of fish harvested each year. The current production of goods can be easily valued by multiplying the quantity produced by the current market price. This production creates a flow of economically valuable ecosystem goods over time.

Ecosystem Services and Their Valuation

Ecosystem Services Defined

Ecological services are defined as "the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfill human life."[34] Ecosystems provide a variety of services that individuals and communities use and rely on, not only for their quality of life but also for economic production.[35] Ecosystem services are measurable benefits that people receive from ecosystems.

The stream of services provided by an ecosystem, referred to as a "service flux," cannot be measured as the physical quantity of a product produced, and is then far more difficult to measure and value. Examples of this are the hurricane buffering of wetlands, water filtration and recreational value.

Most ecosystem services are non-excludable. Wetlands provide hurricane buffering to all who live behind them, aesthetic value to anyone who looks at them, and flood protection for everyone living downstream. Due to this non-excludability, most ecosystem services cannot be traded or sold in markets.

Table 1. Examples of Ecosystem Services

Examples of Ecosystem Services
Purification of the air and water
Mitigation of hurricanes, floods and droughts
Recreation
Detoxification and decomposition of wastes
Generation and renewal of soil and soil fertility
Pollination of crops and natural vegetation
Control of the vast majority of potential agricultural pests
Dispersal of seeds and translocation of nutrients
Maintenance of biodiversity
Protection from the sun's harmful ultraviolet rays
Partial stabilization of climate
Moderation of temperature extremes and the force of wind and waves
Support of diverse human cultures
Provision of aesthetic beauty

Source: Daily et. al, 1997

[34] Modified from Daily et al., 1997
[35] Daily, 1997; Costanza et al., 1997

Structure and Value Production

The quality, quantity, reliability and combination of goods and services that the ecosystems in the Mississippi Delta provide depend on the structure and health of these ecosystems. Structure refers to a specific arrangement of ecosystem components. For instance, the steel, glass, plastic and gasoline that comprise a car must retain a very particular structure to provide transportation service. These very same components cannot provide transportation without a car's structure. Shrimp require certain ecological processes, structures and conditions. Ecological service production is more dependent on structure than the flows of goods. A single species timber plantation may yield a flow of goods (timber) but it cannot provide the same service fluxes (biodiversity, recreation and flood protection) as an intact natural forest.

Integrated Ecosystems and Multiple Benefits

A heart or lungs cannot function outside the body. Neither can the human body function without a heart and lungs. With all the organs functioning, a body can perform many tasks. Good bodily health requires organs to work as part of a coordinated system. The same is true for ecosystems. Interactions between the components make the whole greater than the sum of its individual parts. When separated, each of the physical and biological components of the Mississippi Delta would not be capable of generating the same goods and services that the processes and functions of an intact watershed system provide.[36] The sheet flow of water across the Mississippi Delta for example, maintains wetlands across salinity gradients. Intact ecosystems provide a full basket of goods and services. The Mississippi Delta provides fish, land for habitation and industry, storm protection, clean water, recreation and flood control. Built structures, such as levees or fish hatcheries, may replace only one function, but not the full basket of goods and services. Ecosystems are engines of economic productivity and systems of significant complexity. Individual services influence and interact with each other, often in nonlinear ways. They may collapse if they are stressed beyond critical thresholds. For example, the "dead zone" is an area the size of New Jersey, off the outlet of the Mississippi River created by the nutrient load, plankton bloom and oxygen depletion. This productive area has collapsed ecologically and economically.

Resilience

Resilience refers to the potential of a system to return to a previous state after disturbance. A system is assumed to be fragile when resilience is low. Fragile systems tend to be replaced after disturbance, for example wetlands are converted to open water which produce reduced amounts of ecosystem services and provide less economic value.[37] While symptoms of disturbance may appear when an ecosystem is on the verge of collapse, with the exception of a few well-studied systems,[38] there is little science available to show the minimum threshold of ecosystem infrastructure that is needed to stop the breakdown of services. Likewise, ecosystems have been shown to be quite resilient; in some cases, ecosystem health improves when restoration projects are initiated. Wetlands in coastal Louisiana provide a great example. Thresholds of stress cause loss of large areas of wetlands. Experience in rebuilding wetlands with renewed inputs of sediments and nutrients from the Mississippi River have secured greater resiliency.[39] Subsidence, a natural process, is a characteristic of the Mississippi Delta and all major deltas. It is the lowering of the surface of the land due to compaction,

[36] EPA, 2004
[37] Gunderson & Holling, 2002 also Day et al. 1997
[38] Carpenter & Gunderson, 2001
[39] Tibbets, 2006

consolidation and dewatering of sediments.[40] In order to survive subsidence, wetlands must build upwards at the same rate that the land is sinking and sea level is rising (this is called relative sea level rise or RSLR). Under natural conditions, the Mississippi Delta was highly dynamic and resilient. The delta loses wetlands in some areas and gains in others, but expanded overall despite subsidence and sea level rise. The elimination of sediment and water from the river to most of the delta (it was channeled by levees off the continental shelf) initiated the collapse of wetlands with pervasive changes in hydrology.

Value Production in Perpetuity

The Mississippi Delta has contributed to human economies for thousands of years. This is evidenced by numerous sites where Native Americans lived. Healthy intact ecosystems are self-organizing (require no maintenance) and do not depreciate. They can provide valuable ecological goods and services on an ongoing basis "in perpetuity." A forest can provide water control, flood protection, aesthetic and recreational values, slope stability, biodiversity, water filtration and other services without maintenance costs. This differs from human-produced goods and services (cars, houses, energy, telecommunications, etc.) that require maintenance expenditures, dissipate, may depreciate and usually end up discarded, requiring further energy inputs for disposal or recycling. The benefits that a natural capital provides can be quickly and permanently lost with mismanagement. The loss of an ecosystem's natural flood or storm prevention functions will result in large, long-term and accelerating costs to private individuals, businesses, communities and governments. They either suffer increased storm and flood damage or pay for expensive and often less effective engineering solutions. As the health of ecosystems decline, the natural and economically valuable services are lost. Taxpayers, businesses and governments then incur damage, repair or replacement costs and higher insurance premiums (or loss of access to insurance). When ecological services are restored, the reverse dynamic can occur.

Greatly altered or degraded ecosystems, like those in the Mississippi River Delta, require a combination of built structures, such as water and sediment diversion structures, to restore natural processes and provide the greatest benefits for people. Understanding the value of natural capital is important for all decision makers, from individual residents to corporations, and local and federal governments. All hold assets, earn income, or participate in the long-term economic planning for the region; all would be better off knowing the importance and value of Mississippi River Delta natural systems.

23 Ecosystem Services

De Groot et al. categorized ecosystem services based on the processes and functions they perform to the benefit of humans (see Table 2).[41] Grouped into four categories (regulation, habitat, production, and information), these functions amount to 23 ecological services. The regulation and habitat functions are considered essential before production and information functions can be active.[42] The following table defines and describes ecosystem services that flow from most ecosystems, including those in Coastal Louisiana. The next section gives a more detailed description of wetland ecosystem services.

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[40] Day et al. 1977
[41] De Groot et al. 2002
[42] De Groot et al. 2002; Wilson et al. 2006

Table 2. Categories of Ecosystem Dynamics with Corresponding Goods and Services

Functions		Ecosystem Infrastructure and Processes	Examples of Goods and Services
Regulation Functions		*Maintenance of essential ecological processes and life support systems*	
1	Gas regulation	Role of ecosystems in bio-geochemical cycles	Provides clean, breathable air, disease prevention, and a habitable planet
2	Climate regulation	Influence of land cover and biological mediated processes on climate	Maintenance of a favorable climate promotes human health, crop productivity, recreation, and other services
3	Disturbance prevention	Influence of ecosystem structure on dampening environmental disturbances	Prevents and mitigates natural hazards and natural events that are generally associated with storms and other severe weather
4	Water regulation	Role of land cover in regulating runoff and river discharge	Provides natural irrigation, drainage, channel flow regulation, and navigable transportation
5	Water supply	Filtering, retention, and storage of fresh water (e.g. in aquifers and snow pack)	Provision of water for consumptive use, includes both quality and quantity
6	Soil retention	Role of vegetation root matrix and soil biota in soil retention	Maintains arable land, prevents damage from erosion, and promotes agricultural productivity
7	Soil formation	Weathering of rock, accumulation of organic matter	Promotes agricultural productivity and the integrity of natural ecosystems
8	Nutrient regulation	Role of biota in storage and re-cycling of nutrients	Promotes health and productive soils; gas, climate, and water regulations
9	Waste treatment	Role of vegetation and biota in removal or breakdown of xenic nutrients and compounds	Pollution control/detoxification; filtering of dust particles through canopy services
10	Pollination	Role of biota in movement of floral gametes	Pollination of wild plant species and harvested crops
11	Biological control	Population control through trophic-dynamic relations	Provides pest and disease control, reduces crop damage
Habitat Functions		*Providing habitat (suitable living space) for wild plant and animal species*	
12	Refugium function	Suitable living space for wild plants and animals	Maintenance of biological and genetic diversity; thus the basis for most other functions
13	Nursery function	Suitable reproduction habitat	Maintenance of commercially harvested species
Production Functions		*Provision of natural resources*	
14	Food	Conversion of solar energy into edible plants and animals	Hunting, gathering of fish, game, fruits, etc.; small scale subsistence farming and aquaculture
15	Raw materials	Conversion of solar energy into biomass for human construction and other uses	Building and manufacturing; fuel and energy; fodder and fertilizer
16	Genetic resources	Genetic material and evolution in wild plants and animals	Improves crop resistance to pathogens and pests
17	Medicinal resources	Variety in (bio)chemical substances in, and other medicinal uses of, natural biota	Drugs, pharmaceuticals, chemical models, tools, test and assay organisms

18	Ornamental resources	Variety of biota in natural ecosystems with (potential) ornamental use	Resources for fashion, handicraft, jewelry, pets, worship, decoration and souvenirs
Information and Cultural Functions		*Providing opportunities for cognitive and spiritual development*	
19	Aesthetic information	Attractive landscape features	Enjoyment of scenery
20	Recreation	Variety in landscapes with (potential) recreational uses	Travel to natural ecosystems for eco-tourism, outdoor sports, etc.
21	Cultural and artistic information	Variety in natural features with cultural and artistic value	Use of nature as motive in books, film, painting, folklore, national symbols, architecture, advertising, etc.
22	Spiritual and historic information	Variety in natural features with spiritual and historic value	Use of nature for religious or historic purposes (i.e., heritage value of natural ecosystems and features)
23	Science and education	Variety in nature with scientific and educational value	Use of natural systems for school excursions, etc. Use of nature for scientific research

Source: De Groot et al. 2002

Because decisions turn out to be very costly when the contributions of natural capital to economic activity are not counted,[43] interest in identifying, describing and quantifying the economic value of ecosystem services to improve decision making have increased through the years.[44] This is particularly relevant in coastal areas given that preliminary estimates of the global economic value of coastal (including large estuaries) and marine ecosystems show that are two-thirds of total ecosystem service value of all systems on earth.[45] It is crucial to understand how economic value shifts with changes in natural systems, especially along coastal systems with high development and extraction pressures.[46]

Deriving economic values for ecosystem services is a complex undertaking. Ecosystem services are different from private goods because they do not easily lend themselves to pricing and markets.

Ecosystem functions, and the services they produce, result from broad interactions across large landscapes (e.g., storm buffering) or, in some cases, the whole planet (e.g., climate and carbon sequestration). These interdependent systems make life possible; providing for climate, oxygen, nutrient cycles, water and energy flows, and the movements of seeds. This interdependence and tremendous scale of operation makes nature the best producer of these goods and services. It would be impractical and undesirable to attempt to set up human institutions, markets and factories to provide for global climate regulation, oxygen production and provision of water. [47] It is far better economics to avoid wrecking productive natural systems, or to restore them when damaged, than attempt to displace or do without them.

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[43] Daly & Farley, 2004
[44] Daily, 1997; Costanza et al., 1997; Balmford et al., 2002
[45] Costanza et al., 1997; Costanza 1999
[46] UNEP, 2005
[47] Daly & Farley, 2004

Natural systems like the Mississippi Delta are part of our common wealth. Many are ***public goods and services***. Ascribing economic value to these ecosystem services helps policy makers and the public decide how to allocate public funds for the common good.[48]

Valuation Techniques

Ecosystem goods and services may be divided into two general categories: ***market*** and ***non-market***. Measuring market values simply requires monitoring market data for prices and quantities sold. This production creates a flow of ecosystem goods that have a market-defined economic value over time.

The non-market values of goods and services are more difficult to measure. When there are no explicit markets for services, the more indirect means of assessing values must be used. Table 3 identifies a spectrum of valuation techniques that are commonly used to establish values when market values do not exist. It also summarizes the appropriateness of each technique for different types of services.

Table 3. Valuation Methodologies

Avoided Cost (AC): services allow society to avoid costs that would have been incurred in the absence of those services; storm protection provided by barrier islands avoids property damages along the coast.
Replacement Cost (RC): services can be replaced with man-made systems; nutrient cycling waste treatment provided by wetlands can be replaced with costly treatment systems.
Factor Income (FI): services provide for the enhancement of incomes; water quality improvements increase commercial fisheries catch and the incomes of fisherfolk.
Travel Cost (TC): service demand may require travel whose costs can reflect the implied value of the service; recreation areas attract distant visitors whose value placed on that area must be at least what they were willing to pay to travel to it, including the imputed value of their time.
Hedonic Pricing (HP): service demand may be reflected in the prices people will pay for associated goods; for example, housing prices along the coastline tend to exceed the prices of inland homes.
Marginal Product Estimation (MP): service demand is generated in a dynamic modeling environment using a production function (Cobb-Douglas) to estimate the change in the value of outputs in response to a change in material inputs.
Contingent Valuation (CV): service demand may be elicited by posing hypothetical scenarios that involve some valuation of alternatives; for instance, people generally state that they are willing to pay for increased preservation of beaches and shoreline.
Group Valuation (GV): this approach is based on principles of deliberative democracy and the assumption that public decision making should result, not from the aggregation of separately measured individual preferences, but from *open public debate.*

Source: Costanza et al. 2006

[48] Costanza, 2006

Table 4. Appropriateness of Valuation Methodologies for Ecosystem Service Type[49]

Ecosystem Service	Amenability to Economic Valuation	Most Appropriate Method for Valuation	Transferability Across Sites
Gas regulation	Medium	CV, AC, RC	High
Climate regulation	Low	CV, AC, RC	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC, P	High
Water regulation	High	M, AC, RC, H, P, CV	Medium
Soil retention	Medium	AC, RC, H	Medium
Waste regulation	High	RC, AC, CV	Medium to high
Nutrient regulation	Medium	AC, RC, CV	Medium
Water supply	High	AC, RC, M, TC	Medium
Food	High	M, P	High
Raw materials	High	M, P	High
Genetic resources	Low	M, AC	Low
Medicinal resources	High	AC, RC, P	High
Ornamental resources	High	AC, RC, H	Medium
Recreation	High	TC, CV, ranking	Low
Aesthetics	High	H, TC, CV, ranking	Low
Science and education	Low	Ranking	High
Spiritual and historic	Low	CV, ranking	Low

Adapted from Farber et al. 2006

These tables show that each valuation methodology has its own strengths and limitations, often limiting its use to a select range of ecosystem goods and services within a given landscape. For instance, the value generated by a naturally functioning ecological system in the treatment of wastewater can be estimated by using the replacement cost (RC) method which is based on the price of the cheapest alternative for obtaining that service (the cost of chemical or mechanical alternatives). A related method, avoided cost (AC) can be used to estimate value based on the cost of damages due to lost services. This method was used to value the flood protection services provided by restored habitats and functions within the flood plain. Travel cost (TC) and contingent valuation (CV) surveys are useful for estimating recreation values while hedonic pricing (HP) is used for estimating property values associated with aesthetic qualities of natural ecosystems. Contingent valuation surveys and conjoint analysis can be used to measure existence value of ecosystems and charismatic animals. Marginal product (MP) estimation has generally been used in a dynamic modeling context; it helps examine how ecosystem service values change over time. Finally, group valuation (GV), a more recent addition to the

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[49] This table is adapted from Farber et al. 2006. Some changes are based on our opinion on appropriateness of some techniques for some services.

valuation literature, directly addresses the need to measure social values in a group context. In many applications, the full suite of ecosystem valuation techniques will be required to account for the economic value of goods and services provided by a natural landscape.

Not all ecosystem services listed in Table 4 were readily valued; for some services no valuation studies have yet been conducted. Very important services such as climate regulation, genetic resources, and spiritual and historical significance have low valuation amenability. In addition, nutrient cycling usually receives relatively low values even though life on the planet would not be possible without it.[50]

The diverse structures and processes associated with the landscapes creating ecosystem goods and services that benefit people are linked together. Once valuable ecosystem services are identified, values for some of these goods and services can be assessed where valuation techniques exist. It is easier to note that a service is valuable to people than to attach a dollar value to it. In economic terms, the natural assets of the landscape can yield direct (fishing) and indirect (nutrient regulation) use values as well as non-use (preservation) values of the system. Once accounted for, these economic values can be aggregated to estimate a more complete value of benefits that the landscape provides.

Methodology

Value Transfer Method

A value transfer study appraises the value of ecosystem services in a geographic area based on previously conducted primary valuation studies. Individual primary valuation studies are generally conducted for one or a small number of services in one ecosystem or land-use type using the methods described above. These local studies are precise for individual ecosystem services, but are incomplete, lacking the scope across ecosystems and services necessary to be instructive for policy work at a landscape scale. Conducting primary research for the Mississippi River Delta and examining a wide number of ecosystem services across ecosystems would require over 50 primary studies to cover the full suite of ecosystem services across each vegetation type. It would require an enormous budget and take many years of research. Primary studies are required, and must proceed. The need for more comprehensive value estimates of these values, which can be useful for policy decisions, gave rise to the value transfer method.

Value transfer method involves using existing on-site or, if unavailable, off-site primary valuation studies or data to estimate the value of ecosystem services. Following Desvouges et al., this study uses the term 'value transfer,' instead of the more commonly used term 'benefit transfer,' to reflect the fact that the transfer method is not restricted to economic benefits and can include the analysis of potential economic costs as well as value functions themselves. The transfer method involves obtaining an economic estimate for the value of non-market services through the analysis of a single study, or group of studies, that have been previously carried out to value similar services. The transfer itself refers to the application of values and other information from the original 'study site' to a new 'policy site'.[51]

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[50] UNEP, 2005

[51] Desvouges et al., 1998; Loomis 1992; Smith 1992

This methodology is much like a house appraisal. An appraisal is conducted to provide an estimate of the house's value before the house is put up for sale. A very rough "appraisal" of the house's value can be provided by examining the values of similar houses in the neighborhood or other similar areas and by taking into account particular characteristics, such as an extra bedroom or a bad roof.

Public agencies are increasingly using the value transfer method to inform landscape management decisions.[52] Despite acknowledged limitations, such as context sensitivity of value estimates, existing studies provide a credible basis for policy decisions involving sites other than the study site for which the values were originally estimated. Using the studies that bound low and high values reflects the uncertainty that is implicit to using valuation studies that are older or from another site. The critical underlying assumption, just as in a house appraisal, is that a range in the economic value of ecosystem goods or services provided by existing valuation studies can encompass the site value with sufficient accuracy to be useful. Without this methodology, decision makers have in effect ascribed a zero value to natural services over the past decades.

The accuracy of the value transfer technique improves with increases in the richness, extent and detail of information of the source literature.[53] With the increasing sophistication and number of empirical economic valuation studies in peer-reviewed literature, the value transfer method has become a practical way to inform decisions when budget and time constraints preclude full primary data collection.[54] Although the literature is yet far from complete, the Mississippi River Delta has one of the world's richest collections of primary research on ecosystem service valuation for wetlands. The reference section includes studies by Day, Costanza, Farber, Boesch and others.

There are two parts to this economic analysis. The first part shows the value of ecosystem services from wetlands, with some of the data filled in with studies from wetlands other than the Mississippi River Delta. We also provide similar value transfer results from ecosystem services for non-wetland ecosystem types within the coastal zone that will be affected by loss of wetlands and will therefore be less habitable in the coming decades. Ecosystems and their services will be less valuable to people in the coastal areas if they can no longer live there. Many ecosystems are already less functional, as in the case of fresh water lakes, due to wetland loss and saltwater intrusion.

We then synthesize results and primary data on wetlands functions and values to come up with a value for the specific ecosystem services and functions for which there is Louisiana-specific information. This approach leads to a range of values that carry fewer uncertainties associated with economic results transferred from different sites. These results are underestimates; they provide a high quality "lower bound" set of values of ecosystem services for coastal wetlands in the Mississippi River Delta.

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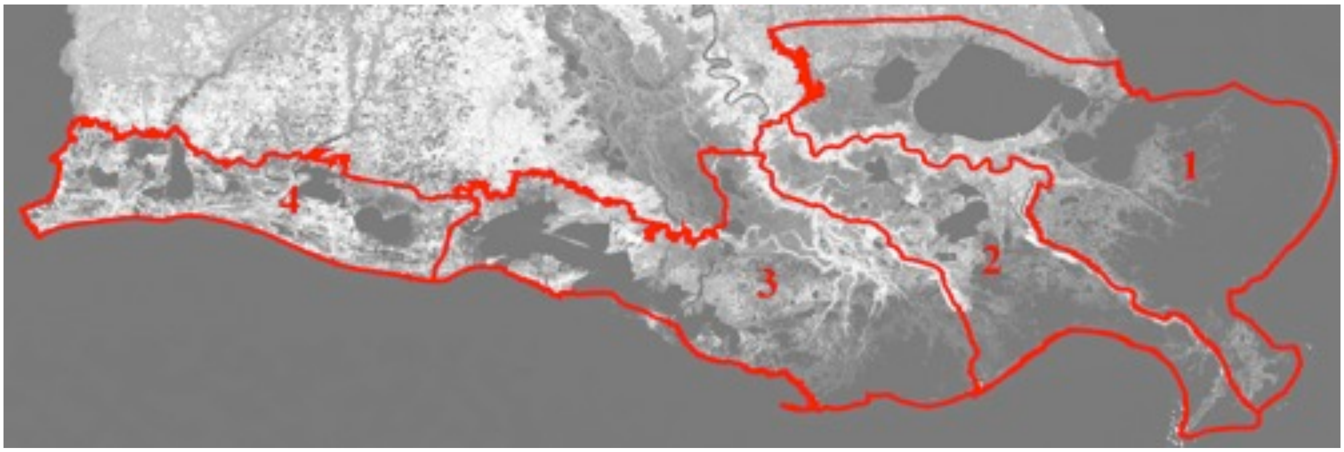
[52] Downing & Ozuna, 1996; Eade & Moran, 1996; Kirchoff et al., 1997; Smith, 1992, Troy and Wilson, 2006
[53] See Spash and Vatn, 2006 for an alternative perspective
[54] Kreuter et al. 2001; Moran 1999

Area of Study and GIS data

Figure 3 shows the geographic boundary of our study area. The Mississippi Deltaic Plain (Units 1-3) and the Chenier Plain (Unit 4) are divided into four subprovinces or units by the U.S. Geological Survey and the State of Louisiana. This includes the wetlands and upland ecosystems that are valued in this study.

Figure 3. Geographic Boundary of Study Area



Source: USGS

Units 1, 2 and 3 form part of the Mississippi River Delta while unit 4 holds the Chenier Plain. All four units comprise the Mississippi River Delta in this report.

Geographic Information Systems (GIS) data for six wetland types in the four subprovinces of the Mississippi Deltaic and the Chenier Plains were used based on 2000 data provided by the US Geological Service.[55] Table 5 shows acres of wetland type by subprovince.

Table 5. Acres of Wetland by Type and Subprovince

Subprovince	Fresh Wetlands	Intermediate Wetland	Brackish Wetlands	Saline Wetlands	Shrub/Scrub Wetlands	Wetland Forest
1	75,388	137,084	154,070	126,484	31,268	345,465
2	168754	78,650	63,603	123,327	22,260	286,864
3	337,266	277,118	134,583	31,032	16,915	10,416
4	295,690	168,080	195,189	140,717	50,823	388,815
Total	**877,099**	**660,933**	**547,445**	**421,561**	**172,106**	**10,311,561**

[55] Kreuter et al. 2001; Moran 1999

Ecosystem Service Valuation Studies

Ecosystem service values were derived from delta-specific data for eight ecosystem services. These are carbon sequestration (gas regulation, see Table 1), water quality (nutrient regulation), water supply, fisheries (food provisioning), fur and alligator production (raw materials production), recreation (cultural and information services), storm protection (disturbance regulation) and cultural value. Details of how we calculated service values or which ones we chose from the literature follow. Louisiana-specific data were not available for all ecosystem services. To provide a more complete estimate, the values for other ecosystem services were based on studies conducted outside Louisiana. Part II of this study discusses the valuation of ecosystem services.

PART II: The Value of Mississippi River Delta's Natural Capital

Mississippi River Delta Ecosystem Services

Below are descriptions of the subset of the ecosystem services identified in Table 2, which were considered in this study. The function of the ecosystem service and the economic value derived are discussed. Ecosystem services often have multiple benefits within each category; it may be possible to value only one or two of these multiple benefits. For example, while wetlands may provide recreation in the form of hunting, fishing, boating, birding and swimming, only one of these benefits may have actually been quantified. This is one reason economists typically view most valuation estimates as conservative.

Water Supply

While some rely on groundwater, most communities in southern Louisiana rely on fresh surface water for their water supplies. Wetlands protect the water supplies of coastal communities by preventing the intrusion of salt water into surface and groundwater supplies. As wetlands retreat, saltwater moves through open water areas where wetlands once existed or seeps into freshwater aquifers, contaminating surface and underground waters. Farber estimates the cost for groundwater-dependent communities to develop alternative sources under future wetland loss scenarios. Farber uses the replacement cost method for groundwater-dependent communities to develop pump and main infrastructure that would deliver water from other communities.[56]

Laska notes that communities that depend on surface water from rivers and bayous rely on coastal wetlands to prevent saltwater intrusion. Laska does not provide economic value estimates for this service. Wetland loss will mean increased salinity problems for these communities.[57] Figures for this service were derived from the replacement cost of desalinization plants for 19 coastal parishes in Louisiana and the population of 2.2 million people they serve. Desalinization of brackish water is less expensive than estuarine saltwater. Assuming that the average American uses 90 gallons of water per day, this amounts to an annual 72.3 billion gallons of water use in the Louisiana coast. Using figures from the American Water Works Association, a "low" cost of $1.50/1000

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[56] Farber, 1996

[57] Laska, 2005

gallons and a "high" cost of $4/1,000 gallons were established. This gives values of $46.67 and $124.47 on a per acre-year basis in 2007 dollars.[58]

Some economists argue that replacement costs provide "upper bound" estimates of ecosystem services values. The replacement cost method is appropriate for valuing the water supply functions of the Mississippi River Delta's wetlands because there are no other alternatives except human-engineered replacements for the provision of freshwater to many communities. In addition, human-built systems, such as a desalinization plant, are more vulnerable to hurricanes damage. Thus the replacement costs may be considerable underestimates because a plant may be destroyed prior to the expected lifetime of the facility. Built replacement options, such as desalinization, are in fact more vulnerable to damage or destruction under conditions of wetland loss. Thus, replacement cost method for human-engineered systems may greatly underestimate the true costs of supplying drinking water.

Water Quality (Nutrient Regulation)

Excess nitrogen, phosphorous, bacteria such as fecal coliform, and other pollutants in water reduce the quality of water for drinking, recreation, agriculture and industrial purposes. Wetlands have a very high capacity to absorb and process excess nutrients as well as destroy harmful bacteria. The Mississippi Delta wetlands absorb nutrients and reduce the "dead zone" or hypoxic area in the Gulf of Mexico (further discussed below). Wetlands are eutrophic systems that are able to process large quantities of nitrogen and phosphorous and rapidly sequester carbon. These benefits are provided throughout the Mississippi Delta.

Many coastal Louisiana studies have examined nutrient removal, primarily as a substitute for tertiary sewerage treatment by towns and industries particularly using swamp forests.[59] Wetland-based filtration provides the benefit of being much less energy intensive than "traditional" wastewater treatment;[60] it can also increase the growth rates and carbon sequestration[61] by bald cypress.[62] More than 15 communities in coastal Louisiana have wetland assimilation systems. These systems proved to be far more resilient to hurricane damage than traditional systems. New Orleans is now pursuing what will be the largest wetland treatment system in the U.S.; it will use wastewater to fertilize 30,000 acres of bald cypress swamp that will in turn be a critical hurricane buffer for the city.

Economic values for wetlands depend on state and federally imposed water quality standards. Most rely on the replacement cost method. These regulatory water standards are attempts to internalize pollution costs and are related to the socially acceptable levels of health standards. Farber provided an extrapolation of the benefits of nutrient removal for all towns in the coastal wetland zone where treatment is a viable option.[63] This study did not include New Orleans, which is adopting wetland sewerage treatment. Rather than per-acre values, he used present value for the entire coastal wetland zone under different discount rates. In a literature review, Kazmierczak provided mean, median, upper and lower bound (the Farber paper) per-acre estimates of the value

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[58] AWWA, 2007
[59] Breaux, Farber & Day, 1995; Cardoch, Day & Kemp, 2000; Kazmierczak, 2001; Day et al., 2004; Ko et al., 2004
[60] Ko et al., 2004
[61] Millennium Ecosystem Assessment, 2005
[62] Hesse Doyle & Day, 1998
[63] Farber, 1996

of wetlands for water quality ($2.85-$5,674/ac-yr range; $975 mean, $281 median for Louisiana 2000 dollars; 2007 are $3.44, $6,832.35, $1,217.96, and $338.37).[64]

Using wetland assimilation also reduces CO_2 release to the atmosphere because these systems are much more energy efficient. Thus wetland assimilation reduces CO_2 release because these systems are more energy efficient. It also enhances carbon sequestration through below and above ground plant growth.

The gulf hypoxic zone at the mouth of the Mississippi River is a related nutrient management problem for the Gulf Coast. Mitsch et al. estimate that reconnecting the Mississippi River to its floodplain would absorb 50,000-100,000 metric tons of nitrogen per year.[65] Nitrogen enrichment also enhances tree stem growth by 23-80%, increasing carbon sequestration.[66] Shrinking the hypoxic zone would also improve fisheries productivity. The complexity between weather and climate patterns, hypoxic zone size, wetland loss, individual species life cycles and habitat requirements make fisheries improvement difficult to estimate.[67] Thus, despite the high likelihood of an important economic linkage between hypoxia and fisheries an estimate on the value of shrinking the hypoxic zone to improvements in fisheries is not included here. This value is highly spatially dependent, with high-value areas for treatment concentrated around human settlements and industrial areas, and likely lower background values for hypoxia reduction throughout the wetlands.

This analysis uses the median $281/acre as a low value and $1,217.96/acre as a high value. There are studies that show far higher values for effluent treatment services. For instance, the $6,224.27 derived from a commercial potato chip plant for effluent treatment is too specific and too small a scale to extrapolate to the entire Louisiana coastal zone.

Fisheries Production

Costanza et al. use a production function developed by Lynne et al. for fisheries production in Louisiana where catch predictions are based on marsh acreage and catch in the previous year and harvesting effort in the current year.[68] Costanza et al. estimate that the per-acre wetland value for brown and white shrimp, menhaden fish, oyster and blue crab total to $25.36/acre/year using 1983 prices ($48.10 2004 dollars).[69] Farber estimates per-acre values of $36.93-$51.52 in 1990 dollars ($58.58 low, $81.73 high in 2007 dollars).[70] Since Farber's range of estimates includes those of Costanza et al., we used Farber's low value for the low value for this category. These figures do not include all of the fish and shellfish species and production from the Mississippi Delta nor the value of fish reared in the Mississippi Delta but caught elsewhere in the Gulf of Mexico. More recent fisheries data available from several sources[71] can be used to update the estimates from Costanza et al. and Farber. Thus, these provide good estimates of the lower boundary. For the high value, the meta analysis mean

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[64] Kazmierczak, 2001
[65] Mitsch et al., 2001
[66] Day et al., 2003
[67] Chesney et al. 2000
[68] Lynne et al., 1981
[69] Costanza et al., 1989
[70] Farber, 1996
[71] See Chesney et al. 2000, Gramling and Hagelman 2005, Lindstedt 2005

for the fisheries production value of wetlands derived from an econometric analysis of 39 studies is adapted from Woodward and Wui at $1,233.49 in 2007 dollars.[72]

Raw Materials: Wild Fur and Alligator Production

Many raw materials produced in the Mississippi Delta, including timber, are not included in the value for this study. For this category, only fur and alligator production was included from the harvest estimates of the Louisiana Fur and Alligator Advisory Council that keeps annual harvest data by species. Assuming that muskrats come from brackish and intermediate marsh, nutria and raccoons from freshwater marsh, and alligators from fresh, intermediate and brackish marsh, harvests for these species can be valued on a per-acre basis. The 2004-2005 harvests and prices provide the low values for this category while the 10-year average values from 1995-1996 to 2004-2005 harvests and prices provide the high values.

Costanza et al. previously used estimates of 0.98 muskrat pelts/ac from brackish and intermediate marsh, and 0.88 nutria pelts/acre from freshwater marsh. They use 1980-1981 values of $6 per muskrat pelt and $7 per nutria pelt, for a total value per acre of $12.04.[73] However, the fur market collapsed in 1987-1988, making these values inappropriate for today's use. More recent data show values of over $1 million per year for trapping pelts and meat between 1993 and 2002 in Louisiana.[74] Of this harvest, 71% of commercial value came from nutria, 18% from raccoon, and 11% from other mammals, including muskrat. The low value used in this study is $4.74/acre/year and the high is $5.38/acre/year.

Carbon sequestration

Carbon sequestration as used in this study refers to the ability of vegetation to take up carbon dioxide through photosynthesis and store it for long periods of time in their woody tissues, in the soil, or in both. There are two parts to valuing carbon sequestration: establishing how much carbon is sequestered each year and establishing a dollar value for that sequestration service.

Herbaceous wetlands store large amounts of carbon in the soil while forested wetlands store it in both woody tissue and in the soil. Chmura et al. found median carbon uptake rates for all wetland types and the median carbon uptake rate to be 186 g/m^2/year. The uptake was greater in fresh to intermediate marsh than in brackish to salt marsh. Fresh and intermediate marsh had lower soil carbon density.[75] Choi et al. found far higher soil carbon sequestration rates than Chmura in salt marsh (2900 g/m^2) and in brackish to intermediate (1300-1500 g/m^2).[76] These results are specific to the Barataria Basin in coastal Louisiana. These marshes had the Net Primary Productivity (NPP) of 1,000-4,000 g C/m^2-year. This is much greater than that of the surrounding upland forests, which are estimated at 200-1,000 g C/m^2-year. Due to sulfate reduction, salt marshes do not generate significant methane. Yu et al. showed that mature Louisiana swamp forests accumulate

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72 Woodward and Wui, 2001
73 Costanza, Farber & Maxwell, 1998
74 Lindstedt, 2005
75 Chmura, 2003
76 Trulio, 2007

carbon, but that atmospheric methane release offset these gains.[77] Sea level rise may cause upland forests to transition into swamp forests, affecting their greenhouse gas balance. Day et al. showed tree stem growth enhancement of 23-80% under enhanced nutrient conditions in swamp forests.[78] Day and Kemp[79] have produced more recent estimates of marsh and wetland forest carbon sequestration rates which show degraded marsh sequestering 4.5 tons CO_2/acre/year, healthy marshes sequestering 11 tons CO_2/acre/yr, and wetland forests sequestering 10 tons CO_2/acre/year with forests enhanced with waste assimilation sequestering up to 25 tons CO_2/acre/year including both above and belowground sequestration. Full analysis with methane production is not yet complete.

There is a significant range in carbon sequestration depending on the health of the wetland or forested wetland. For this study we use the Day et al. low value, which assume that all wetlands are in a degraded state of 4.5 tons CO_2/acre/year for the low value of all wetland types and shrub/scrub wetlands. This study uses 11 tons CO_2/acre for the marsh high value, which is also in line with the findings of Choi et al. We use the Day et al. value of 10 tons CO_2/acre/year for the high and low of wetland forest carbon sequestration as this includes both above and belowground sequestration.

For a dollar value per ton of CO_2 sequestered, a low value of this service inclusive of both a market and social cost is provided by Pearce & Pearce who recommend the use of $10/ton ($11.71 in 2007 dollars) of carbon sequestered as a conservative estimate.[80] Such a market does not exist yet.[81] The Stern Report, probably the most widely quoted economic report on climate change, established a social cost value of $85/ton. This value is used for the high value.[82]

Market prices for a ton of carbon based on voluntary markets fluctuate dramatically, making it difficult to determine a clear market value for CO_2. Being voluntary and without full participation of all CO_2 emitters, the market price of the Chicago and European trading systems do not reflect full market prices. Both markets have fluctuated greatly. At the European Union Emissions Trading Scheme, carbon prices rose to $36/ton early in 2006 and fell to under $3/ton by spring 2007.[83] The Chicago Climate Exchange priced carbon at $4/ton in 2007 and $8/ton in 2006.[84] Voluntary carbon markets in the United States have sold carbon "offsets" at prices ranging from $5-25/ton with an average of $10/ton.[85]

Although carbon markets are yet at early stages of development, the science is clear. Removing carbon from the atmosphere will reduce global warming and help secure the valuable ecosystem service of better climate stability reducing draught, floods, storms and broad climate shifts.

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[77] Yu & DeLaune, 2006
[78] Day et al., 2003
[79] Day and Kemp manuscript
[80] Pearce & Pearce, 2001
[81] Zhang (2000) provides similar estimates for an "ideal" global market - at $11.23-14.74/ton C.
[82] Stern Report
[83] Ecosystem Marketplace, 2007
[84] Chicago Climate Exchange, Mar. 2006; Chicago Climate Exchange, Sept. 2006
[85] Clean Air-Cool Planet, 2006

Recreation

Numerous studies have estimated the recreational benefits of coastal Louisiana's wetlands. Most of these studies give a present value for each acre of wetlands or the entire coast. Since Bergstrom et al. provide a per-acre-year value and the different studies find values to be similar, Bergstrom's value of $147.57/acre/year is used here.[86]

Bergstrom et al. similarly used TC and CV across seven parishes. They estimated a value of $224.21/ha-yr for marshland only in the study area ($147.57/acre/year in 2007 dollars). Bergstrom et al. stratified their sample for sites in fresh and saltwater marsh, at high and low-density recreation sites and across an east-west gradient. Unfortunately only total values were reported since these would be useful distinctions for recreational valuation across coastal Louisiana. Farber modeled recreational loss under wetland decline as a function of willingness to pay, quality of the experience and population, and projects declining values as fishing and hunting quality falls.[87] Bergstrom et al. found values for fishing on the lower Atchafalaya almost identical to Bergstrom et al. 1990, supporting the use of similar values for the entire Louisiana Coast.[88]

Storm Protection (Disturbance Regulation)

If there is one area that exemplifies the rapid increase in value of ecosystem services, it is storm protection value. It also shows how our understanding of ecosystem services improves with time as wind and storm surge damage area included in the most recent analysis. Storm protection refers to the function of wetlands in reducing storm energy and storm-generated water surges that cause flooding. This ecosystem service is very important to residents of the Mississippi Delta, the Gulf of Mexico and U.S. Eastern Seaboard.

Farber and Costanza first estimated wetland value for hurricane protection from wind damage at $63,676/mile strip of wetlands (1980 dollars), with a present value of $23/acre discounted at 3%.[89] Martinez et al. developed a study about the coasts of the world, estimating a value for the ecosystem services provided by terrestrial and aquatic ecosystems. They estimate in 2004 dollars $\$436.3*10^9$ per kilometer per year for permanent wetlands in terrestrial ecosystems and $\$24,364.72*10^9$ per kilometer per year for the whole aquatic ecosystem including coral reefs, mangroves, sea grass, coastal shelf, swamps-floodplains and estuaries.[90] Costanza et al. provide estimates for both wind and flood damage; Farber provided estimates for capital, land and maintenance costs associated with levee construction and property loss from wetland disintegration.[91]

In a 2008 study, Costanza et al[92] provide the most timely and accurate value estimates for storm protection values. Their analysis includes Hurricanes Katrina and Rita. They use estimates of spatially explicit GDP (flows of value from built capital at risk) along with storm probabilities to model value per hectare for gulf and Atlantic coast states. They estimate the value of wetlands for storm protection in Louisiana at $3,446/hectare/year (2007 dollars - $1,530.82/acre). It is highly probable that this figure will rise with Hurricane Gustav. Future

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86 Bergstrom & Stahl, 1993; Bergstrom et al., 1990
87 Farber, 1996
88 Bergstrom et al., 2004; Bergstrom et al., 1990
89 Farber & Costanza, 1987
90 Martinez et al., 2007
91 Costanza et al., 1989; Farber, 1996
92 Costanza et al., 2008

estimates may refine values spatially by examining the differences in built capital across Louisiana's coast from east to west.[93] Given the importance of the 2008 Costanza et al. study, we appended their methods section to this report.

Our understanding of the storm protection value of wetlands is increasing rapidly. Wetlands tend to be most effective at reducing the storm surge of hurricanes where the storm surge is most intense. Thus, they likely provide a higher value than estimated here. In addition, the vegetation of wetlands reduce hurricane storm surge in three ways: they reduce the height of the storm surge directly with the drag of vegetation thus holding water back, they physically slow the movement of the storm surge forward thus allowing for greater dissipation of the storm surge, and they physically rob the hurricane of the ability to pull up water into the storm surge.

Wetlands reduce the wave action of the storm surge, thus protecting levees from pounding waves and increasing the effectiveness and lifespan of levees. The full value of these preventative and protective benefits has not been fully valued. Costanza's analysis provides a tremendous improvement and is the best estimate of the value of wetlands for reducing storm surge to date.

Other important ecosystem services for which adequate results or data from Louisiana could not be found include aesthetics, habitat for threatened and endangered species, and cultural values. Values from other studies on wetland ecosystems from other parts of the country and of the world were substituted to provide estimates for these services.

Other Wetland Ecosystem Values

Values for endangered species habitat[94] and aesthetics,[95] adjusted to 2007 dollars per acre per year, were adopted from original peer-reviewed studies. Values for gas regulation (distinct from carbon sequestration) and water flow regulation were adjusted to 2007 dollars per acre from 1994 dollars per hectare.

Water Flow Regulation: Flood Protection

Wetlands provide protection from the wind and storm surge of hurricanes from the Gulf of Mexico and flood protection from waters flowing from the Mississippi River Basin. Across a geographic area the physical functions provided by the wetlands may be similar. However, the valuable service provided to people varies with where people live and the value to them. Value is then distinct from function. This section discusses the flood protection value of the Mississippi Delta, which is unique in North America due to the size of its drainage area and the levees on the Mississippi River. Both built structures and natural ecosystems in the Mississippi Delta provide flood protection benefit for areas downstream and for the cities upstream in the Mississippi Basin by receiving floodwaters out of the Basin and effecting more rapid drainage.

The Mississippi River used to flood 50 miles wide on either side of the river. Over the decades the Army Corps of Engineers has leveed the main stem of the Mississippi River and separated the river from the wide flood

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[93] Costanza & Farley, 2007
[94] Kazmierczak, 2001b
[95] Thibodeau, 1981; Mahan, 2000

plain. In addition the Corps corked rivers that distributed water out of the main stem of the river and into wetlands and the Gulf of Mexico. The 2008 record flooding along the Mississippi River in the Midwest was not caused from water rushing down and flooding cities from the upper watershed down, but from the Mississippi River backing up into tributaries to flood cities like Cedar Rapids, Iowa. This flooding results from engineering actions like confining the river too tightly within levees and separating the river from its floodplain. All the surface water that flows through the 1.2 million square miles of the Mississippi River Basin draining over 40% of the continental U.S. is funneled to the Old River Control Structure in Louisiana. Before the levees were built, the Red River and many other rivers branched off from the Mississippi River to distribute water across the Mississippi Delta. Tributaries are rivers that come together to form a larger river while distributaries are rivers branching out in the delta to distribute the river's waters and sediment across the delta.

The Old River Control Structure divides the waters of the Mississippi River sending them down two great distributaries, not yet cut off by levees, the lower Mississippi River and the Atchafalaya River. They finally enter the Gulf of Mexico at the Birdfoot outlet and Wax Lake Delta. River diversion structures act as controlled distributaries letting water and sediment flow into the deltaic plain and reducing flooding on the main stem upstream and downstream. Diversions increase the capacity of water and sediment to escape into wetlands, which then lowers the main stem water level allowing floodwaters further upstream to drain more quickly. Wetlands both absorb water and further move water in a sheet flow toward the Gulf of Mexico. This also reduces damage to levees and flood protection structures upstream and downstream.

During flood periods, the Old River Control Structure diverts far greater amounts of water and sediment down the Atchafalaya River and through a vast floodway and expanse of wetlands to relieve flooding pressure far upstream in the Mississippi River and to protect New Orleans and other cities downstream. Mississippi Delta wetlands provide high value flood protection by receiving these floodwaters. Without this "uncorked" area available to contain a tremendous quantity of floodwaters, flooding would be greater and longer lasting in the Midwestern U.S. Ultimately cities like Chicago are dependent on the Mississippi Delta as the outlet for water and some flood reduction benefits. Both in water quantity and the vastness of area served, the Mississippi Delta is absolutely unique in the provision of flood protection in North America.

In addition, although coastal areas are sparsely populated, the value of these wetlands may be more similar to wetlands providing benefits to urban areas. The Mississippi Delta houses extremely high value oil and gas infrastructure. Delta wetlands protect oil and gas production facilities, pipelines and refineries providing over a quarter of U.S. domestic oil and gas supplies. Wetlands provide flood and storm protection to oil infrastructure by reducing erosion and damage to pipes buried within the wetlands and by buffering other infrastructure from flood (and storm) waters. Hurricane Katrina revealed the vulnerability of both gas and oil pipelines by devastating enormous areas where oil and gas pipes had been exposed through wetland loss. Katrina caused 44 oil spill incidents with over seven million gallons of oil spilled.[96]

The full flood protection value of Mississippi Delta wetlands cannot easily be separated from the built structures, such as the Old River Control Structure and levees. There is great debate on how much local flood protection levees provide during low flood years and how much flooding they cause during peak flood years,

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[96] Llanos, 2005

like 2008 and 1993. Despite the critical importance of flood protection for safety and economic assets, few studies on wetland flood protection value exist.

There are no ecosystem service valuation studies in Louisiana that show the high value flood protection benefits of Mississippi Delta. In addition, there are no studies that examine flood protection over great landscapes such as the Mississippi River Delta or the extensive upstream flood protection benefits. There are no studies examining the value of these wetlands for protection of oil and gas infrastructure. The few studies that do exist primarily examine flood protection benefits provided by wetlands to nearby urban areas. The full flood protection that the Mississippi Delta provides upstream and downstream to public safety and economic assets such as oil and gas assets is perhaps one of the most important studies yet to be conducted.

The lack of local studies poses a problem in placing a dollar equivalent to the extensive flood protection value that the Mississippi Delta natural systems provide. This presents a difficult choice between excluding the value of a clearly high value ecosystem service the Mississippi Delta provides and using values from studies in other locations for comparison. How applicable these comparative studies are depends on the ecosystem service, the vegetation type and the site. Carbon sequestration provides a case of easy transferability. For instance, although they may be of different locales, similar forest ecosystems of similar structure and growth rates provide equal carbon sequestration functions. Carbon sequestration is of value in stabilizing the climate anywhere it takes place. The value is not dependent on the location. Here studies from distant but similar systems likely describe the value of carbon sequestration very well. Endangered species habitat, however, is more unique. The value of preserving one endangered species habitat on one continent may not transfer to another entirely unique species' habitat elsewhere.

The analysis in this paper is partial. More than a dozen ecosystem services identified as present and valuable in the Mississippi River Delta are not valued. This is largely due to a lack of local or comparable valuation studies. Overall, the study, analogous to a house appraisal, is an inexact approximation. In the authors' view, it is better to include an imperfect comparable value, than to simply give a highly valuable and clearly present asset a value of zero.

The flood benefit studies used in this analysis are for wetlands providing flood benefits to urban areas. These are wetlands in close proximity to urban areas with high value infrastructure. Although freshwater, intermediate and brackish wetlands all provide the function of flood protection, freshwater wetlands are most closely associated with urban areas. They also provide the greatest upstream flood relief, as in the case of the Atchafalaya basin. In this study, the greater values for flood protection are attributed only to freshwater wetlands and not to intermediate, brackish, or salt marshes.

A study by Thibodeau[97] values the flood protection of wetlands outside Boston at $6,539.19 per acre in 2007 dollars. Another study in Washington State examined two wetland areas (one near the city of Renton and the other near Lynnwood) establishing a per acre values with a low of $8,000/acre and a high of $51,000/acre.[98]

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[97] Thibodeau et al., 1981
[98] Leschine et al., 1997

Flood and disturbance protection value is provided by all of the wetlands where they are protecting people, towns, oil and gas or other infrastructure. In this study, the mean value from Woodward and Wui was applied for the low value and the $6,539.19 value from Thibodeau was applied as high value for fresh marsh, shrub and forested wetlands. These wetlands are further inland and tend to be closer to cities and other built infrastructure; they contribute to the protection of cities further up the Mississippi Basin. Brackish and saline marsh still protect high value oil and gas infrastructure, towns and businesses on the coast; lower values based on the low values from Woodward and Wui were thus applied to these areas.[99]

Habitat Refugium

The Mississippi Delta is a tremendous area for aquatic and terrestrial wildlife. The area is a critical and irreplaceable stopover for migratory North American birds. The area provides valuable habitat to a number of endangered and threatened species. In addition, by providing sufficient habitat to keep other species off the threatened and endangered species lists, the Mississippi Delta relieves other jurisdictions in the continental U.S. of costly expenditures that would arise if these species were listed. No full study of the value per acre of provided by the Mississippi Delta exists. However, Kazmierczack provides the figures used here as the low and high values of $203.63/acre/year and $485.92/acre/year.

Upland Ecosystems

Despite the substantial number of economic valuation studies that have been completed for coastal Louisiana's wetlands, less work has been done for the region's upland ecosystems. As an initial effort to assess values for upland areas, the value coefficients from a project at the University of Vermont to estimate ecosystem service values for the state of New Jersey were utilized.[100] Although New Jersey has a different ecoregional and socioeconomic setting, it is a coastal U.S. state whose natural capital base faces pressure, albeit largely from development and not wholesale wetlands decline. The studies selected for the New Jersey value transfer exercise were selected from across the U.S. including some from the Mississippi Delta.

To round out our estimate of the value of Mississippi River Delta's natural capital when local data was not available and when other values were not present, the values from Costanza et al. were used[101] for the ecosystem services that more recent studies did not cover. Although these numbers are likely less accurate, we chose to use all available data to get a more complete picture and estimate. The greatest error of most valuation studies has been the omission of values for clearly valuable ecosystem services, thus significantly underestimating the value of benefits that ecosystem services provide to people. Further refinement of the value estimates for these upland ecosystems will improve the value estimates for the Mississippi River Delta. All values were converted into 2007 dollars using the Bureau of Labor Statistics' Consumer Price Index.

It is important to note that this study does not pick a single number as a value, it establishes a low and high value range. This helps us understand some of the inherent uncertainty held in this process. The most prevalent

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[99] Woodward and Wui, 2001
[100] Costanza et al., 2006a
[101] Costanza et al. 1997

error is that of omission; for instance, agricultural land provides greater benefits but few studies examining them exist.

Although these express the range of possible values for each land cover type, each estimate is a composite value for all relevant ecosystem services where data is available; it is unlikely that a particular ecosystem would have the highest or lowest values for all ecosystem services.

Results and Discussion

Land cover Types, Ecosystem Services and Dollar Value Estimates

The next three tables provide an overview of results. Table 6 shows values per acre (in 2007 dollars) for all land cover types including wetlands and all ecosystem services for which data is available. It shows the dollar value per acre of each ecosystem service for each land cover type. The highest values per acre are provided by fresh water wetlands and forested wetlands at $3,200-12,000. All natural systems provide economic benefits. For some systems, there is far more valuation data available than for other systems. Generally, estuarine and open water systems are far less studied than wetlands and forested systems. Water regulation and storm protection benefits have the highest values per acre. Flood prevention and hurricane protection are two of the most important functions of coastal systems in the Mississippi Delta.

Forested wetlands provide the significant value for both low and high values in the Mississippi Delta. This is directly tied to the physical functions of these forests. Wetland forests provide strong hurricane protection value by slowing and reducing the storm surge and breaking up hurricane force winds at the surface where it is most important. Bald Cypress trees, for example, are excellent hurricane buffers because they are well buttressed by an extensive root system that provides tall, sturdy and highly resilient barriers to wind and water. They have evolved to withstand strong wind and water action. All of the marsh types provide hurricane buffering. Salt, brackish and intermediate marshes provide greater buffering value along the coastline. More research is needed to fully understand the mechanics of natural systems in buffering hurricanes.

The color codes in Table 6 correspond to the general source of academic valuation studies. Green indicates numbers derived from local Mississippi Delta data. We used other study references where there was no local data. Purple corresponds to figures used in the 2005 New Jersey study, most of which were derived outside New Jersey. Blue corresponds to the Kazmierczack 2001 wildlife value study. Pink corresponds to Costanza (1997) and yellow to studies from the Gund Institute for Ecological Economics database. Appendix A contains all of the references for the value transfer studies from which each of these figures is derived. Appendix B provides a table of the land cover type, authors, the type of valuation analysis conducted (one of seven valuation study types, avoided cost, contingent, etc.) and the high and low values in 2004 dollars which corresponds to the values in Table 6 (converted to 2007 dollars).

The greatest source of error is introduced by lack of data. Many of the boxes in the table are empty. In many cases, economically valuable services are clearly provided but no valuation studies have been conducted. This is the case for over 50 clearly valuable ecosystem service/land cover type combinations such as the value of wetlands for erosion control. Thus the high and low values are likely underestimates of the true high and low values of these systems. In a few cases, the service may not be provided, for example pollination in marine environments. Because there were no newer and better studies, many of the studies used here are over a decade old. Despite these shortcomings, this table to date provides the most comprehensive accounting of ecosystem services provided by the Mississippi Delta.

Table 6. Per Acre Values for Land Cover Types and Ecosystem Services in the Mississippi River Delta (2004 Dollars/Acre/Year)

	Fresh Wetland		Intermediate Wetland		Brackish Wetland		Saline Wetland		Shrub-scrub Wetland		Forested Wetland		Open Fresh Water		Open Estuarine Water		Upland Shrub-Scrub		Upland Forest		Pasture/ Agriculture Land	
Ecosystem Service Type	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Carbon Sequestration	35.14	382.52	35.14	382.52	35.14	382.52	35.14	382.52	52.71	382.52	117.12	850.05					5.81	7.32	11.60	14.63		
Atmospheric Composition Regulation	149.99	149.99	149.99	149.99	149.99	149.99			149.99	149.99	149.99	149.99					3.96	3.96				
Waste Treatment	308.45	1,174.05	308.45	1,174.05	308.45	1,174.05	308.45	1,174.05	308.45	1,174.05	308.45	1,174.05	376.70	376.70			49.28	49.28	49.28	49.28		
Water Supply	46.67	124.47	46.67	124.47	46.67	124.47	46.67	124.47	46.67	124.47	46.67	124.47	30.24	788.82	6.07	131.49			9.88	422.61		
Water Flow Regulation	612.14	6,539.19	141.27	612.14	141.27	612.14	141.27	612.14	612.14	6,539.19	612.14	6,539.19					1.70	1.70				
Storm Protection (Disturbance Regulation)	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82	1,530.82							1.13	1.13		
Food Production	58.59	1,354.00	58.58	1,354.00	58.58	1,354.00	58.59	1,354.00	58.58	1,354.00	58.58	1,354.00	23.23	23.23					28.32	28.32	34.28	34.28
Raw Materials Production	4.75	5.38	4.68	4.76	4.68	4.77			4.68	4.76									14.16	14.16		
Recreation	205.74	644.20	205.74	644.20	205.74	644.20	205.74	644.20	205.74	644.20	205.74	644.20	1.58	1,794.37	11.88	1,425.07	14.35	1,198.56	0.40	2,368.84	28.29	28.29
Aesthetic	74.74	239.07	74.74	239.07	74.74	239.07	74.74	239.06	74.74	239.07												
Pollination																	1.24	6.22	64.76	290.89	2.47	12.45
Soil Formation																	0.56	0.56	5.66	5.66	0.56	0.56
Nutrient Cycling																			204.49	204.49		
Erosion Control																	16.42	16.42	54.38	54.38		
Biological Control																	13.32	13.32	2.26	2.26	13.32	13.32
Genetic Resources																			9.08	9.08		
Habitat Refugium	203.63	485.92	203.63	485.92	203.63	485.92	203.63	485.92	203.63	485.92	203.63	485.92			1.39	365.30	0.60	298.26	1.15	596.51		
Cultural																						
Total	3,230.67	12,629.60	2,759.73	6,701.94	2,759.73	6,701.94	2,605.06	6,547.19	3,248.17	12,628.99	3,233.16	12,852.69	431.78	2,983.12	19.34	1,921.86	107.20	1,595.60	456.55	4,062.24	78.90	88.88

Table 7 shows the land cover types, acres of each land cover type, low and high value estimates per acre, and the sum of ranges in value these vegetation types provide on the Mississippi Delta. Thus, this study presents the low and high value estimates of ecosystem services that the Mississippi River Basin provides in one year. The range between the high and low total values – $25 billion – is substantial and reflects the uncertainty and differences in valuation studies. Both the low and high values are large and demonstrate that the natural systems in the Mississippi Delta provide valuable economic benefits. These natural systems are also highly efficient at providing this value. To replace them with built capital alternatives would be far more costly or impossible. In addition, if restored to health, these natural systems are self-maintaining and can, without charge, provide services, such as hurricane buffering.

The large values of wetlands and wetland forests in the Mississippi Delta primarily come from the water regulation and hurricane protection. These areas deserve further study. As is the case with all economic measures, this measure of value is not perfect. Like other aggregate economic measures such as the Gross Domestic Product, or total assessed property values, this analysis takes the marginal value per unit (dollars per acre) multiplied by the total number of units (acres) to estimate a “gross” total value. A better, far more difficult, and not yet developed measure would consider the dynamic nature of the change in value as trade-offs between these land cover types takes place. The Gund Institute for Ecological Economics is developing dynamic tools for this purpose.

The spatial distribution of services is another difficult issue. Not every acre of wetland provides equal amounts of storm protection value, as was assumed here. Because every storm differs in location, intensity, storm surge, wind speed, aspect to the coastline etc., the value of wetlands for storm protection will be different for every storm. With greater Geographic Information System data, and better predictive data on hurricane strength, location and occurrence as well as land cover types along the expected hurricane route and the lives and value of property protected would provide the basic information needed to improve this valuation. One advantage to increased coastal wetlands, as opposed to levees, is that a wide skirt of wetlands provides buffering against hurricanes approaching from any angle, speed, or storm surge height. The cumulative nature of wetland protection value is also not measured here.

Every individual acre of wetland provides differential benefits. As better techniques for valuation become available, this differential value will be better measured. However, most economic measures, such as the gross domestic product (GDP), are incapable of accounting for this individual difference in expressed value. Every new automobile of an identical make also provides differential benefits. For example, consider two new trucks of the same model sold for the same price, one performs poorly while the lasts for decades. They are valued identically in the GDP. A more useful economic measure of value would be based on the actual economic performance and benefit provided by each truck (analogous to the actual value an acre of wetland provides for hurricane protection). However, this would be impossible to calculate. Imperfect as it is, the GDP is a useful aggregate measure of value. Similarly, this report provides an aggregate value of natural systems in the Mississippi River Delta that can be improved upon. Although the values provided here are underestimates of the true value Mississippi Delta ecosystems provide, they meet the same basic standard of accepted economic measures and are certainly better than nothing.

Based on available data, the value of the services examined here and provided by the Mississippi Delta is estimated between $12-47 billion annually. Retaining and expanding this annual flow of benefits is good economics. Unfortunately, these benefits have been largely counted as zero for most of the last century.

Table 7. Total Value Based on Acreage for Each Ecosystem Type (2007 Dollars)

Land Cover Type	Acres	Low Value Estimate	High Estimate
Fresh Water Marsh	877,099	$2,833,616,569	$11,077,411,806.55
Intermediate Marsh	660,933	$1,823,993,642	$4,429,535,089.73
Brackish Marsh	547,445	$1,510,797,014	$3,668,942,825.58
Saline Marsh	421,561	$1,098,191,310	$2,760,038,549.65
Shrub-scrub wetland	172,106	$393,890,419	$1,531,460,185.19
Forested/Swamp Wetland	1,031,561	$3,335,203,387	$13,258,333,954.99
Open Fresh Water	992127	$428,346,204	$2,959,631,369.64
Open Estuarine Water	3,549,990	$68,661,717	$6,822,566,401.65
Upland Shrub-Scrub	84,799	$9,090,572	$135,305,795.41
Upland Forest	172,106	$78,575,469	$699,135,025.33
Pasture-Agriculture	481,575	$37,997,389	$42,802,567.96
Total	8,940,461	$11,953,060,333	$47,385,163,571.67

Table 8 shows the equivalent of an asset value for the economic benefits derived from Mississippi Delta's natural systems. This is the present value of the flow of benefits from these services in a 100-year period, shown for the four discount rates. The asset value of Mississippi Delta ecological systems (a partial value since not all ecosystem services were valued) varies from $237 billion at the low end using a 5% discount rate to $4.7 trillion if the benefits to people in the future are treated equally to the benefits we receive in the present over a 100-year period. This demonstrates that the natural capital asset value of the Mississippi River Delta is tremendous by any measure.

Since open water provides fewer benefits than land in this area, continued land loss will result in a decline in asset value. In addition, the dead zone reduces the value of estuarine waters within the area of study, thus providing a lower value. The reduced value on account of the dead zone was not included. The reality is that all ecosystems in the Mississippi Delta contribute value to citizens both within the delta and the nation. Local, state and national investment decisions should be informed by the value of natural capital.

Table 8. Present Value of Ecosystem Services over 100 years (2007 dollars).

Discount Rate	Low Estimate	High Estimate
0 %	1.2 trillion	4.7 trillion
2 %	513 billion	2.3 trillion
3.5%	330 billion	1.3 trillion
5%	237 billion	940 billion

The differences between these values depend on the discount rate chosen, as shown by Table 8. How value across time is treated, particularly in respect to renewable resources that provide value across vast amounts of time. A short discussion of how an “asset” value is calculated from the value of annual benefits that the Mississippi Delta provides and some of the implicit issues behind the choice of a discount rate follows.

The difference between an annual flow of benefits and an asset value is often not intuitive to non-economists. Consider first that ecosystems provide an annual flow of benefits, some of which can be expressed in dollar value as shown in Tables 6 and 7. From this annual flow of value, the value of the asset or the structure that produces that value can be estimated. This is analogous to comparing an annual mortgage payment for a house (the value of living in the house for a year) and the total “asset value” or price of the house.

A natural capital asset value is *analogous* to a built capital asset value because unlike a house or car, ecosystems the size of the Mississippi Delta cannot be bought or sold as a whole asset and because many of the most important benefits are public goods and services which by their physical nature (like oxygen in the air or hurricane buffering) cannot be bought or sold in markets. However, just as the value of a “built capital” asset can be calculated from the annual flow of net income it produces (annual flow of value) a “natural capital” asset value of the Mississippi Delta can also be calculated from the estimated annual flow of benefits that it provides.

Calculating the present value of an asset requires the use of a discount rate. Discount rates measure the extent to which people value benefits in the present versus benefits at a future date. Current environmental economics literature yields a healthy discussion about whether or not to use discount rates and what rate should be applied to calculate the value ecological assets over time;[102] there is a variety of alternatives to standard exponential discounting, including using declining rates[103] and “intergenerational” discounting which allows the assignment of different, lower discount rates for future generations versus the current generation.[104]

Renewable resources should be treated with lower discount rates than built capital assets because they provide a rate of return over a far longer period of time (potentially thousands of years or longer, for example, the ozone

[102] Azar and Sterner, 1996
[103] Newell and Pizer, 2003
[104] Sumaila and Walter, 2005

layer). It would be unwise and a tremendous economic blunder to treat value across time for the ozone layer's protection the same way we treat the useful life of a throwaway coffee cup. The discarded coffee cup provides no value to our grandchildren. Since the value of the ozone layer and a coffee cup are fundamentally different in importance and value to people across time, a coffee cop and the integrity of the ozone layer should be valued differently across time.

Natural capital, when healthy, is an appreciating and self-maintaining asset while built capital depreciates and requires active maintenance or it falls apart. This has profound implications for defining sustainability and how assets and investments are treated across time. The benefits that a natural asset provides are garnered across time, most in the distant future, whereas the benefits of built capital, such as a car or levee, are largely delivered in the immediate future, depreciating rapidly, with few or no benefits provided in the distant future. Both built and natural assets are necessary to maintain a high quality of life for people. What is more important now than at any time in the past, when natural capital was abundant, is how we balance investments in natural and built assets. In the past, investments in built capital have substituted for and damaged natural capital. In the future, wiser investments in both natural and built capital should be complementary. For example, wetland expansion protects levees and diversion structures enhance wetland restoration.

Discounting tilts valuation and decision making toward choices that pull the benefits into the present and push costs into the discounted future. High discount rates are biased toward investments that have a high and quick pay off, even though their value may quickly disappear and cause large and long lasting costs. Low discount rates give greater value to future benefits.

For simplicity, we use the four discount rates of 0, 2, 3.5 and 5 percent to underscore the difference in asset value depending on the value given to future benefits. A zero discount rate implies that we in the present hold future flows of ecosystem services to be just as important to people living in the future as the value of those assets are to us today. We limit the time horizon arbitrarily to 100 years for the zero discount rate. This is short sighted. Without limiting the time period the value of natural assets would be infinite, compared to any built capital asset that depreciates. This reflects the true nature of a potentially sustainable flow of value and an asset that falls apart and can only provide a finite flow of value. However, built capital provides important current benefits. A 2-3.5% discount rate implies that people today have a positive time preference so that what remains in the future is less important in meeting current needs than what we have today. It gives more value to the future than the 5% rate or greater, a range that is typically used to value built capital assets or to calculate expected rates of return on monetary investments.

The fact is that how we treat great amounts of value provided for long periods of time into the future is fundamentally an ethical decision; it cannot simply be left to a mathematical calculation based on today's prime interest rate or any other arbitrarily set discount rate.

To conclude this section, calculations of the present value of the flow of ecosystem services show that intact natural systems provide enormous value to society in the short and long term. While we currently need and enjoy the benefits, such as hurricane protection or the supply of drinking water, most of the benefits that healthy natural capital provides, like all renewable resources, will be gained in the future. The cumulative economic benefits from healthy, functioning natural capital across time and generations is tremendous.

At one time, we could assume that all natural capital was basically healthy and functioning well. This is no longer the case. For example, cypress trees cannot grow in saltwater. They will die off if saltwater intrudes through canals or coastal land loss in their area. The economic value that cypress trees provide, such as hurricane protection, will also be lost.

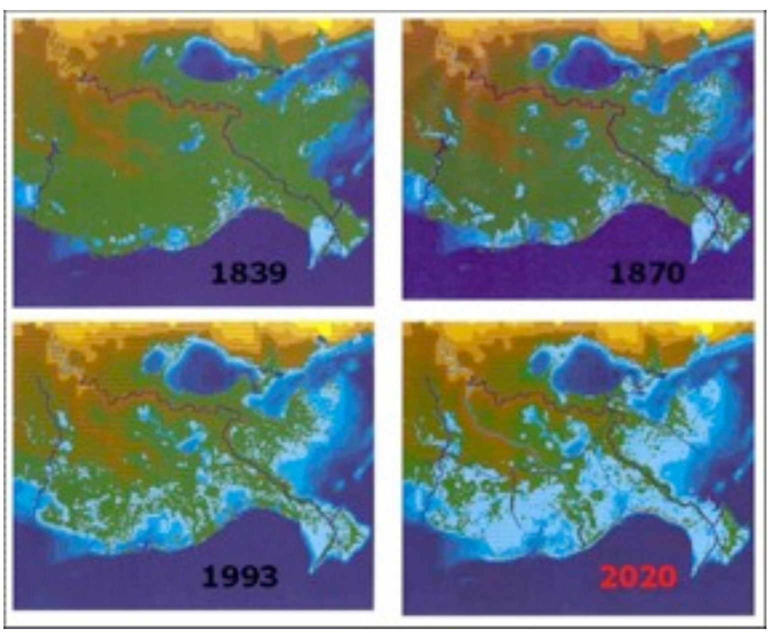
PART III: Lessons from the Delta's Physical Reality

This section examines the changing physical reality of the Mississippi Delta and its importance to the economy. It deals with observed and incontrovertible scientific facts which have very significant economic implications.

A Rapidly Shrinking Delta

After expanding for tens of thousands of years, the Mississippi River Delta started to shrink rapidly eight decades ago, losing over 1.2 million acres of land.[105] This trend continues. An increase in hurricane activity can accelerate this loss.[106] Without renewing the deltaic processes which built and maintained the Mississippi River Delta, land loss acceleration will continue. Land loss carries the loss of critical benefits, including hurricane protection. To understand the economics of the Mississippi Delta, it is important to understand the rates and patterns of land loss from the reduction of sediment and water, hydrological disruption, subsidence, how wetlands and barrier islands buffer against hurricanes, and the full suite of physical changes and their implications. Figure 5 shows the actual and projected loss of coastal wetlands between 1839 and 2020.

Figure 4. Loss of coastal wetlands: 1839 -2020



[105] CPRA, 2007b
[106] Barras et al., 2003

Rates and Patterns of Wetland loss

All deltas grow in some areas and deteriorate in others as the river deposits sediment in one lobe and then shifts sedimentation to another lobe. Sedimentation and wetland plant growth caused the Mississippi River Delta's net land expansion for thousands of years. However, its deterioration in the last 80 years showed a land loss as high as 24,710 acres per year[107] or a total wetland loss of over 1.2 million acres.[108] The land loss rates were highest in the 1960s and 1970s.[109] Current rates of loss were estimated before 2005 at 15,360 acres per year, still a high rate of loss, with a total expected loss of over 328,000 acres in the next 50 years.[110] However, hurricanes Katrina and Rita may have rewritten the estimates of potential land loss. The US Geological Survey stated in 2006:

> "Land transformed to water along the coast and on barrier islands further reduces Louisiana's natural protection from future storms. Louisiana had already lost 1,900 square miles of coastal lands, primarily marshes, from 1932 to 2000. The 217 square miles of potential land loss from the 2005 hurricanes represent 42 % of what scientists had predicted before Hurricanes Katrina and Rita would take place over a 50-year period from 2000 to 2050, even though they had factored storms into their model."

The USGS estimated that 138,000 acres of land were lost to open water due to the 2005 hurricanes.[111] Healthy wetlands are often horizontally compacted by hurricanes only to re-expand after the storm. Similarly, storms can actually benefit wetlands by bringing additional sediment in from the continental shelf. However, if wetlands are unhealthy, as is largely the situation along the coast, hurricanes can physically break them up or bring in saltwater.

As long as the landscape of the Mississippi Delta is deteriorating, the ecological services that are derived from that landscape and are vital to the economy and habitation will continue to deteriorate. A complex array of factors has led to land loss where there should have been a net gain. Human activities primarily caused land loss in the last 80 years.[112]

More than 1.2 million acres of land have been lost to open water with the coast receding 30 miles in some areas.[113] The main causes of this loss are the leveeing of the Mississippi River and the construction of oil, gas and shipping canals which allow saltwater to seep in from the coast thereby increasing salinity and killing freshwater wetlands. This introduced large interior open water areas. Waves attack and wash away land at the expanding land-water interface. Most land loss was in the interior for most part of the 20th century[114] but as wetlands opened up into large lakes, wave erosion has become more damaging.[115] Erosion and stress from the loss of fresh water and sediment inputs, combined with natural land subsidence and sea level rise, cause submergence and increase salinity, killing vegetation.

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[107] Gagliano et al., 1981
[108] Boesch et al., 1994
[109] Baumann & Turner, 1990; Britsch & Dunbar, 1993; National Biological Survey, 1994
[110] Barras et al., 2003
[111] USGS, 2006
[112] Boesch et al., 1994; Boesch et al., 2006; Day et al., 2000
[113] USGS, 2006
[114] Day et al., 2000
[115] Day et al., 2000; Barras et al., 1994

Reduction of Riverine Sediment and Water

The isolation of the Mississippi River from the deltaic plain was accomplished by levees that physically separate the river from the delta and severely damages the delta's health.[116] The Mississippi River is leveed up to its mouth to prevent overbank flooding and crevasse formation. The Old River Control Structure was designed to retain the main channel of the Mississippi River and prevent it from being captured down the Atchafalaya River, a shorter course to the Gulf of Mexico. Because of this, the Mississippi River runs to the edge of the continental shelf; most of the freshwater and sediment load that would have previously nourished the delta is now deposited in deep water. In addition, large quantities of freshwater and nutrients that would have once supplied marshes are lost to the Gulf of Mexico. The large amounts of nitrates that the Mississippi River has been discharging into the Gulf of Mexico has created another problem, a "dead zone" or oxygen-deprived "hypoxic" area which is about the size of New Jersey. Microorganisms use the nitrogen and remove the oxygen from the water. Wetlands are heavy nitrate consuming systems; increases in nitrates promote plant growth and carbon sequestration. Thus wetlands are far better recipients of nutrient-rich water than offshore marine ecosystems. There has also been a reduction of sediment in the river due to the construction of dams and reservoirs in the upper watershed.[117]

Hydrological Disruption of the Delta

There has been pervasive alteration of the Mississippi River Delta's hydrology; it has lost the familiar branching pattern of river deltas. Except for the Atchafalaya River, all the Mississippi River distributaries have been closed. More than 9,000 miles of canals have been dredged for navigation, drainage and logging, but mostly for oil and gas development.[118] These canals form a dense network that effectively changes hydrology and sediment transport in the coastal zone. Figure 6 shows an area, once completely composed of wetlands, crossed with canals and largely converted to open water. Spoil banks associated with canals also reduce the natural sheet flow of water.[119] Deep, straight navigation canals, stretching inland from the Gulf of Mexico to freshwater areas, have caused significant saltwater intrusion and killed vast areas of freshwater wetlands.[120] One of the most notable navigation canals, the Mississippi River Gulf Outlet which was dredged through the Breton Sound Basin in the late 1950s, has an average depth of 30 ft and width of 1,500 ft. Saltwater intrusion caused by MRGO has led to widespread land and freshwater wetland loss.

Katrina's path crossed Breton Sound and areas that were formerly wetlands and are now bounded by spoil banks (dirt accumulated from excavation) created by MRGO. This created a funnel effect for Hurricane Katrina's storm surge, further building it up in height and power and causing the catastrophic levee failure that flooded eastern New Orleans and St. Bernard parish. MRGO resulted in the death of over 10,000 acres of cypress forests in Orleans and St. Bernard Parishes. To prevent future funneling of hurricane storm surges, the U.S. Congress subsequently approved the closure of MRGO upon request by the Louisiana Legislature.

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[116] Day et al. 2000
[117] Kesel, 1989
[118] Day et al., 2000, and Day et al., 2007
[119] Swenson & Turner, 1987
[120] Day et al., 2000 and Day et al., 2007

Cypress forests are highly resistant to being blown down by hurricanes; they reduce storm surge and the wave generation on top of the surge. Had these forests been in place during Hurricane Katrina, the flooding would have been greatly reduced.

Figure 5. Network of Canals in the Mississippi Delta

Source: USGS

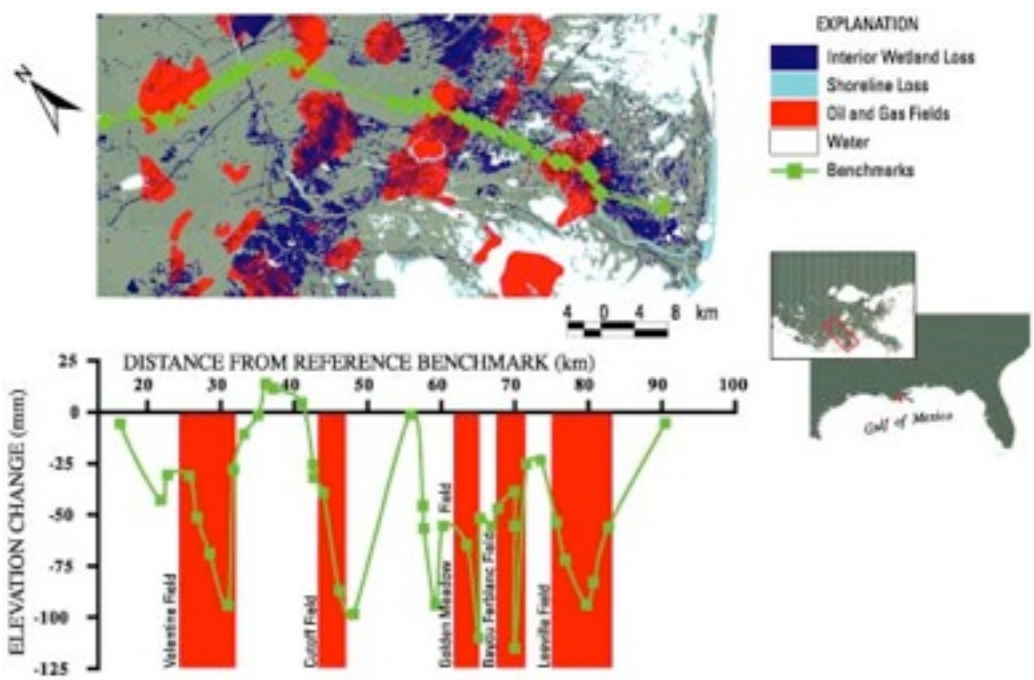
Subsidence

Natural subsidence of river deltas result from the compaction of loosely deposited sediments and dewatering. The Mississippi Delta, like other deltas, constantly subsides, sinking as sediment settles. However, the constant deposit of new sediments for thousands of years brought about a net gain of land and elevation.

Enhanced Subsidence from Oil and Natural Gas Production

Recent evidence from examining large areas of the coast shows that extraction of oil and natural gas increases the rate of land subsidence near oil and gas fields by two to three times, a critical factor contributing to land loss.[121] Morton, a former petroleum geologist who is now with the USGS, found that the highest rates of wetland loss occurred during or just after the period of peak oil and gas production in the 1970s and early 1980s. After much study, Morton concluded that the removal of millions of barrels of oil, trillions of cubic feet of natural gas, and tens of millions of barrels of saline formation water lying with the petroleum deposits caused a drop in subsurface pressure known as regional depressionism. That led nearby underground faults to slip and the land above them to slump downward. Morton does not give a percentage of wetland loss that can be attributed to oil and gas recovery.

Figure 6. Fossil Fuel Extraction and Subsidence



Source: Morton, Buster & Krohn, 2002

[121] Morton, Buster & Krohn, 2002

The upper area of Figure 6 shows the areas of oil and gas fields in a portion of the Mississippi Delta. Oil and gas fields are shown in red while shoreline and wetland loss are in blue. The graph along the transect shows the correspondence between areas of high elevation change (subsidence) and areas where oil and gas have been extracted.

Wetlands and Storm Surge Reduction

Hurricanes gain power over hot, open and deep water; they lose power over coastal barrier islands and wetlands. The Mississippi River Delta wetlands provide hurricane buffering, reducing storm surges. The storm surge of a hurricane is a circulating disk of water that is pulled up by the low pressure of the storm and moves with it. All storms are different but in a perfect storm, the highest point of the storm surge follows the hurricane's eye. As a hurricane approaches shore, the storm surge builds up enormous waves bringing in hundreds of billions of gallons of water.

Wetlands reduce storm surge waters. Marshes provide drag and resistance to water movement, reducing the storm's ability to gather storm surge waters. This physically slows the progress of hurricanes and weakens their strength. Wetlands loss results in more open water and less capacity for buffering between land and the Gulf of Mexico where hurricanes develop. The loss of wetlands in the critically important area of the East Orleans land bridge exacerbated the damage that hurricane Katrina wrought because it allowed more storm surge waters to flood into Lake Pontchartrain, causing sea walls in New Orleans to fail and catastrophically flood the city. The receding of areas of the coastline by 20-30 miles since the 1930s removed a significant capacity to diminish the power of hurricanes in Southern Louisiana.

The U.S. Geological Survey (USGS) estimated that wetlands reduce hurricane storm surge by one foot for every 2.5 miles of wetlands. More recent measurements of the effects of wetlands on Hurricane Rita's storm surges indicate that the wetlands may be even more effective at reducing the height of the surges, depending on the storm, by as much as one foot for every 1.4 to 5.9 miles of wetlands. The storm surge models used by the Army Corps of Engineers did not include the wetland buffering function of wetlands.[122] A post-hurricane modeling effort predicted that if all the wetlands near New Orleans had been lost, storm surges from Katrina would have been up to six feet higher, causing far more substantial damage.[123] Other modeling indicates that the loss of barrier islands significantly increases the wave energy hitting the coast, even in mild weather.[124] The Army Corps of Engineers storm surge models do not yet include wetlands as features that reduce storm surge.

Figure 7 shows the expected attenuation (blue) based on modeling which did not include the storm surge weakening effects of wetlands and the observed attenuation (purple) for Hurricane Rita based on the physical measurement of water marks on trees and structures.

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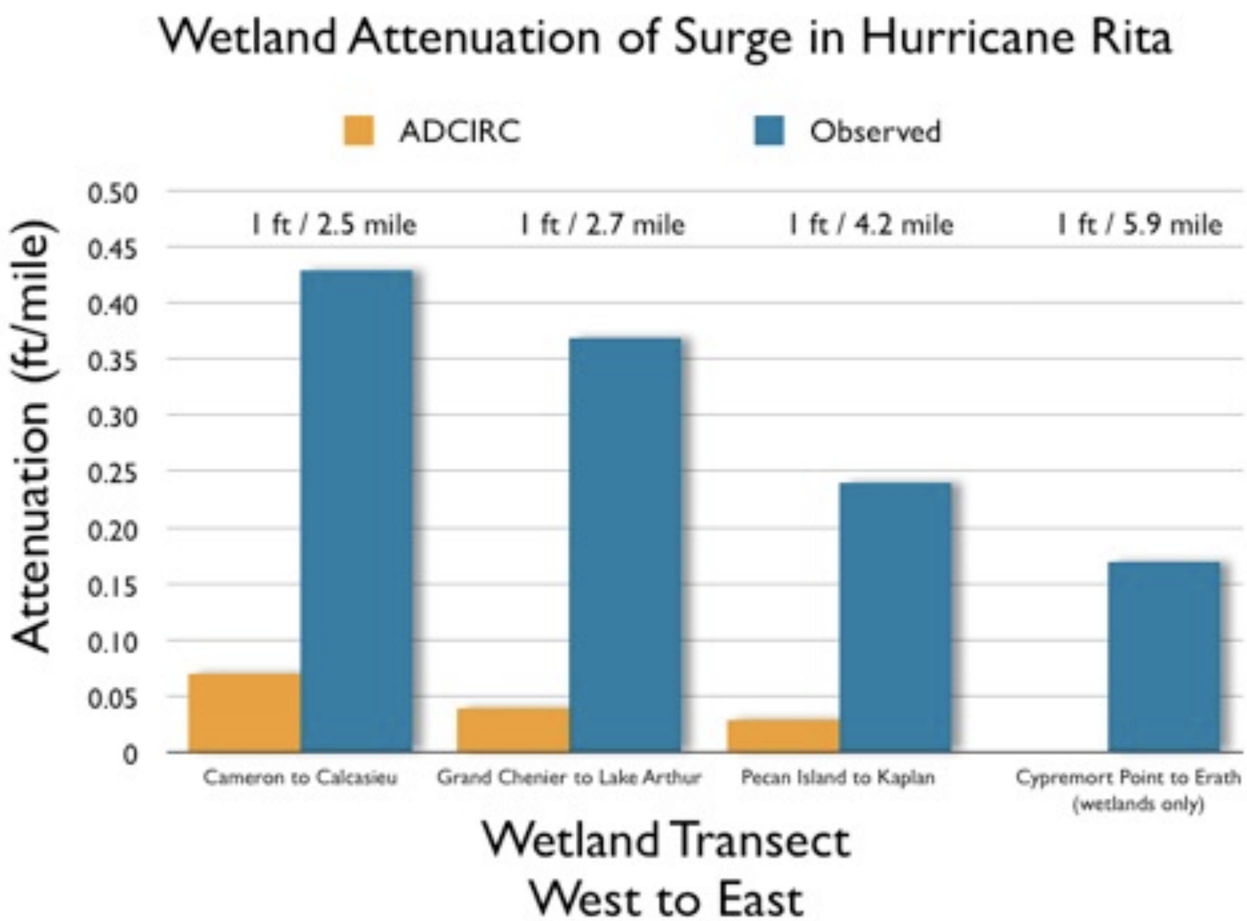
[122] Kemp & Mashriqui, 2006; pers com

[123] Working Group for Post-Hurricane Planning for the Louisiana Coast, 2006

[124] Stone, 2004

Figure 7. Kemp and Mashriqui's Wetland Attenuation of the Hurricane Rita Storm Surge



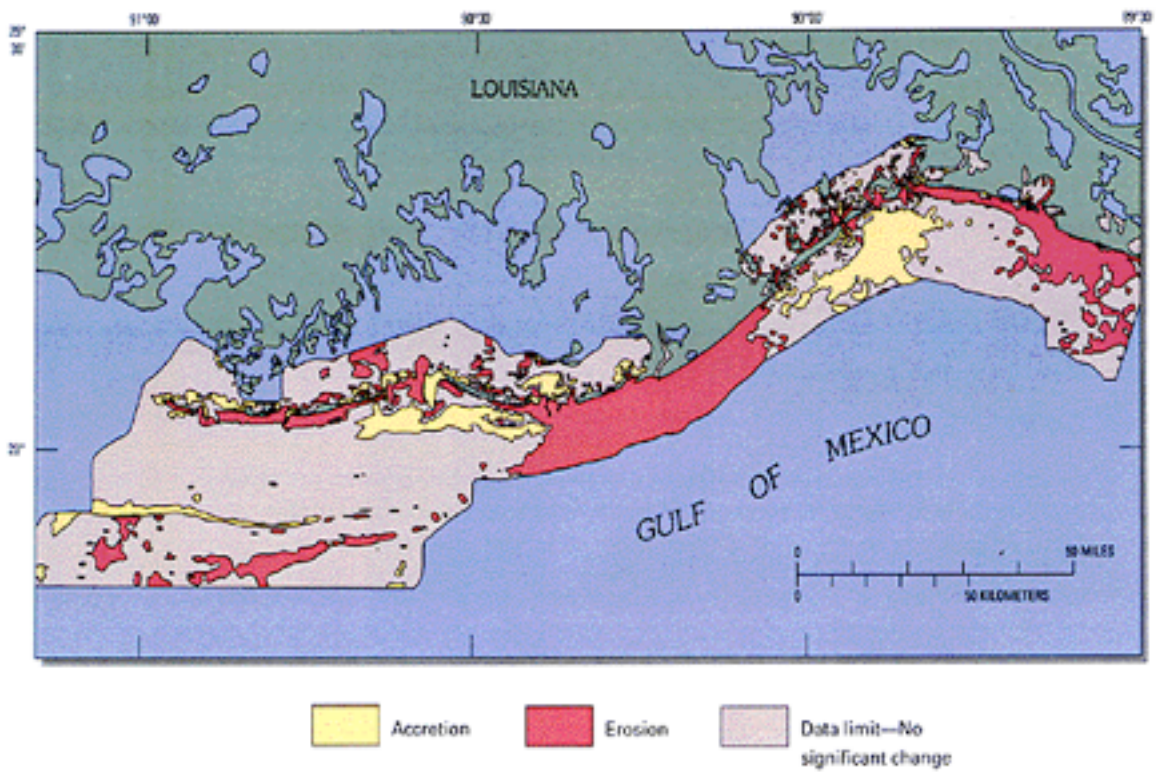
Source: Kemp and Masriqui, 2006

The Chenier Plain, which lies to the west of Mississippi River Deltaic Plain, has also lost wetlands and barrier islands. The Mississippi and the Atchafalaya Rivers influence the Chenier Plain over long periods, but its landforms are different from the Mississippi River Deltaic Plain. Ridge systems made of sand and shells give its coastal landscape a more forested character. No major rivers currently flow through the Chenier Plain. Sediment deposition and land loss mechanisms are also different in this area of coastal Louisiana. Saltwater intrusion from canals and navigation channels has caused the loss of freshwater marsh and forested wetlands. The diminution of the barrier islands have caused increased coastal erosion due to wave energy. Saltwater intrusion also threatens to alter freshwater lakes and reduce water supplies for agriculture. During Hurricane Rita, many levees surrounding freshwater and low salinity impoundments were overtopped by saltwater, leading to widespread death of these marshes and damaging agricultural fields because the saltwater could not retreat or be flushed out by natural processes. Unlike the more populated Deltaic plain, population is more dispersed in the Chenier Plain where agriculture is a mainstay of the local economy.

Wetlands and Barrier Islands

Barrier islands also provide considerable protection against hurricanes and storm surges. They absorb wave energy and provide a direct physical barrier to storm surges, helping protect people and structures from hurricane-generated waves. The Mississippi Coast had barrier islands, like Ship Island, as buffers. These provided important storm protection, reducing storm surges by three feet or more.[125] Construction and management of levees, reservoirs, and flood-control structures have reduced the input of coarse sands that are necessary to maintain barrier islands. As a result, all barrier islands in the delta, and most of the barrier islands in the Gulf of Mexico and along the Eastern seaboard, are deteriorating.[126] The deterioration phase of the barrier island cycle has accelerated while the building phase has stopped. Figure 8 shows the areas where barrier islands have deteriorated (red) and areas of barrier island building continues (yellow).

Figure 8. Areas of Barrier Island Accretion and Deterioration



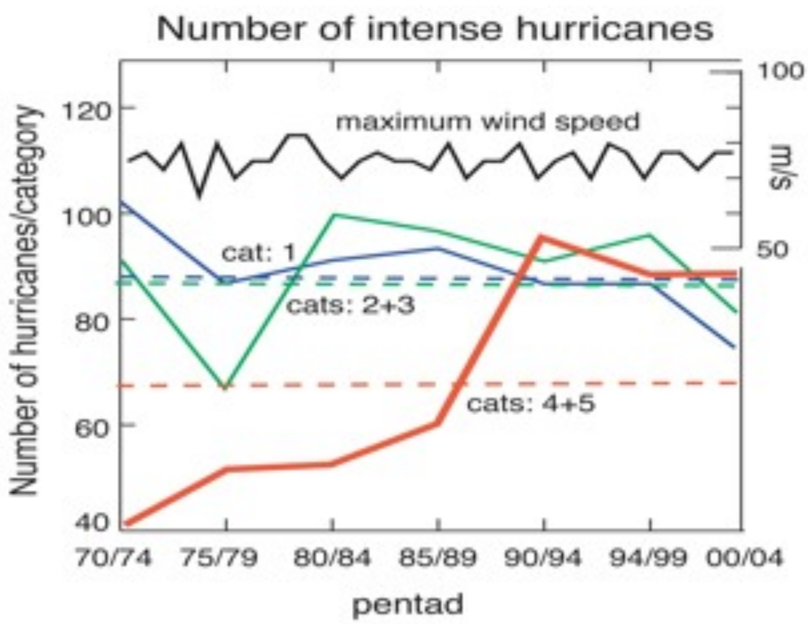
Source: USGS

[125] Farber & Costanza, 1987
[126] Pilkey, 2003

Bigger, Stronger, More Hurricanes

Hurricanes have increased in strength and duration of by 50% in the last 30 years.[127] Maximum wind speeds have increased by 60%, holding about twice the total amount of energy compared to hurricanes more than 30 years ago. The frequency of category 4 and 5 hurricanes, the most powerful and damaging hurricanes, have also risen sharply over the same period. Hurricanes that would have been within category 1-3 are encountering conditions that feed hurricane growth – especially warmer water – and are becoming more powerful category 4-5 hurricanes. There were 171 severe hurricanes 1975-1989, the number rose to 269 in 1990- 2004. Figure 9 from the journal *Science* demonstrates the increase in numbers of more powerful hurricanes.[128]

Figure 9. Increase in Category 4-5 Hurricanes and Reduction in Category 1-3 Hurricanes between 1970 and 2004



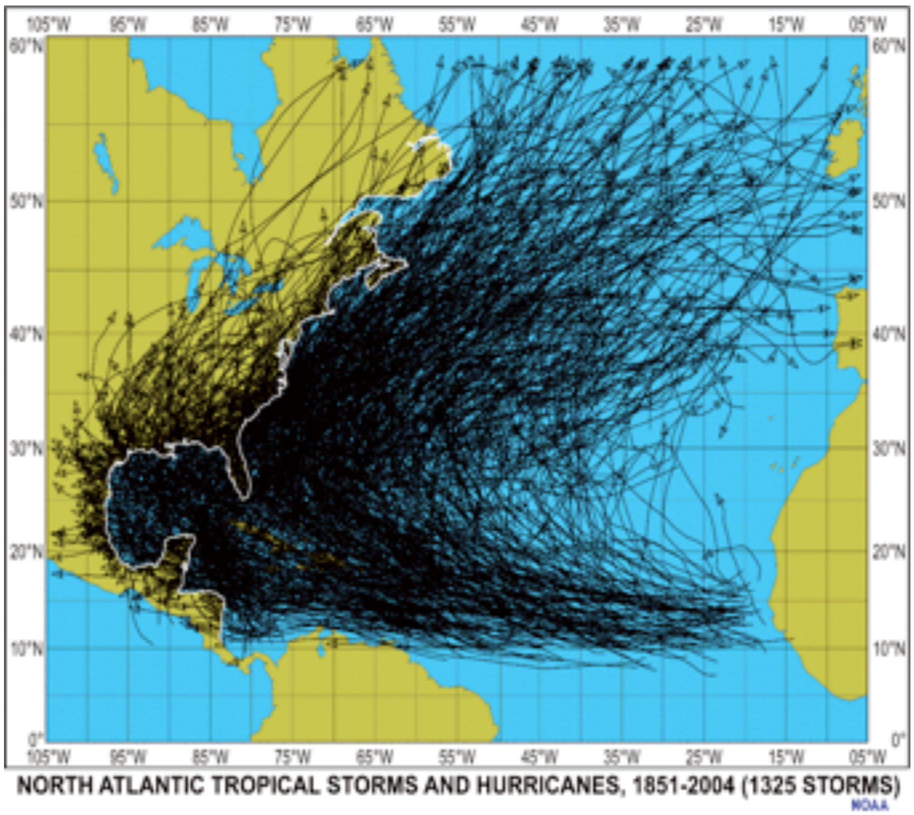
Source: Emanuel, 2005

NOAA's findings also show that the intensity of hurricanes has risen since 1980.[129] Hurricanes Katrina, Rita, and Wilma started out as tropical storms – all weaker than category 1 hurricanes when they were in the Atlantic but when they entered the Gulf of Mexico, the hot waters sparked these storms to massive category 5 hurricanes in just a few days.

[127] Emanuel, 2005
[128] Webster & Curry, *2005*
[129] Landsea, 2005

More storms will hit the U.S. Figure 10 shows the paths of Atlantic hurricanes in 1851-2004. The trend toward larger and more powerful hurricanes associated with increases in global and oceanic temperatures is a concern for the United States' entire eastern seaboard.

Figure 10. Atlantic Hurricane Paths, 1851-2004



Source: NOAA

The Earth is Warming Up

Tens of thousands of temperature measurements over the last 150 years and geologic, plant and ice data that provide the earth's historical temperatures show that the earth's surface temperature has increased in the last century. Figure 11 shows increases in the earth's surface temperature.[130]

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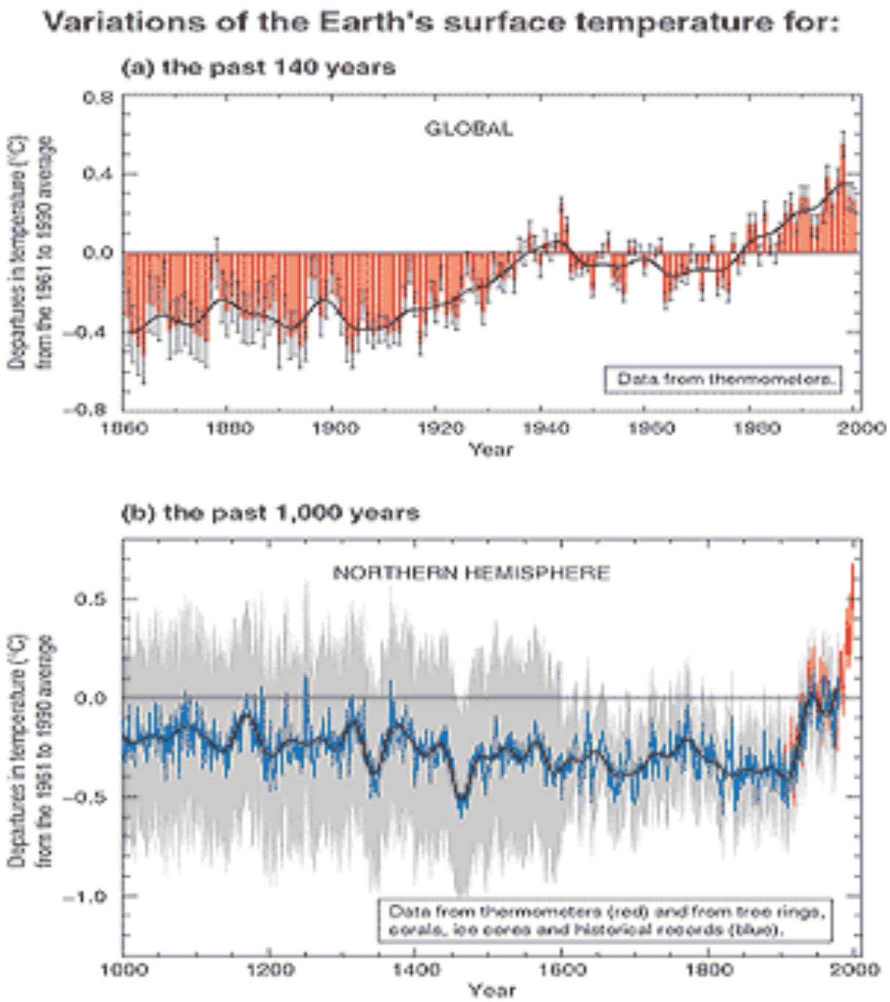
[130] Intergovernmental Panel on Climate Change, 2001

Figure 11. The Earth's Surface Temperature from 1860 to 2000



Source: IPCC, 2001

Two general theories explain this observed increase in temperature. A very small number of scientists, primarily without climate science training, contend that the burning of fossil fuels does not drive the observed increase in the earth's surface temperature. They assert that it is part of a natural cycle and predict that temperatures will again decline at some future time. On the other hand, more than 400 of the world's top climate scientists at the Intergovernmental Panel on Climate Change (IPCC) have ascertained that human activities, including the burning of fossil fuels, partially caused the observed increase in global temperatures.[131]

[131] IPCC, 2001

IPCC scientists predict that global temperatures will rise by 1-5^{o}C within the 21st century. The increase in temperature will directly affect coastal areas, lead to changes in precipitation, increase the conditions for more powerful hurricanes, and accelerate sea level rise. It is predicted that as the tropics gain more heat, there will be a greater transport of water vapor toward higher latitudes.

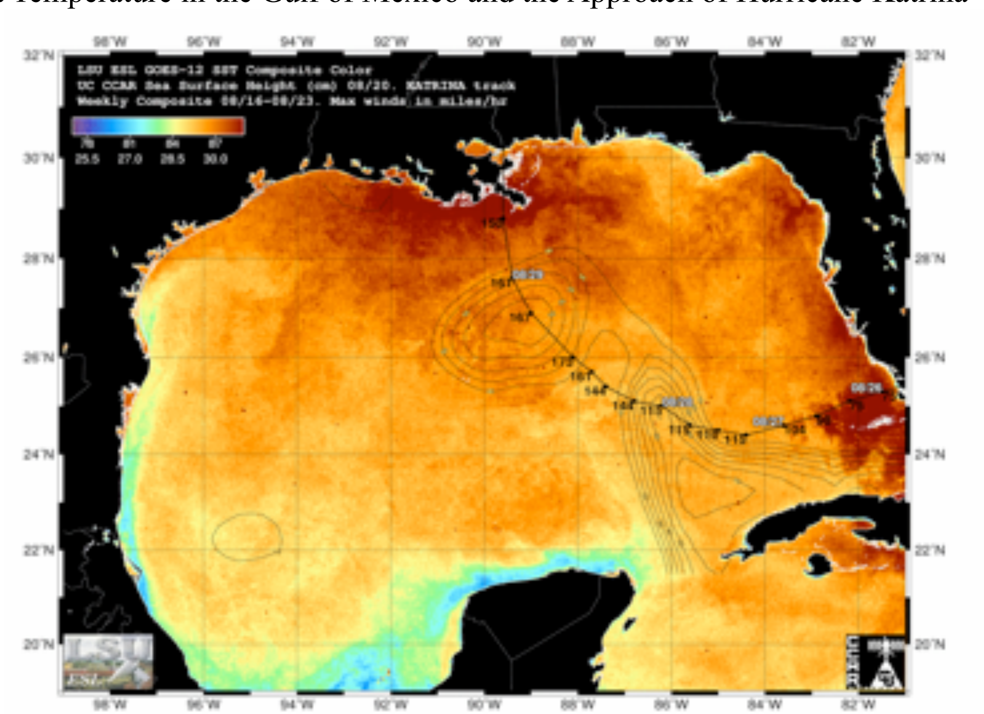
Sea Surface Temperatures

The transfer of heat from marine waters to the atmosphere creates hurricanes. The higher the sea surface temperature, the more quickly hurricanes gain power, the more powerful they become. Rising sea surface temperatures, half a degree globally,[132] are cause for great concern.

The 2005 Hurricane season saw tropical storms Katrina, Rita and Wilma explode from tropical storms into huge category 5 hurricanes upon entering the Gulf of Mexico.

Below is an image provided by the LSU Earth Scan Laboratory that shows the sea surface temperature in the Gulf of Mexico in August 2005. The darkest orange areas correspond to higher sea surface temperatures. The path of Hurricane Katrina and the sea surface height, building of the storm surge is also shown along the black tracking line.

Figure 12. Sea Temperature in the Gulf of Mexico and the Approach of Hurricane Katrina



Source: LSU ESL, 2008

[132] Elperin, 2005; Bart et al, 2007

Sea Level Rise

In low elevation coastlines like Louisiana's and much of the Gulf Coast's, a rise in sea level can profoundly impact wetlands and other ecosystems, particularly with the removal of historic sedimentary sources. Sea level and subsidence combine to increase the effective change in sea level in Mississippi River Delta. For about 3,000 years before 1900, sea levels did not change very much, perhaps rising very slightly. Since 1900 however, global sea levels rose by nearly 20 cm.[133] The IPCC predicted that by the year 2100, the sea level will rise another 11-88 cm.[134] Based on empirical relationships between temperature and sea level rise in the 20th century, Rhanstorf predicted that sea level rise may be one meter or more.[135] Despite these uncertainties, there is no doubt that coastal wetlands in Louisiana will see a high rate of relative sea level rise due to the combination of subsidence and eustatic sea level rise.

The Importance of Levees

The U.S. Army Corps of Engineers (USACE) found that wetlands and swamp forests provide storm buffering that helps protect levees. Heavy waves associated with storm surges force water into the pour structure of levees, weakens them, sometimes to the point of failure. Wetlands break up the wave action of hurricanes so that water rises with less force. Levee specialist Dr. Paul Kemp best described what wetlands do: level out waves so that rising water may overtop levees – not breach them – like water flowing over a bathtub lip, as opposed to a failure, which is like the whole side of the bathtub giving away. Overtopping allows far less water through with far less force, and results in far less damage. While levees are built to protect human safety and economic assets, the 2005 hurricane season showed that levees can also amplify hurricane storm damage.

The Issue with Levees

Tens of billions of dollars were invested in building levees in the Mississippi Delta without considering the land loss this would cause, or the increased vulnerability and economic costs associated with losing vast areas of land, wetlands and barrier islands. Canals for oil and gas drilling were dug, also without concern for the resulting land loss.

Despite having sufficient shipping channels in the Mississippi River, Congress appropriated funds to build and maintain the MRGO canal in the 1960s to shorten the shipping trip from the Gulf of Mexico to New Orleans to 76 miles. Saltwater came up the canal and killed thousands of acres of freshwater wetlands converting them to an open water area shaped like a funnel in St. Bernard Parish southeast of New Orleans.[136] Cypress trees are highly resistant to blow down even with hurricane intensity winds. The sturdy three-dimensional structure of cypress forests reduces surface winds, hurricane storm surge and wave heights on top of the surge. In the wake of Hurricane Katrina, experts and the public decried the "funnel" effect caused by MRGO and the wetland loss it caused which focused and piled up hurricane storm surge waters and demolished protective levees causing much of the destruction in New Orleans and St. Bernard Parish.[137] The USACE initially contested the assertion that the MRGO canal caused the vast loss of wetlands and increased the damage to New Orleans. However, the

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[133] United Nations Environment Programme, 2007
[134] IPCC, 2007
[135] Rahmstorf et al, 2007
[136] Day et al, 2006
[137] Day et al, 2006

evidence that MR-GO both caused wetland destruction and substantially focused and increased the height of Hurricanes Katrina and Rita's storm surge is now widely accepted. The U.S. Congress, upon request of the Louisiana Legislature, directed the USACE to close MRGO. In 2007 the Army Corps settled on a plan and received funding to block the navigation canal. It is now clear that the design of the MRGO shipping canal for the promotion of shipping was at the expense of wetlands "natural capital" and the hurricane protection they provided. This investment in built capital caused greater overall damage than benefit to New Orleans. The substantial cost of closing the canal and restoring the protective wetlands is a good investment.

Levee Successes and Failures

Many levees protecting New Orleans and other areas of the Mississippi Delta performed well while some failed. The 17th Street and London Avenue Canals were lined with levees with seawalls atop, these structures failed because they simply did not meet their required engineering specifications. There is a great deal of research and discussion of these failed structures.[138]

Wetlands protect levees. The photo below shows a section of a levee where Hurricane Katrina storm surge hit from left to right. Notice the base of the photo where a wetland buffers the levee. Water overtopped the levee, flowed over it, scoured the other side, but did not breach or destroy the levee. Wetlands broke the wave action associated with the hurricane storm surge. This protected the levee and seawall from the pounding wave action of the storm surge; the storm surge rose more gently, like water filling up a bathtub. The structure was overtopped, but not destroyed. The top of the photo shows that where there was no wetland buffer, storm surge waves were unbroken. The full wave action pounded the levee and floodwall structure. The levee was breached, allowing a torrent of floodwaters to enter A levee breach lets in the full depth of floodwaters, causing catastrophic damage, like punching a large hole in the side of a bathtub. Where levees are overtopped, they allow some water to flow while yet holding most of the floodwaters back until the storm surge recedes, causing far less flooding and far less damage.

Figure 13. Levee Damage after Hurricane Katrina

Photo Credit: G. Kemp

[138] Louisiana Department of Transportation, 2007

Levees Can Amplify Hurricane Storm Surge and Damage

It now appears that the 29-foot storm surge from Hurricane Katrina that devastated the Mississippi coastline was partially created by levees along the Mississippi River. Hurricane storm surges move in a rotation around the eye of the storm. A northward arm of the storm surge struck the coastline directly, while a southern moving arm of the storm surge was reflected off the Mississippi River Levee and back toward the Mississippi coastline, creating an additive effect.

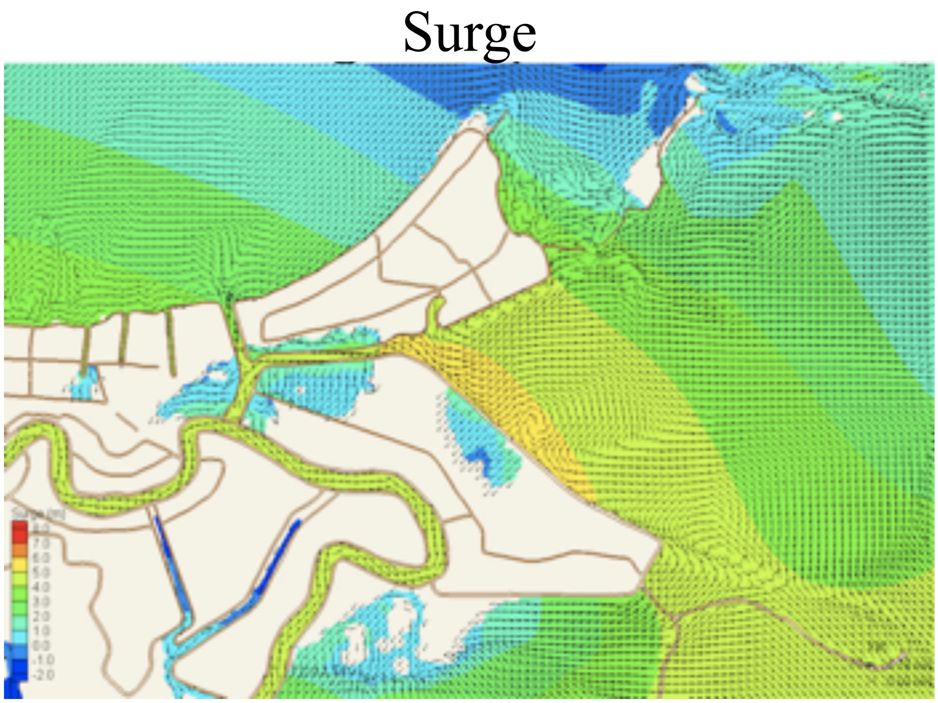
The levees that maintain the MRGO Canal on the northeast boundary of St. Bernard Parish and the shipping canal to the south of eastern Orleans Parish created a v-shaped funnel, leading storm surge waters directly into New Orleans. As storm surge waters moved west from the path of Katrina into this "V" created by the canals, the funneling effect increasingly confined the storm surge waters as they approached New Orleans, increasing the height of the storm surge and demolishing the levees that protected the southern part of the city.

Figure 14. The "Funnel" Exposing New Orleans to Increased Storm Surge Damage

Source: Dr. Paul Kemp, 2006

Dr. Hassan Mashriqui modeled the storm surge of hurricane Katrina showing the amplification of the storm surge in the funnel. This is just a "snap shot" of one point in time as the storm surge built up then overtopped or breached levees in St. Bernard Parish, East New Orleans, and New Orleans.

Figure 15. Katrina Storm Surge "Snap Shot"



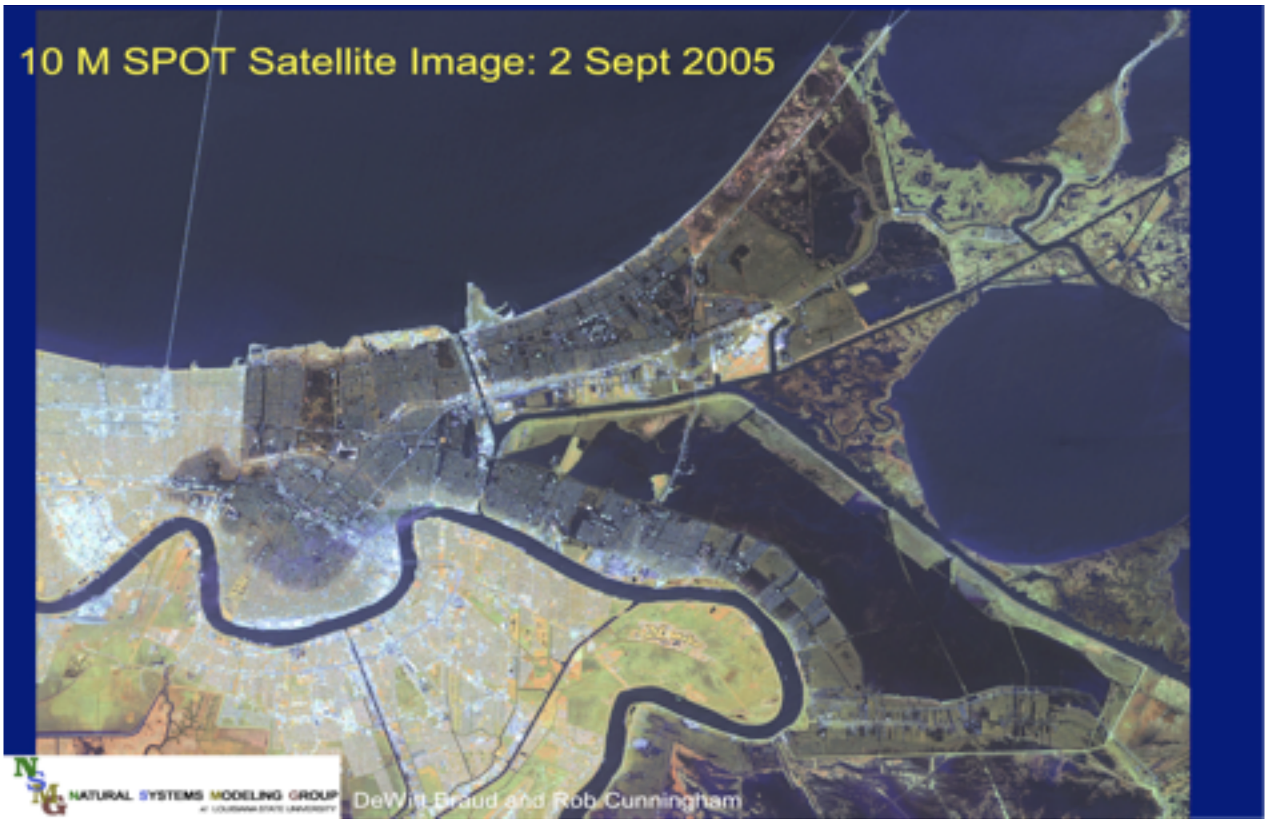
Source: Dr. Hassan Mashriqui of Louisiana State University, 2006

Figure 16. Storm Surge of Hurricane Katrina Amplified by Levees in the "Funnel"

Picture taken by an automatic camera located at an electrical generating facility on the Gulf Intracoastal Waterway (GIWW) where the Route I-510 bridge crosses the GIWW. This is close to where the Mississippi River Gulf Outlet (MRGO) enters the GIWW. The shot clearly shows the storm surge, estimated to be 5.5-6m (18-20 ft.) in height.

An automatic camera from an electric-generating plant at the Interstate Bridge on Parish Road caught an image of the massive storm surge likely amplified by this funnel effect close to the end of the funnel. The levees' constricting effect amplified the storm surge to a height of 18-20 feet.

Figure 17. Flood Caused by the Breaching of New Orleans' Protective Levees



Source: National Systems Modeling Group, 2006

The Decline of Oil and Natural Gas Reserves and Production

One of the most profound global and local physical changes affecting energy prices and industrial society is the global decline in oil reserves. This has an important bearing on wetland restoration decisions. Some delta restoration and levee options are more energy intensive than others. Allowing the Mississippi River to move vast amounts of sediment and water is far less expensive than constructing levees and pumping sediment. With rising fossil fuel prices, restoration options that utilize the river's energy will continue to be less expensive than extensive levee works and other energy intensive options. Another critical fact to consider in levee/delta restoration is the depletion of oil and gas reserves in Louisiana, the U.S. and the world. Vast, easily accessible fossil fuel reserves have been depleted; cheap oil will not be available in the future.

In the past, if world demand for oil rose, supply could be easily expanded. This is no longer true today. Because the world's oil supply has become inelastic (the supply curve is close to vertical, and supply does not readily expand in response to increases in price), when demand is high, prices rise dramatically. When demand falls, prices fall dramatically. This was borne out in just the few months between the high demand period of the summer of 2008, where oil prices surpassed $140/barrel, and the fall of 2008 when global recession depressed demand and prices fell to less than $40/barrel.

U.S. oil production peaked in the early 1970s. Except for a brief smaller peak in production from Alaska's Prudhoe Bay, U.S. oil production has declined steadily. According to the Louisiana Department of Mineral Resources, "overall crude oil production in the state has fallen considerably from peak production levels attained in the mid 1960s (North Louisiana) to early 1970s (offshore and South Louisiana). Today, crude oil production is 17% of its 1965 peak production in North Louisiana, 12% of its 1970 peak in South Louisiana, and 12% of its 1972 peak in offshore Louisiana. Relative to their respective peaks, crude oil production in North Louisiana has experienced an annual average decline of almost 5%, with South Louisiana and offshore Louisiana each seeing a 6% average decrease per year."[139] Louisiana's oil production has been in decline for over 35 years and continues to decline.

Natural gas production in Louisiana has also peaked and is now declining. Offshore production will peak. Oil and gas have been a major part of Louisiana's economy for decades. With the decline oil and gas reserves, these non-renewable resources may play a smaller role in the state's economy. Production is expected to trail off considerably in another 10 years. These declines in production are critical; they signal a need for a post-oil economic strategy for the state and nation. Renewable resources will need to play a larger role in the future. As global oil reserves are depleted, oil prices as well as transportation and construction costs will rise in the long run despite temporary declines in price associated with demand reductions, as in the current recession. Energy prices have a dramatic effect on the cost of energy intensive projects, such as levees, and improve the overall economics of restoration projects, such as diversions, which utilize the Mississippi River's energy to transport water and sediment.

It is wise to now invest in large diversions to restore the Mississippi Delta. Diversions have upfront costs and provide employment opportunities in construction and very low operating costs. The upfront construction costs of diversions will most likely be less today than they will be in the future while the benefits will accrue in the future as oil and gas revenues decline. Energy intensive restoration techniques, such as piping dredged sediments, are likely to become less viable in the future.

Summary: Facing Physical Realities

Economies depend on ecosystems, natural resources and stable landscapes. Science has clearly shown that physical processes are driving larger hurricanes and destroying wetlands and barrier islands. The loss of land is reducing the valuable wetland and barrier island storm buffering endangering economic assets and people. If these trends continue unabated, viable economies may decline in many parts of the Mississippi Delta. These facts lay the groundwork for a better economic understanding of the Mississippi Delta and the profound

[139] Dismukes et. al, 2004

implications of a very physically dynamic system for people, local governments, infrastructure, housing and industries, including the oil and gas industry.

These are measured scientific observations and physical facts, not theory:

- Hurricanes are getting larger, more destructive, and more costly.
- Land, wetlands and barrier islands (horizontal levees) reduce hurricane impact.
- Land, wetlands and barrier islands are being lost and converted to open water.
- Hurricanes gain power over deep, warm, open water.
- Some levee configurations magnify storm surge and storm surge damage.
- The Mississippi River Delta is subsiding (sinking).
- Land expands where water and sediment are provided.
- Sea level is rising.
- Global atmospheric and ocean temperatures, including the Gulf of Mexico, are rising.
- Oil and gas reserves are declining in Louisiana, the U.S. and the world. Energy intensive options will become more expensive and less feasible.

The physical reality of these dynamic changes holds tremendous economic implications for the United States, the Mississippi River Delta and the states along the Gulf of Mexico and Atlantic coastline. Part IV of this study examines three scenarios and their economic implications.

PART IV: Restoration Scenarios

This section examines three management scenarios of the Mississippi Delta and the economic implications of each scenario in 100 years. The values of ecosystem services provided by each scenario are calculated. Estimating the cost of each scenario is outside the scope of this study but should be examined.

The ecosystems of the Mississippi Delta provide benefits ranging from $330 billion to $1.3 trillion, contributing to the national economy and the quality of life. How much, where, and by whom should investments in restoration and levees be made? What should the balance be? These are critical questions arise with radically different alternatives being considered.

One thing is certain. The continued degradation of the Mississippi River Delta threatens public safety, economic productivity and ecosystem services. The damage to oil production, pipelines and refineries has national economic implications. Without wetland expansion hurricane damage will result in higher prices for gasoline, jet fuel, diesel, fuel oil and natural gas for the entire U.S. as it did after Hurricanes Katrina, Rita, Gustav and Ike. Better management of the Mississippi Delta is critical to the U.S.

Part 1 of this study introduced a "new view on value," and the critically important role of natural capital for the economy of the Mississippi River Delta. Part II provided a valuation of 11 ecosystem services and net present value calculations establishing that the delta is an enormously valuable natural capital asset. Part III of this study shows how the dramatic, dynamic physical changes affecting the Mississippi River Delta have profound economic implications. This section examines three scenarios for the Mississippi Delta: continued delta deterioration and land loss, a modest investment in delta restoration, and a more aggressive investment in the restoration of the Mississippi River and the delta.

Three Scenarios

Hurricanes Katrina, Rita, Gustav and Ike renewed wake-up calls for the large-scale physical and economic changes that have been taking place in the Mississippi Delta. Greater efforts need to be exerted toward determining how to best respond to the physical, economic and social dynamics of a changing delta.

The three scenarios considered here are: 1) do nothing new 2) hold the line and 3) restore the delta. These scenarios actually represent the three general suites of approaches to the problem of land loss in the Mississippi Delta. Each has a set of different possible actions, investments in built and natural infrastructure, and economic and social ramifications. This is not intended to be an exact analysis but a broad examination of three overarching approaches. It is intended to shed light on the set of alternatives currently being considered for the delta and to offer far more economically productive options.

The "do nothing new" scenario assumes the continuation of the past management of the Mississippi River. Large investments in levees and reconstruction of hurricane-damaged structures to keep water and sediment flowing off the continental shelf pertain to a management regime that has lead to the loss of 1.2 million acres in the delta. The Mississippi River will remain, as it does today, separated from the Mississippi Delta resulting in greater wetland losses, greater losses of ecosystem services, and the increased exposure of towns and cities to hurricanes.

This scenario is based on the U.S. Geological Society's estimate of wetlands loss of 328,000 acres in the next 50 years.[140] It is assumed that an additional 272,000 acres will be lost as the impact of subsidence and sea level rise intensify in the next 50 years. This may be a very conservative estimate since 42% of the predicted land loss for the next 50 years has already occurred with the loss of 138,000 acres from Hurricanes Katrina and Rita. Based on the pattern of land loss in the last 80 years and on the experience of hurricanes Katrina and Rita, wetland loss is not linear. Hurricanes may also abruptly increase the loss of wetlands where they are not healthy. Initially, high wetland loss rates decline as there are fewer wetlands to lose. Thus, the shape of the wetland loss curve adopted is concave, reflecting the history and nature of wetland loss.

The "hold the line" scenario carries the entire set of issues on coastal restoration presently considered by the U.S. Army Corps of Engineers. There are many potential project combinations to try to achieve this goal. If successful, it will result in no net land loss. The delta will lose land in some areas and gain land elsewhere with overall land coverage remaining the same. Although this scenario significantly improves on the first scenario with the use of some small diversions, it does not bring a fundamental management shift. The Mississippi River will remain disconnected to the delta and most of its water and sediment of the will continue to flow off the continental shelf.

[140] U.S. Geological Survey, 2004

Questions persist whether this scenario can be achieved. Deltas involve large landscape processes that create and maintain them. They are either restored so that they shift toward sediment/water/land building balance or are not restored resulting in land loss. This analysis assumes the viability of holding the line. If the deltaic processes are not restored at the scale required, the Mississippi River Delta will continue to shrink and fall apart. Trying to hold the line through a combination of small projects or energy-intensive sediment pumping can be considerably costlier than a fundamental reworking of the system with large diversions that, once in place, move far more water and sediment per dollar spent.

The “sustainable restoration” scenario – rejoining the river and the delta – brings a fundamental shift in policy and action. This scenario includes large diversions and crevasse structures in the levees of the Mississippi River that can be opened, particularly during flood periods when the flow and sediment loads are high. This moves water and sediment into large wetland and open water areas to restore wetlands. Other restoration ideas also need to be considered, such as a structure in the bottom of the river to force bottom sediment up and into diversion channels when desired. Diversion and crevasse structures can always be closed to accommodate shipping or low water periods.

Most of the water and sediment would be taken out of the Mississippi River during peak flows when sediment and water levels are highest, thereby providing the greatest restoration value and the least conflict with navigation. During periods of low flow, the quantity of water diversion would be scaled back to allow continued navigation.

Restoration planning over longer periods and inclusive of a greater area of the Mississippi Basin dramatically improves results. Much of the larger grain sediment from the Mississippi Basin has been trapped behind dams for 80 years. These dams will be filled with sediment in coming decades. Upper Mississippi River dams will require decommissioning or sediments flushing in the next 100 years. If developed as part of a Mississippi River basin plan, this heavier sediment can be provided through a controlled release, adding very substantially to the quality and quantity of the river’s sediment load and capacity for coastal restoration. Barrier Islands throughout the Atlantic and Gulf Coast have been deprived of sand from upstream rivers. Under this scenario, upper basin sediment will be managed to increase downstream benefits. Another option in the short term, prior to further reductions in oil production and increases in price, sediments can be pumped to promote rapid wetland recovery and expansion.

Like the “hold the line” scenario, there are many combinations of potential projects that can achieve this goal. Identifying the suite of projects to be implemented involves the use of spatially specific modeling which can account for multiple benefits, such as storm protection, land building, coastal economic recovery potential, recreation and carbon sequestration to set up and test different suites of river reconnection projects.

This excludes the cost of a sustainable restoration for lack of full project identification that can be used as basis of costs. Like the other two scenarios, this also needs to include the returns in avoided costs and a suite of sustainable and valuable economic goods and services gained. Trapping the water and sediment of the Mississippi River will bring significant co-benefits, including a reduction in the “dead zone” hypoxic area in the

Gulf of Mexico, as the nitrogen is trapped and utilized by wetland plants in the delta. These co-benefits are not included in this preliminary analysis.

Modeling has not included the eventual release of currently impounded sediments. Thus, there is no clear estimate of land restoration under a scenario that utilizes currently- impounded sediments, some sediment pumping, and release of as much of the water and sediment of the river as possible. The sustainable restoration scenario assumes that with the release of large sediment loads, wetland recovery and growth rates, increased release of silt and sand in coming decades, diversions and some sediment pumping, 500,000 acres of wetlands can be created or restored in the next 100 years. Data and modeling are not yet available for accuracy in estimating the acreage of wetlands restored from a long term, coast-wide restoration. This is intended to promote a wider analysis and the consideration of the general suite of restoration options and to recognize that economic analysis, which includes ecosystem services supports the implementation of restoration projects now.

It is important to consider this scenario. Academics, NGOs, businesses and coastal communities have been calling for restoration on a scale that would reestablish deltaic processes and result in a net gain in land in the long run. With the addition of wetlands, the ecosystem services these lands provide, especially hurricane buffering, would expand over time.

Costs and Scenario Details

No option is cheap. Under the “no action” scenario, the deterioration of the delta will continue along with the loss of nature’s services and increasing damages to communities and economic assets. It will ensure a costly retreat of people and economic productivity. The “hold the line” scenario requires an unknown set of smaller projects to stop land loss without restoring the functions of the Mississippi River Delta. The third scenario entails large projects that reconnect the sediment, water and energy of the Mississippi River with the delta. All these options entail significant expenditures. Further analysis would refine the costs, benefits and net rate of return on restoration investments.

These three scenarios are meant to spur further research rather than present a detailed modeling effort. Economic analysis of changes in wetland values relies on the accuracy of the physical changes in each wetland type. This analysis is of three very broad scenarios with coarse physical estimates, thus the economic analysis is also coarse. Since the exact changes in wetland type for each scenario are unknown, single average values for wetland values were used. As the physical analysis of restoration alternatives becomes more robust, more refined economic analysis based on ecosystem-specific values can be produced.

The restoration of wetlands largely involves the conversion of estuarine open water to wetlands with a movement of the salt gradient toward the coast and conversion of salt marsh to brackish marsh, brackish to intermediate, and intermediate to fresh marsh.

The inland movement of the salt gradient and conversion of wetlands into estuarine open water results in wetland loss. The low value of estuarine wetlands was subtracted from the average low value per acre per year for all wetland types, excluding the highest wetland value for forested wetlands to derive a net loss or gain value of $4,515/acre with the conversion of wetlands to open water or open water to wetlands for the three scenarios.

- Land loss in the “do nothing new” scenario in 100 years is set at twice what the U.S. Geological Survey predicts to occur over the next 50 years. This adds up to a loss of 500,000 acres in the next 100 years.
- The “hold the line” scenario assumes there is no net gain or loss of land in the next 100 years.
- The “sustainable restoration” scenario assumes that with large-scale restoration over a 100-year period, roughly 40% of the wetlands lost in the last 80 years would be restored totaling 500,000 acres. This is a speculative scenario if short-term sediment pumping, long-term river restoration and release of basin sediments were secured.

Each scenario translates into a net loss or gain of ecosystem service values in the next 100 years. A larger time horizon would accentuate the differences between the scenarios. The net present value of benefits from ecosystem services, not total project costs, for each scenario was calculated. Cost projections for the various restoration scenarios are not included because they are difficult to ascertain without actual project identification.

The calculation of net present value of land loss or land gain depends on the discount rate chosen, which reflects how value received in the future is counted in the present. A lower discount rate implies giving greater weight to the benefits that storm protection, fisheries and other ecosystem services provide to people in the future. A vast majority of benefits from renewable resources are provided in the future. Healthy natural capital does not depreciate. Lower discount rates for natural capital restoration are justified – as opposed to built capital that depreciates. The choice of a discount rate is arbitrary. At times the US Prime rate is used as a marker. As of February 2009, the commercial bank prime rate of interest was 3.25%. In February 2009, the U.S. Federal Reserve Bank Open Market Committee in continued response to the financial crisis retained the remarkable fed funds rate of 0-0.25%[141]. This is the interest rate that banks lend cash to each other overnight in the Federal Funds Market.

Table 9 shows the Present Value of the conversion of wetlands and open water. It does not include the total cost of implementing each of the scenarios. This is a comparison of an estimated net gain or loss in ecosystem services associated with each scenario.

Table 9. Three Scenarios of Present Value of Wetland Ecosystem Services for 100 years (in billions, 2007 dollars).

Present Value of Scenario				
Scenario	**Discount Rate 0%**	**Discount Rate 2%**	**Discount Rate 3.5%**	**Discount Rate 5%**
Do Nothing New	-190	-72	-41	-26
Army Corps No Net Loss	0	0	0	0
Sustainable Restoration	132	41	21	12

141 U.S. Federal Reserve Bank, 2009

Depending on the discount rate chosen, the “no action” scenario will result in losses of $26-190 billion in ecosystem services alone. This does not include losses such as the costs of future damage by hurricanes, retreat of economic infrastructure, or loss of life. Losing over 500,000 acres of wetlands would leave New Orleans and other coastal cities far more exposed to hurricanes. Hurricane Katrina showed that a single event can cause $200 billion in damage.

The “no change” scenario has no net increase or decrease in values. This scenario would avoid the negative costs associated with the “no action” scenario, but would not increase storm protection or other ecosystem services provided at higher levels in the past.

The “sustainable restoration” scenario will add over 500,000 acres of wetlands in a century and significantly add to the hurricane protection of New Orleans and other cities and communities on the Mississippi River Delta. Because this is a building process, the benefits will increase dramatically in the future. The benefits from the net gain in wetland area will be between $12-132 billion. In addition, the costs associated with the “no action” option will be avoided.

Table 10 shows the total present value of benefits in scenario 3, the sum of avoided costs associated with the “do nothing new” option, and the gains from the increase in additional wetlands.

Table 10. Total Present Value for Scenario 3, Avoided Losses and Gains Realized in $ Billions

Major Restoration Scenario	**PV 0% Discount Rate**	**PV 2% Discount Rate**	**PV 3.5% Discount Rate**	**PV 5% Discount Rate**
Total PV Avoided Costs and Direct Gains	322	113	62	38

Scenario 3 increases the area of land and avoids the costs associated with the current path of land loss. This provides a net benefit of $322 billion with a zero discount rate if future benefits to people are counted equally as benefits to people in the present or $38 billion at a 5% discount rate if renewable benefits provided in the future are rather steeply discounted and deemed as having little value. The US Prime Rate of Interest as of February 1, 2009 was 3.25%. The figure conservatively adopted here is $62 billion at a 3.5% discount rate. Not included in this analysis, these wetlands would also provide greater protection for any built structure, including levees. Adoption of a 2% discount rate, that is recognizing the greater benefits of restoration in the future, would show over $100 billion in benefits.

Restoration of the coastline would reduce levee maintenance and reconstruction costs substantially. A larger skirt of wetlands around the Mississippi Delta would provide greater hurricane buffering. This alone could reduce future damage to cities like New Orleans by tens or hundreds of billions of dollars.

Even though many of the most important cost and benefit outcomes of these scenarios are beyond the scope of this study or not easily expressed in dollar value (human safety, future FEMA relief costs or community stability), the direction of the outcomes for each scenario is clear. For this reason, we present two tables that examine the likely outcomes of each scenario rated simply “Up, Down, or Same”.

Table 11 shows the direction of the cost/damage outcomes for each scenario. The list of costs and damages is not comprehensive. It includes: loss of life, displacement of people, loss of infrastructure, storm-associated national energy price increase, insurance costs, FEMA and other relief costs, storm damage costs, post storm litigation, loss of the coastal economy, and area of the hypoxic dead zone in the Gulf of Mexico.

Table 11. Likely Cost or Damage and Scenario Outcomes

Cost/Damage	**Scenario Outcomes**		
	“Do Nothing New”	**Hold the Line**	**Sustainable Restoration**
Loss of life	Up Greatly	Same	Down
Dislocation of People	Up Greatly	Same	Down
Loss of infrastructure	UP Greatly	Up	Down
Storm Associated Energy Price Rises	Up Greatly	Up	Down
Insurance costs	Up Greatly	Up	Down
FEMA and relief costs	Up Greatly	Same	Down
Storm Damage Costs	Up Greatly	Up	Down
Post Storm Litigation	Up Greatly	Up	Down
Loss of Coastal Economy	Up Greatly	Up	Down
Area of Dead Zone	Up	Same	Down

Table 12 shows the direction of the benefit outcomes for each scenario. The list of costs and damages is not comprehensive. It includes: coastal stability, land building, storm protection, community stability, protection of levees, protection of energy infrastructure, wetland expansion, economic development potential, food, furs and fiber, wildlife habitat, water quality, carbon sequestration, waste treatment, recreation, aesthetic value, people’s sense of security and national pride.

Table 12. Likely Benefit Scenario Outcomes

Benefit	"Do Nothing New"	Hold the Line	Sustainable Restoration
Coastal Stability	Down	Same	Up
Land building	Down	Same	Up
Storm Protection	Down	Same	Up
Community Stability	Down	Same	Up
Protection of Levees	Down	Same	Up
Protection of Energy Infrastructure	Down	Down	Up
Wetland Expansion	Down	Same	Up
Coastal Economic Development Potential	Down	Same	Up
Food, Furs, Fiber	Down	Same	Up
Wildlife Habitat	Down	Same	Up
Water Quality	Down	Down	Up
Carbon Sequestration	Down	Same	Up
Waste Treatment	Down	Same	Up
Recreation	Down	Down	Up
Aesthetic Value	Down	Same	Up
People's Sense of Security	Down	Down	Up
National Pride	Down	Same	Up

Tables 11 and 12 provide the direction of impact of each scenario for each outcome area. The "do nothing new" scenario will increase costs in virtually every category over current costs.

The "hold the line" scenario stabilizes some of the outcomes. If the goal of no net land loss is attained, overall coastal stability and land building will not deteriorate further but it will not experience a net advance either. Stopping land loss will not stop the deterioration of water quality but it will likely result in a decline in the protection of energy infrastructure because land building in a hold the line scenario will be focused where it protects inhabited areas and land loss will likely continue to take place where important energy infrastructure exists more distant from population centers.

The "sustainable restoration" scenario provides greater benefits and fewer costs by providing a net gain in land and large diversions that enable controlled distribution of sediment and water across the Mississippi Delta. Overall, sediment pumping, barrier island reconstruction and other restoration methods all increase land and the suite of benefits they bring. The dollar calculation of benefits based on a few ecosystem services and a cursory examination of the direction of benefits for the three options clearly show that the "sustainable restoration" option provides the greatest benefits and least costs. Neither the full costs nor full benefits of the projects are included. For example, the "do nothing" option may entail the outstandingly costly relocation of the people and assets of New Orleans. The sustainable restoration option may ensure the viability of New Orleans and secure vast assets and less disruption for many people.

One of the most persistent political tragedies has been that while the scientists, academics, state officials and citizens have emphasized the importance of reconnecting the Mississippi River to the delta as proposed in the Louisiana Coastal Protection Restoration Draft Technical Report, this option has not been considered by decision makers, such as the Army Corps of Engineers, as an option for coastal restoration.[142] This scenario analysis indicates that investing in sustainable restoration at a larger scale is the best approach. It provides the greatest benefits under any discount rate. The sustainable restoration scenario provides far greater and more comprehensive hurricane protection and provides for greater economic productivity in the Mississippi Delta. The sustainable restoration option to reconnect the Mississippi River to the delta should be the basis for restoration investment in the Mississippi Delta.

The many different combinations of delta and levee restoration each produce a different land restoration or deterioration scenario. Human safety, the impact on economic assets and the overall dynamics and sustainability of the Mississippi River Delta are critical to determining which levee/coastal restoration option will provide the greatest public safety, protection of economic assets (including natural assets) and coastal restoration value. The current levee designs are not integrated with wetland restoration models. None of the economic analyses fully include the value of ecosystem services. Including ecosystem services and their value would provide a better understanding of the value of public investments in restoration.

The persistent pursuit of restoration projects that are too small compared to the scale of the Mississippi Delta and its land loss is another notable flaw in the current management. The Coastal Protection and Restoration Authority of Louisiana has recognized this and said that "Creating a sustainable deltaic system requires that we reestablish the processes that originally created the landscape." The plan specifically recommends "building very large diversions that will use the majority of the river's sediment and fresh water to both create new delta lobes and nourish existing wetlands."[143] The report does not identify the locations and size of these diversions, but has produced a list of projects that comprise a partial coastal restoration plan. This was an important step forward but it needs the set of projects for moving very large amounts of water and sediment out of the Mississippi River and into the deltaic plain.

The scientific and coastal communities as well as the State of Louisiana are calling for far larger diversion projects that will significantly restore the Mississippi Delta's natural sediment regime and provide a net increase in and more enduring maintenance of existing wetlands. The natural functioning of the delta must be a guide to restoration. Before the levees became widespread, there were many crevasses, often as large as or larger than the Bonnet Carre spillway. This scale of diversion must be considered especially with the increasing sea level rise. A primary concern has been maintaining navigation channels however this is relatively easily addressed by constructing locks or using peak flow periods which are the natural sediment load land building potential is greatest and where utilization of diversions does not interfere with navigation.

Larger restoration projects may be the only hope for a maintaining a sustainable landscape and economy as well as the long-term sustainability of ports and cities like New Orleans.

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[142] Army Corps of Engineers, 2008

[143] Executive Summary, CPRA, 2007a

CONCLUSIONS

Mississippi River Delta Ecosystems provide economically valuable services, including hurricane storm protection, water supply, climate stability, food, furs, waste treatment, wildlife habitat, recreation and other benefits. These services are valued at $12-47 billion/year.

This flow of annual benefits provides a vast amount of value to people across time. A "natural capital asset value" can be established from these annual benefits. The present value of the benefits from these ecosystem goods and services provided by the Mississippi Delta, analogous to an asset value, is worth at least $330 billion to $1.3 trillion.

Wetlands – a product of Mississippi River deltaic processes including freshwater, saltwater, estuaries/tidal bays and cypress swamps – account for more than 90% of the Mississippi Delta's estimated total value of ecosystem services.

These benefits are derived from "natural capital" which is self-maintaining and lasts for a long time; it is fundamentally different from "built capital" which depreciates quickly and requires capital and maintenance costs.

In the past, our natural capital was taken for granted. Although natural systems provide economic goods and services such as fish and hurricane protection, they have not been valued as economic assets and were excluded from economic analysis and investment decisions.

Large-scale physical changes are affecting the Mississippi River Delta. In the last 30 years, oil and energy costs have been increasing, hurricanes have become larger and more frequent, sea level has risen, atmospheric temperatures have risen, the delta has been subsiding and, since 1930, has lost 1.2 million acres of land. This loss has had tremendous economic implications, including exposing cities like New Orleans to greater threats from hurricanes.

Hurricanes Katrina and Rita triggered a warning that has been sounded several times before. The current management of the Mississippi River, moving the sediment and fresh water of the river off the continental shelf has damaging economic costs in terms of land loss. The river has been walled off from the Mississippi River Delta since the 1930s. The public, academics and the State of Louisiana have sought to reconnect the river to the delta and utilize its sediment, water and energy to renew the processes that added land to the delta for thousands of years.

It is clear that restoration of the deltaic processes and levees are needed to secure public safety, economic assets and valuable ecosystem services.

A "do-nothing" scenario will result in continued land loss costing the U.S. at least $41 billion. A "hold the line" scenario could avoid the $41 billion, but would provide no additional benefits at a 3.5% discount rate. A third "sustainable restoration" option would avoid $41 billion in losses and secure an additional $21 billion in benefits, providing $62 billion in net present value benefits.

This analysis does not include many ecosystem services with clear economic value. It is part of a series of efforts to understand the value of the natural capital in the Mississippi Delta. More work is critically needed to understand how and what investments in diversions, levees or other structures can produce the best and most long-lasting benefits.

A major investment to restore the deltaic processes of the Mississippi River Delta is required to maintain or expand the vast value of this natural asset. The movement of water and sediment and the maintenance and expansion of land underlies the production of many economic benefits, including protection against hurricanes. Without this investment, people and economic assets will be forced to retreat from the coastline.

Ecological engineering must form the basis of delta restoration. High and rising energy costs will erode the economics of energy intensive options, such as levees and sediment pumping while water and sediment diversions utilize the Mississippi River's energy and can be easily maintained over many decades.

The overarching solution is well understood: large diversions of water and sediment from the Mississippi River are required to rebuild the Mississippi Delta and to secure the many benefits, including the economic productivity that the river provides. Management of more coarse sediments in the Mississippi Basin, currently trapped behind dams, should also be considered as these sediments will eventually be released in the next 100 years and can contribute substantially to the delta's restoration.

Overall, this study shows that a major investment of $15-20 billion for restoring the Mississippi River Delta to significantly increase land building would return at least four to five times that amount in the order of $62 billion in net present value at a 3.5% discount rate.

Once restored in a manner that allows the maintenance of natural processes, these wetlands will continue to support the economic health of the Mississippi River Delta. With the river reconnected to the delta, the system will be closer to self-maintaining at the operating cost for diversion structures.

Without a large investment in restoration, hurricane damage will clearly increase and other ecosystem services will be lost. The economic viability and habitability of the Mississippi River Delta will be threatened. This could result in vast losses to the country in terms of irreplaceable cultural and natural resources.

Within the context of the current financial crisis, investment in the restoration of the Mississippi River Delta provides high short and long term returns. The Army Corps of Engineers, Federal, State and local governments should dramatically increase expenditures for the restoration of the Mississippi Delta.

The Mississippi River Delta, the largest delta in North America, houses oil and natural gas resources, refineries, fertilizer and chemical facilities and other industries that are vital to the country's economic health. It also comprises 40% of U.S. coastal wetlands, a crucial flyway for migratory birds. It is by far the most productive delta in the United States.

Economies need nature. This is very evident in the Mississippi River Delta. If the Mississippi River is not reconnected to the delta on a large-scale basis, the land, culture and economy of this vast and productive area will be lost. Effective hurricane defenses require wetland expansion. Reconnecting the river to the delta at the appropriate scale will accomplish restoration that is needed. This is in the best interest of the people of the United States.

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APPENDICES

APPENDIX A: List of Value-Transfer Studies Used for Data Sources

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APPENDIX B: Table of Land Cover Type, Ecosystem Services, Valuation Study Authors, Low and High Values

Land Cover/Ecosystem Service	Valuation Study Author	Method	Minimum Value	Maximum Value
Fresh Marsh				
Carbon sequestration	Chmura et al., 2003; Pearce, 2001; Tol, 2005	MP	$29.43	$267.53
Gas regulation	Costanza et al., 1997		136.64	136.64
Nutrient regulation	Kazmierczak, 2001	RC	$3.13	$1,069.56
Water supply	AWWA. 2007	RC	$42.52	$113.39
Flood protection	Thibodeau et al, 1981	AC	5,957.20	5,957.20
Hurricane protection	Costanza , 2008	AC	$1,394.58	$1,394.58
Fisheries production	Farber, 1996	PF	$53.37	$74.46
Fur & alligator production	Lindstedt, 2005	MP	$4.33	$4.90
Recreation	Bergstrom et al., 1990	TC, CV	$134.44	$134.44
Aesthetic				
Fresh Marsh Total			**$1,661**	**$3,059**
Intermediate Marsh				
Carbon sequestration	Chmura et al. 2003; Pearce 2001, Tol 2005	MP	$29.43	$118.59
Nutrient regulation	Kazmierczak, 2001	RC	$3.13	$1,069.56
Water supply	AWWA, 2007	RC	$42.52	$113.39
Hurricane protection	Costanza et al., 2008	AC	$1,394.58	$1,394.58
Fisheries production	Farber, 1996	PF	$53.37	$74.46
Fur and alligator production	Lindstedt, 2005	MP	$4.26	$4.34
Recreation	Bergstrom et al., 1990	TC, CV	$134.44	$134.44
Aesthetic				
Intermediate Marsh Total			**$1,656**	**$2,910**
Brackish Marsh				
Carbon sequestration	Chmura et al. 2003; Pearce 2001, Tol 2005	MP	$29.43	$118.59
Nutrient regulation	Kazmierczak 2001	RC	$3.13	$1,069.56
Water supply	AWWA 2007	RC	$42.52	$113.39
Hurricane protection	Costanza et al., 2008	AC	$1,394.58	$1,394.58
Fisheries production	Farber 1996	PF	$53.37	$74.46
Fur & alligator production	Lindstedt 2005	MP	$4.26	$4.34
Recreation	Bergstrom et al. 1990	TC, CV	$134.44	$134.44
Aesthetic				
Brackish Marsh Total			**$1,658**	**$2,910**
Saline Marsh				
Carbon sequestration	Chmura et al. 2003; Pearce 2001, Tol 2005	MP	$29.43	$118.59
Nutrient regulation	Kazmierczak 2001	RC	$3.13	$1,069.56
Water supply	AWWA 2007	RC	$42.52	$113.39
Hurricane protection	Costanza et al., 2008	AC	$1,394.58	$1,394.58
Fisheries production	Farber 1996	PF	$53.37	$74.46
Recreation	Bergstrom et al. 1990	TC, CV	$134.44	$134.44
Aesthetic				
Saline Marsh Total			**$1,653**	**$2,905**

Wetland Forest				
Carbon sequestration	CCX n.d., Pearce 2001, Tol 2005	MP	$21.11	$191.87
Nutrient regulation	Kazmierczak 2001	RC	$3.13	$1,069.56
Water supply	AWWA 2007	RC	$42.52	$113.39
Flood protection	Thibodeau et al, 1981	AC	5,957.20	5,957.20
Hurricane protection	Costanza et al. 2008	AC	$1,394.58	$1,394.58
Fisheries production	Farber 1996	PF	$53.37	$74.46
Wetland Forest Total			**$1,515**	**$2,844**
Beach				
Disturbance protection	Parsons et al. 2001, Pompe and Rinehart 1995	HP	$20,814	$33,738
Recreation & aesthetic	Edwards and Gable 1991, Kline and Swallow 1998	HP, CV	$131	$42,654
Cultural	Taylor and Smith 2000	HP	$24	$24
Beach total			**$20,969**	**$76,416**
Cropland				
Recreation & aesthetic	Alvarez-Farizo et al. 1999, Bergstrom et al. 1985	CV	$25.77	$25.77
Pollination	Southwick and Southwick 1992, Robinson et al. 1989	MP, AC	$2.25	$11.34
Cropland total			**$28**	**$37**
Forest				
Carbon sequestration	Reyes and Mates 2004, Pimentel 1998	AC	$10.57	$13.33
Recreation & aesthetic	Willis 1991, Bishop 1992	TC, CV	$0.15	$543.42
Habitat refugia	Haener and Adamowicz 2000, Amigues et al. 2002	CV	$1.05	$2,158.01
Forest Total			**$12**	**$2,715**
Open Water				
Water supply	Piper 1997, Ribaudo and Epp 1984	CV, TC	$27.55	$718.62
Recreation & aesthetic	Patrick et al. 1991, Ward et al. 1996	TC	$1.44	$1,634.67
Open Water Total			**$29**	**$2,353**
Riparian Buffer				
Water supply	Rich and Moffitt 1982, Matthews et al. 2002	HP, CV	$4.40	$11,088.93
Disturbance prevention	Rein 1999	TC	$6.44	$200.84
Recreation & aesthetic	Greenley et al. 1981, Bowker et al. 1996	CV, TC	$7.30	$9,051.84
Cultural	Greenley et al. 1981	CV	$3.98	$3.98
Riparian Buffer Total			**$22**	**$20,346**
Urban Open Space				
Climate regulation	McPherson et al. 1998, McPherson 1992	MP, AC	$25.12	$819.68
Recreation & aesthetic	Tyrvainen 2001	CV	$1,181.85	$3,464.50
Water regulation	McPherson 1992	AC	$5.63	$5.63
Urban Open Space Total			**$1,213**	**$4,290**

Wetland				
Water supply	Lant and Tobin 1989, Pate and Loomis 1997	CV	$169.64	$3,065.76
Recreation & aesthetic	Thibodeau and Ostro 1981, Doss and Taff 1996	CV, TC	$26.81	$3,942
Habitat refugia	Vankooten and Schmitz 1992	CV	$5.04	$5.04
Water regulation	Thibodeau and Ostro 1981	AC	$5,957.20	$5,957.20
Wetland Total			**$6,159**	**$12,970**

Estuary				
Water supply	Whitehead et al. 1997, Bockstael et al. 1989	CV	$5.53	$119.79
Recreation & aesthetic	Whitehead et al. 1997, Johnston et al. 2002	CV, TC	$1.27	$332.79
Habitat refugia	Farber and Costanza 1987, Johnston et al. 2002	PF	$10.82	$1,298.23
Estuary Total			**$18**	**$1,751**

Saltwater Wetland				
Nutrient regulation	Breaux et al. 1995	AC	$102.86	$16,560.46
Habitat refugia	Lynne et al. 1981, Bell 1997	PF, FI	$1.10	$953.01
Saltwater Wetland Total			**$104**	**$17,513**

APPENDIX C: Limitations of Approach

Transferred value analysis estimates the economic value of a given ecosystem (e.g., wetlands) from prior studies of that ecosystem. Like any economic analysis, this methodology has strengths and weaknesses. Because this is a meta-study, it has greater opportunity or error, and as the numbers show, a very wide range between low and high estimates. Some have objected to this approach on the grounds that:

1. Every ecosystem is unique; per acre values derived from another part of the world may be irrelevant to the ecosystems being studied.
2. Even within a single ecosystem, the value per acre depends on the size of the ecosystem; in most cases, as the size decreases, the per-acre value is expected to increase and vice versa. (In technical terms, the marginal cost per acre is generally expected to increase as the quantity supplied decreases; a single average value is not the same as a range of marginal values). This remains to be an important issue even though this was partly addressed in the spatial modelling component of this project.
3. Gathering all the information needed to estimate the specific value for every ecosystem within the study area not feasible. Then the "true" value of all of the wetlands, forests, pastureland, etc. in a large geographic area; cannot be ascertained. In technical terms, we have far too few data points to construct a realistic demand curve or estimate a demand function.
4. To value all, or a large proportion, of the ecosystems in a large geographic area is questionable in terms of the standard definition of "exchange" value; we cannot conceive of a transaction in which all or most of a large area's ecosystems would be bought and sold. This emphasizes the point that the value estimates for large areas (as opposed to the unit values per acre) are more comparable to national income accounts aggregates and not exchange values (Howarth & Farber, 2002). These aggregates (i.e. GDP) routinely impute values to public goods for which no conceivable market transaction is possible. The value of ecosystem services of large geographic areas is comparable to these kinds of aggregates (see below).

Proponents of the above arguments recommend an alternative that amounts to limiting valuation to a single ecosystem in a single location and only using data developed expressly for the unique ecosystem being studied, with no attempt to extrapolate from other ecosystems in other locations. For an area with the size and landscape complexity of the Mississippi River Delta, this approach will make valuation extremely difficult and costly at this point in time.

In effect, these proponents would look at the problem of conducting a house appraisal as an impossible goal. The comps, other houses sold in the neighborhood, never match well enough to make an estimate. However, they would advocate an estimate the dollar value of a bathroom, stove or door knob with good precision.

Responses to these critiques can summarized as follows (See Costanza et al 1998 and Howarth and Farber 2002 for more detailed discussion):

1. While every wetland, forest, or other ecosystem is unique in some way, ecosystems of a given type, by their definition, have many things in common. The use of average values in ecosystem valuation is no more and no less justified than their use in other "macroeconomic" contexts, e.g., developing economic

statistics such as Gross Domestic or Gross State Product. This study's estimate of the aggregate value of the Mississippi River Delta's ecosystem services is a valid and useful (albeit imperfect, as are all aggregate economic measures) basis for assessing and comparing these services with conventional economic goods and services.

2. The results of the spatial modelling analysis that were described in other studies do not support an across-the-board claim that the per-acre value of forest or agricultural land depends on the size of the parcel. While the claim does appear to hold for nutrient cycling and probably other services, the opposite position holds up fairly well for what ecologists call "net primary productivity" or NPP, a major indicator of ecosystem health – and by implication of services tied to NPP – where each acre makes about the same contribution to the whole regardless of whether it is part of a large patch or a small one. This area of inquiry needs further research, but for the most part the assumption (that average value is a reasonable proxy for marginal value) seems appropriate as a first approximation.
3. As employed here, the prior studies we analyzed (most of which were peer-reviewed) encompass a wide variety of time periods, geographic areas, investigators, and analytic methods. Many of them provide a range of estimated values rather than single point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed to be "too high" or "too low." Limited sensitivity analyses were performed. The approach is similar to defining an asking price for a piece of land based on the prices for "comparable" parcels; even though the property being sold is unique, realtors and lenders feel justified in following this procedure, even to the extent of publicizing a single asking price rather than a price range.
4. The objection as to the absence of even an imaginary exchange transaction was made in response to the study by Costanza et al. (1997) of the value of *all* of the world's ecosystems. Leaving that debate aside, one can in fact conceive of an exchange transaction in which all or a large portion of, e.g., Louisiana's wetlands were sold for development, so that the basic technical requirement that economic value reflect exchange value could in principle be satisfied. But even this is not necessary if one recognizes the different purpose of valuation at this scale – a purpose more analogous to national income accounting than to estimating exchange values (cf. Howarth and Farber 2002).

In the last analysis, this report takes the position that "the proof is in the pudding", i.e., the possibility of plausibly estimating the value of an entire state's ecosystem services is best demonstrated by presenting the results of an attempt to do so. In this report we have tried to display our results in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not extremely precise. However, they are much better estimates than the alternative of assuming that ecosystem services have zero value, or, alternatively, of assuming they have infinite value. Pragmatically, in estimating the value of ecosystem services it seems better to be approximately right than precisely wrong.

The estimated value of the world's ecosystems presented in Costanza et al. (1997) has been criticized as both (1) "a serious underestimate of infinity" and (2) impossibly exceeding the entire Gross World Product. These objections seem difficult to reconcile, but that may not be so. Just as a human life is "priceless" so are ecosystems, yet, people get paid for work. Thus Costanza's estimate of the work that ecosystem do, is an underestimate of the "infinity" of pricelessness because that is not what he estimated. That the value ecosystems provide to people exceeds the gross world product should, perhaps not be so surprising. Consider the value of one ecosystem service, photosynthesis, and the ecosystem good it produces, atmospheric oxygen, neither valued in Costanza's study. Given the choice between breathable air, and possessions, informal surveys have shown the choice of oxygen over stuff is unanimous. This indicates that the value of photosynthesis and atmospheric oxygen to people exceeds the value of the gross world product. That is only a single ecosystem service and good.

In terms of more specific concerns, the value transfer methodology introduces an unknown level of error, because we usually do not know how well the original study site approximates conditions in the Mississippi River Delta, with the exception of some wetlands studies that were conducted in this area. Other potential sources of error in this type of analysis have been identified (Costanza et al. 1997) as follows:

1. Incomplete coverage is perhaps the most serious issue. Not all ecosystems have been well studied and some have not been studied at all as is evident from the gap analysis presented below. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of less than zero.
2. Distortions in current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities and are therefore again likely to be underestimates of "true" values.
3. Most estimates are based on current willingness-to-pay or proxies, which are limited by people's perceptions and knowledge base. Improving people's knowledge base about the contributions of ecosystem services to their welfare would almost certainly increase the values based on willingness-to-pay, as people would realize that ecosystems provided more services than they had previously been aware of.
4. The valuations probably underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. If the Mississippi River Delta's ecosystem services are scarcer than assumed here, their value has been underestimated in this study. Such reductions in "supply" appear likely as land conversion and development proceed; climate change may also adversely affect the Mississippi River Delta's ecosystems (e.g., more intense hurricanes), although the precise impacts are harder to predict.
5. The valuations assume smooth responses to changes in ecosystem quantity with no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services (Limburg et al. 2002).
6. As noted above, the method used here assumes spatial homogeneity of services within ecosystems. The spatial modeling component of the project was intended to address this issue and showed that, indeed, the physical quantities of some services vary significantly with spatial patterns of land use and land cover. Whether this fact would increase or decrease valuations is unclear, and depends on the specific spatial patterns and services involved.
7. Our analysis uses a static, partial equilibrium framework that ignores interdependencies and dynamics. More elaborate systems dynamics studies of ecosystem services have shown that including

interdependencies and dynamics leads to significantly higher values (Boumans et al. 2002), as changes in ecosystem service levels ripple throughout the economy.

8. The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced.
9. The approach does not fully include the "infrastructure" or "existence" value of ecosystems. It is well known that people value the "existence" of certain ecosystems, even if they never plan to use or benefit from them in any direct way. Estimates of existence value are rare; including this service will obviously increase the total values.
10. There are great difficulties and imprecision in making inter-country comparisons on a global level. This problem was of limited relevance to the current project, since the majority of value transfer estimates were from the U.S. or other developed countries.
11. In the few cases where we needed to convert from stock values to annual flow values, the amortization procedure also creates significant uncertainty, both as to the method chosen and the specific amortization rate used. (In this context, amortization is the converse of discounting.)
12. All of these valuation methods use static snapshots of ecosystems with no dynamic interactions. The effect of this omission on valuations is difficult to assess.
13. Because the transferred value method is based on average rather than marginal cost, it cannot provide estimates consumer surplus. However, this means that valuations based on averages are more likely to underestimate total value.

The result would most likely be significantly higher values if these problems and limitations were addressed. Unfortunately, it is impossible to know how much higher the values would be if these limitations were addressed. One example may be worth mentioning, however. Boumans et al. (2002) produced a dynamic global simulation model that estimated the value of global ecosystem services in a general equilibrium framework to be roughly twice of what Costanza et al estimated using a static, partial equilibrium analysis. Whether a similar result would obtain for the Mississippi River Delta is impossible to say, but it does give an indication of the potential range of values.

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