Wetlands and Hurricanes

Author contact information

Wynn W. Cudmore, Ph.D., Principal Investigator
Northwest Center for Sustainable Resources
Chemeketa Community College
P.O. Box 14007
Salem, OR 97309
E-mail: wynn.cudmore@chemeketa.edu
Phone: 503-399-6514

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NCSR curriculum modules are designed as comprehensive instructions for students and supporting materials for faculty. The student instructions are designed to facilitate adaptation in a variety of settings. In addition to the instructional materials for students, the modules contain separate supporting information in the "Notes to Instructors" section, and when appropriate, *PowerPoint* slides. The modules also contain other sections which contain additional supporting information such as assessment strategies and suggested resources.

Acknowledgements

We thank Richard O'Hara and Anna VanDeWalle of Chemeketa Community College for their thoughtful reviews. Their comments and suggestions greatly improved the quality of this module. We thank NCSR administrative assistant, Liz Traver, for the review, graphic design and layout of this module. Carla Cudmore located appropriate photographs and figures for this module and obtained permission for their use.

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NCSR *Wetland Ecology and Management Series*
Introduction

Wetlands are among the most productive ecosystems on earth, and as such, provide countless ecological and economic benefits to humans. Management of this valuable resource is complex and represents an opportunity to approach the nature and management of a natural resource from several different perspectives in natural resource or environmental science programs. The NCSR *Wetland Ecology and Management Series* is designed to support the instruction of wetlands topics at the undergraduate level. It is modular in nature and instructors can pick and choose some topics for coverage and de-emphasize or ignore others. Thus, these curriculum materials are designed to meet a variety of instructional needs and strategies. The NCSR *Wetland Ecology and Management Series* is comprised of the following modules:

- ***Wetlands – An Introduction***

This module characterizes the wetlands resource and introduces students to wetlands as ecosystems and to the rationale for wetlands management. Wetland functions and values are also described.

- ***Wetlands – Then and Now***

This module describes the current status of wetlands and compares that to their place in history. Wetland types, classification schemes and causes for wetland loss and degradation are also discussed.

- ***Wetlands Management I – Determination and Delineation***

This module introduces wetlands management and describes wetland determination and delineation as first steps in wetland management projects. A field activity is included that engages students in the essential elements of wetland determination and delineation.

- ***Wetlands Management II – Compensatory Mitigation***

This module introduces the concept of compensatory mitigation and evaluates its effectiveness as a strategy for managing the wetland resource. A wetland mitigation field activity is included that describes how instructors can identify appropriate local wetland mitigation sites and how to organize a mitigation tour.

- ***Wetlands and Climate Change***

This module describes the complex relationship between wetlands and climate change.

- ***Wetlands and Hurricanes***

This module examines the impact of hurricanes on wetlands as well as the role of wetlands in the protection of coastal areas.

- ***Wetland Restoration in the Everglades***

This module uses restoration efforts in south Florida as a case study of wetland restoration.

Each module includes a lecture outline, *PowerPoint* presentation and detailed instructor notes. Modules with field-based activities also include student handouts, detailed procedures, data sheets and notes to instructors. In addition to the presentations and field activities described above, complete citations and brief summaries of relevant web, print and video resources are provided that can be used to:

- Enhance existing lecture topics
- Develop lectures on new topics
- Develop geographically relevant case studies
- Update wetlands statistics
- Select articles for student reading
- Access video and photos for presentation purposes

Intended audience

The NCSR *Wetland Ecology and Management Series* is intended to provide instructional support for undergraduate education at the freshman/sophomore level. Technical programs that include wetlands topics such as Wetlands Management, Civil Engineering and Biological Technician programs will find the modules to be a useful introduction to wetlands science and management. The materials are not designed to provide the training that is required by individuals to become certified wetland delineators or other types of wetlands technicians, as these curriculum materials and mechanisms for their delivery are available elsewhere. Also, NCSR wetlands materials are not designed for K-12 as a number of efforts have addressed wetlands for this level. In addition to providing background for those who will work with wetlands in their profession, NCSR materials also provide the background and context for students in other undergraduate programs. The materials may generate interest in some to pursue wetlands management as a career, but more importantly will result in an informed citizenry on wetlands issues. It is hoped that a more informed public will gather support for wetland conservation efforts as they occur in their local communities and help build a greater understanding of their importance.

The need for an undergraduate wetlands curriculum

Recent interest in wetlands as a valuable and dwindling resource has resulted in a large and growing volume of wetlands-related curriculum. However, the vast majority of these wetlands education resources target audiences other than first- and second-year college students. The K-12 audience, for example, has been well-served by efforts such as Project WET (Slattery and Kesselheim, 2003). The demand for training of wetlands delineators and those with expertise in wetland mitigation has driven the development of a number of continuing education classes that teach this material. The intended audience is those who are in the wetlands profession who seek the proper certification to conduct these activities. Examples include:

The Ohio State University
Olentangy River Wetland Research Park
www.swamp.osu.edu

North Carolina State University
Forestry and Environmental Outreach Program (FEOP)
http://www.ces.ncsu.edu/nreos/forest/feop/

Portland State University
Environmental Professional Program
http://epp.esr.pdx.edu/

The Swamp School
www.swampschool.org

Some degree programs at 4-year colleges and universities include courses in wetland ecology and management. However, the majority are taught at the graduate level and curriculum materials are not widely available for use outside of those institutions.

Thus, there appears to be a lack of classroom-ready materials and resources available for **undergraduate courses** that include some coverage of wetlands topics and form a bridge between the various wetlands curriculum materials described above. The NCSR *Wetland Ecology and Management Series* is designed to fill that void.

Guidelines for use

The manner in which instructors use the modules in this series will depend upon:

- The course in which the module will be used

The wetland mitigation modules are most appropriate for inclusion in undergraduate courses such as *Environmental Science, Introduction to Natural Resources, Wetlands Ecology* and *Introduction to Wetlands Management*. Parts of the modules may also have application in courses with a broader scope such as *General Ecology* and *General Biology*.

- The background of the students

The wetland mitigation modules assume some basic understanding of basic ecology including populations, communities and ecosystem structure and function. The treatment of ecology in either a college- or high school-level general biology course should be sufficient. Instructors may need to provide additional background to students who are not familiar with this material.

- The time that will be dedicated to the study of wetlands

There is sufficient information and resources in the wetlands mitigation modules to present anything from a single one-hour lecture to a significant portion of a full semester-long or quarter-long course. Instructors may select from the various components depending on course objectives and the amount of time allocated for wetlands topics.

A note on wetland field and laboratory experiences

The NCSR *Wetland Ecology and Management Series* emphasizes lecture support for instructors who are looking for wetlands material to insert into their courses. Although classroom lectures and discussions are a necessary element of a course that deals with wetlands issues, field and laboratory experiences enhance the learning experience and allow the instructor to explore topic areas that are not easily covered in the classroom. Additionally, students are more likely to become engaged in the topic when they can experience it firsthand.

Field activities may include a wide variety of experiences ranging from "tours" of various wetland types and restoration or mitigation projects to investigative experiences where students are actively engaged in the "scientific process."

Types of field activities (adapted from Baldwin, 2001):

- Field identification of wetland plants
- Preparation of plant collections using standard herbarium techniques
- Field identification of wetland animals
- Estimates of animal diversity and abundance (e.g., collection of invertebrates in soil litter samples, mammal livetrapping, amphibian surveys)
- Vegetation sampling methods (e.g., qualitative, line-intercept, transect, quadrat sampling)
- Analysis of wetland plant diversity and abundance
- Determination of hydric soils indicators
- Determination of site hydrology

Details of these methods are beyond the scope of this series and have been well-documented elsewhere in field and laboratory manuals designed for college-level courses. See resources below for some examples.

RESOURCES

Baldwin, A.H. 2001. Got mud? Field-based learning in wetland ecology. Journal of College Science Teaching 31:94-100.

O'Neal, L.H. 1995. Using wetlands to teach ecology and environmental awareness in general biology. American Biology Teacher 57:135-139.

Slattery, B.E. and A.S. Kesselheim. 2003. WOW! The wonders of wetlands: An educator's guide. Environmental Concern, Inc., St. Michaels, MD and The Project WET International Foundation, Bozeman, MT. 348 pp.

Wetlands and Hurricanes

Module Description

This instructional guide is designed to provide instructors with lecture materials and resources that examine the complex relationship between wetlands and hurricanes using Hurricane Katrina as a case study. Student objectives, a general lecture outline and a more detailed *PowerPoint* presentation with instructor notes are provided. This module describes the vulnerability of the Gulf Coast to damage from hurricanes and the role that wetlands and barrier islands play in coastal protection. An evaluation of hurricane impacts on the Gulf Coast using "before" and "after" satellite images and aerial photography is included. Proposals for the restoration of wetlands as a method for increasing protection of the region from future hurricanes are also described.

Instructors who are looking for videos or additional print and web-based resources on the topics covered here should consult the resources list provided at the end of this module where these resources are summarized and cited.

Objectives

Upon successful completion of this module, students should be able to:

1. Describe the vulnerability of the Gulf Coast to damage from hurricanes
2. Describe the role of wetlands and barrier islands in storm protection
3. Describe the impacts of hurricanes on wetlands and barrier islands
4. Describe the benefits and challenges of wetland restoration as a mechanism for providing storm protection

Wetlands and Hurricanes - General Lecture Outline

I. The Gulf Coast Environment
   A. The Mississippi River Basin
   B. Wetlands of the Gulf Coast
   C. Wetlands of coastal Louisiana
   D. New Orleans – layout and development

II. Wetland functions
   A. Wetlands as buffers
   B. Wetlands loss along Louisiana Coast
      1. Lack of sediment
      2. Saltwater intrusion
      3. Sea level rise
   C. Barrier islands protect coast

III. Hurricane Katrina
   A. Impacts on manmade structures
   B. Impacts on wetlands
   C. Impacts on Mississippi Delta
   D. Impacts on barrier islands
   E. Impacts on coastal forest

IV. Wetland Restoration
   A. Coast 2050 Wetland Restoration Plan
   B. Marsh terraces

V. Summary

PowerPoint Presentation with Instructor Notes

Wetlands and Hurricanes

By Wynn W. Cudmore, Ph.D.

Northwest **C**enter for **S**ustainable **R**esources

DUE # 0757239

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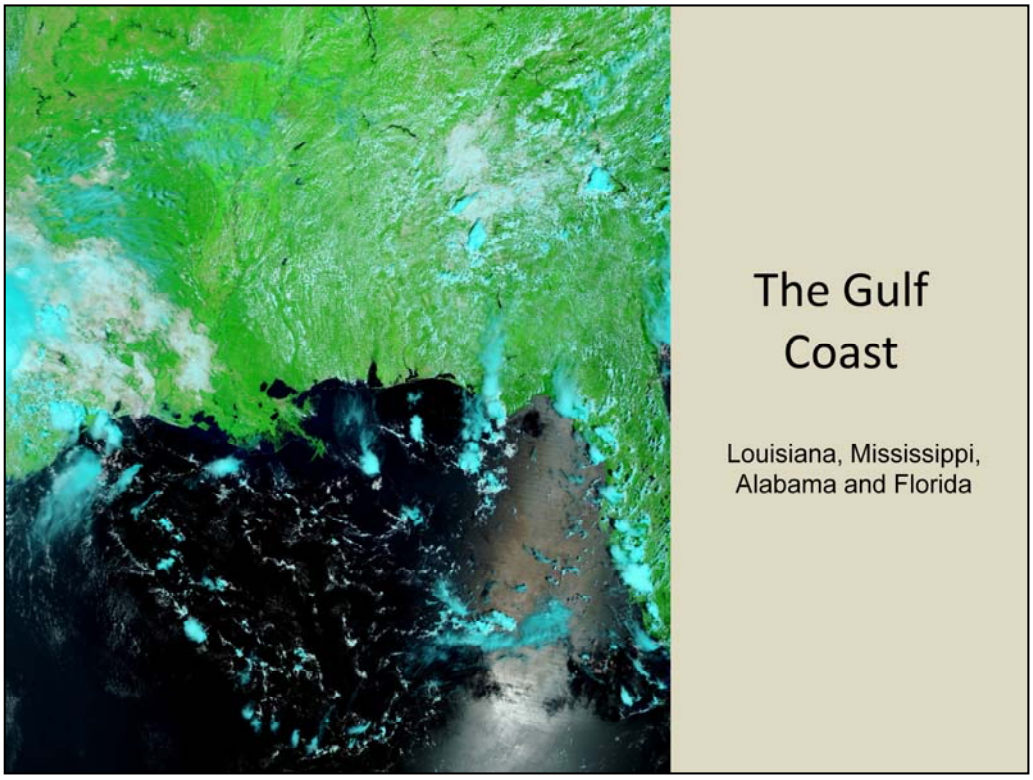
In 2005, Hurricane Katrina reminded the world of the effects a powerful hurricane can have on both the manmade and the natural world. Although the human tragedy caused by the storm captured most of the headlines, the impact on Gulf Coast wetlands, the role that wetlands have in moderating storm impacts and the consequences of wetland loss gradually became part of the discussion. This module examines the complex relationship between wetlands and hurricanes using Hurricane Katrina as a case study.

The image on the right shows the development and path of Hurricane Gustav as it passed through the Caribbean and made landfall along the Gulf Coast of the U.S. This sequence of satellite images was taken on 25 August to 1 September 2008 (from right to left).

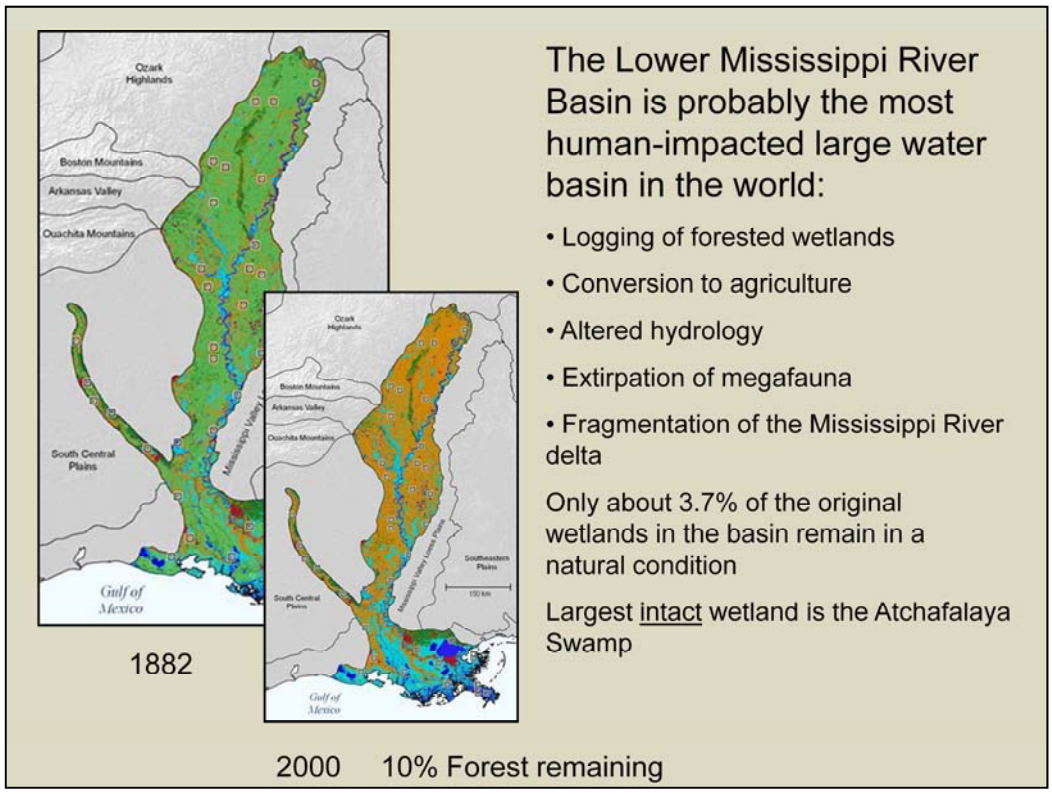
Photo credit:

Right: ESA Envisat/Marine Photobank



This is a satellite image of the Gulf Coast of the United States. The shorelines of Louisiana, Mississippi, Alabama and Florida (left to right) can be seen. A variety of coastal and inland wetland types dominate the vegetation here. Note the signature “crow’s foot” of the Mississippi Delta near the center of the image.

Image credit: NASA/courtesy of nasaimages.org



The Lower Mississippi River Basin as a specific example:

Among the largest wetlands of the world, those associated with the vast Mississippi River Basin are probably also the most disturbed by humans. Primary causes for loss and degradation include:

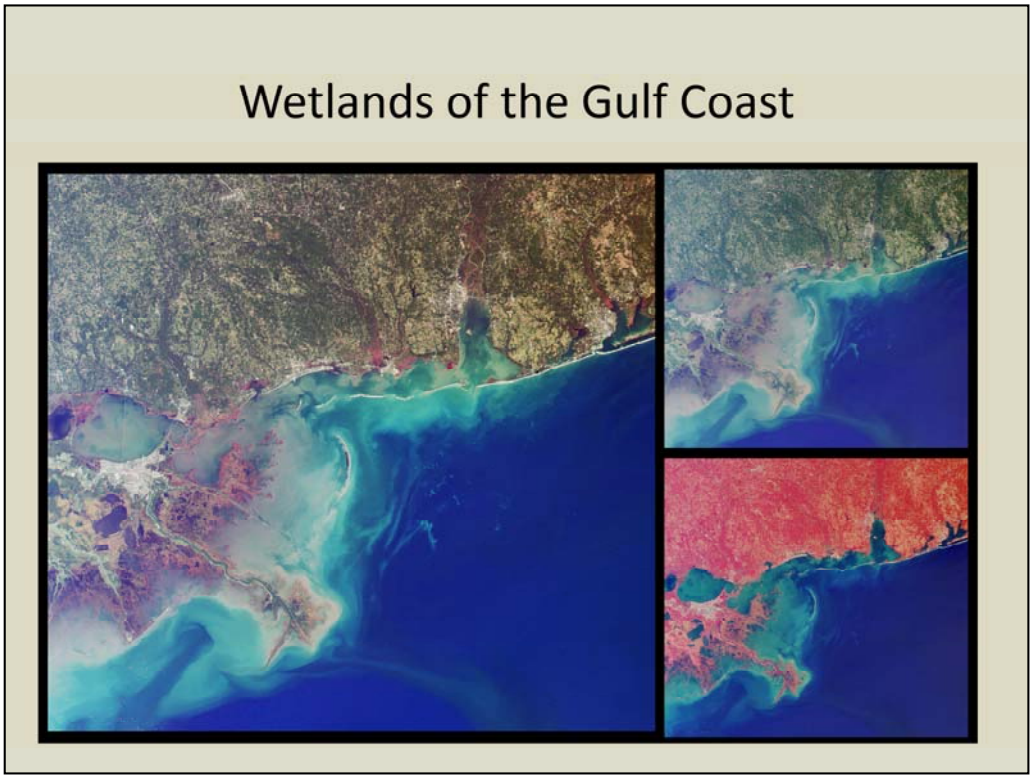
- logging and clearing of forested wetlands
- land conversion to agriculture – resulting habitat loss and agricultural runoff, particularly nitrate-based fertilizers, which have been shown to contribute to the hypoxic "Dead Zone" in the Gulf of Mexico
- altered hydrology as a result of massive engineering projects and elaborate systems of levees, canals, reservoirs, etc. This significantly reduced sediment flow to wetlands in the lower basin
- extirpation of megafauna – e.g., bison, panthers, red wolves, black bear
- fragmentation of the Mississippi River delta by channels cut for cypress logging, navigation and, most recently, for the oil and gas industry. Allows saltwater intrusion.

Wetland deterioration in the lower Mississippi river basin makes the region more vulnerable to the effects of hurricanes.

Of the original wetlands in the Lower Mississippi River Basin, only about 4000 km^2 (3.7%) remain in a somewhat natural condition. The largest relatively intact (though still impacted by all of the above to some degree) wetland in the Mississippi River Basin is the Atchafalaya Swamp, which lies to the west of the Mississippi River in southern Louisiana.

Map shows the extent of remaining bottomland forests (1991) of the Lower Mississippi River basin. The map insert shows the extent of the same feature in 1882.

Image credit: Adapted from USGS



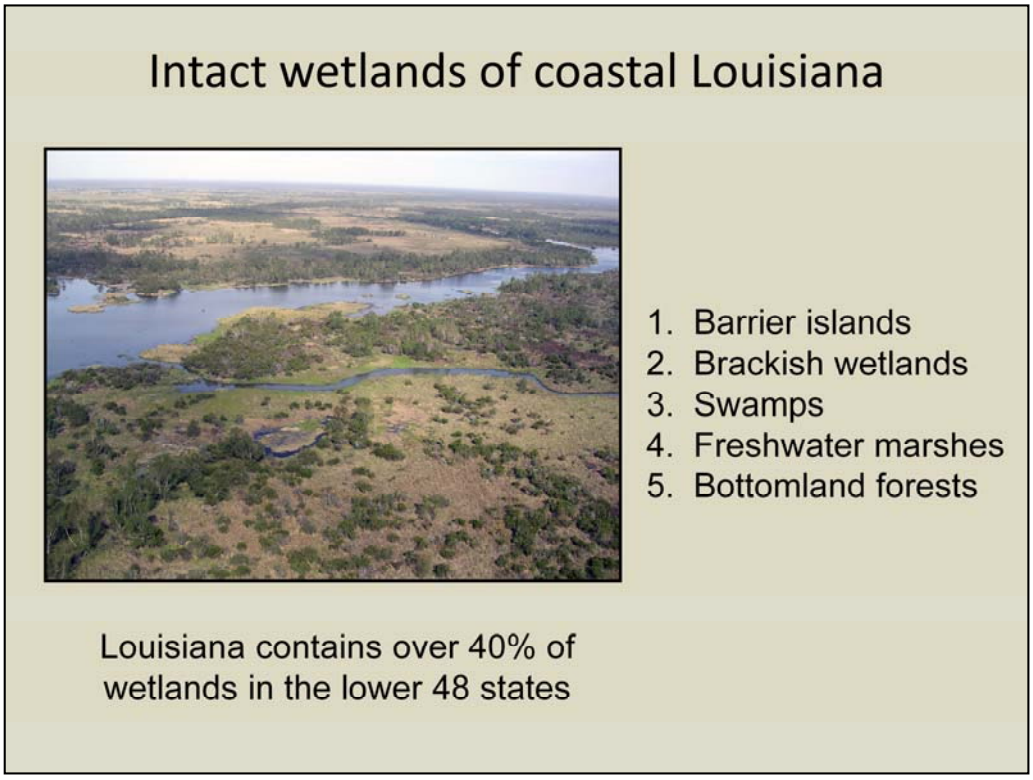
These satellite images highlight coastal areas of four states along the Gulf of Mexico - Louisiana, Mississippi, Alabama and part of the Florida panhandle. The images were acquired on October 15, 2001.

The two smaller images on the right are a natural color view (top) and a false-color view (bottom) comprised of near-infrared, red, and blue band data from the same camera. The predominantly red color of the false-color image is due to the presence of vegetation. Cities appear as grey patches, with New Orleans visible at the southern edge of Lake Pontchartrain, along the left-hand side of the images. The distinctive shape of the Mississippi River Delta can be seen to the southeast of New Orleans. Other coastal cities are visible east of the Mississippi, including Biloxi, Mobile and Pensacola.

The large image on the left is similar to the true-color view. The red colors, present particularly near the mouth of the Mississippi River, highlight areas with wetland vegetation associated with poorly drained bottomlands, marshes, and/or estuaries from the surrounding surface vegetation. These wetland regions are not as well differentiated in the images on the right.

Note also, particularly in the image on the left, the variations in ocean color, representing the outflow of suspended sediment into the open waters of the Gulf of Mexico. On the Mississippi Delta large amounts of land-derived sediments have been deposited in the shallow coastal waters forming a complex of estuarine channels and extensive coastal wetlands that provide important habitat for fish and wildlife.

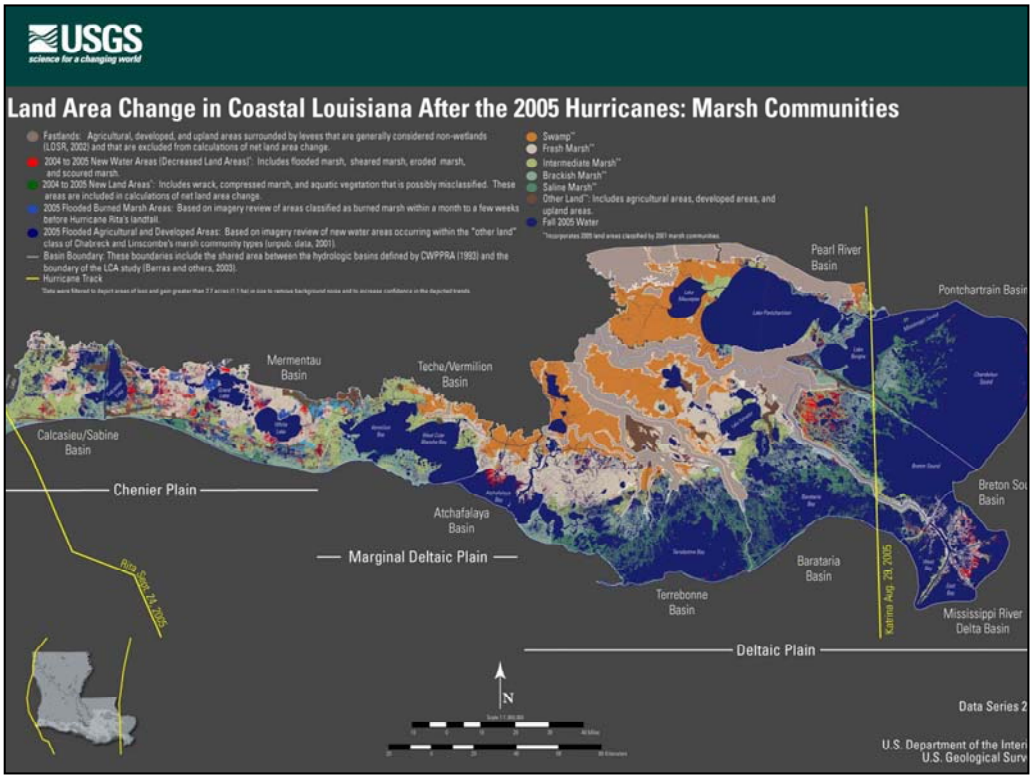
Image credit: Image courtesy NASA/GSFC/LaRC/JPL, MISR Team



Louisiana contains over 40% of wetlands in the lower 48 states. Several types are represented including (listed roughly from those more closely associated with the ocean to those more inland) :

1. Barrier islands
2. Brackish/saline wetlands – dominated by saltmarsh grasses (*Spartina*) and black mangrove
3. Swamps (dominated by baldcypress and water tupelo)
4. Freshwater marshes – cattails, water lilies, sedges, rushes
5. Bottomland hardwood forests (dominated by elm, maple, hackberry, and ash)

Image credit: Tim Carruthers, IAN Image Library (ian.umces.edu/imagelibrary/)



This U.S. Geological Survey map shows the distribution the various wetland communities of coastal Louisiana:

Light greens – brackish and saline marshes

Orange – swamps

Light brown - freshwater marshes

Blue – open water

NOTE: Red areas represent new open water areas created by the 2005 Gulf Coast hurricanes and will be discussed later.

Image credit: USGS

The city of New Orleans, Louisiana is prone to flooding, with about 45% of the metropolitan core situated at or below sea level. The city is protected by levees, but its associated wetlands, which also function as a buffer from storm surges have been disappearing.

This image, taken on 29 April 2008, shows New Orleans, sandwiched between the Mississippi River and Lake Pontchartrain following heavy spring rains. To reduce the volume of the river through New Orleans, the Army Corps of Engineers opened the Bonnet Carre Spillway (shown in lower left), which diverts some of the river's flow into Lake Pontchartrain. A system of levees along the Mississippi River protects New Orleans from catastrophic flooding. The spillway control structure is visible as a thin, discontinuous, white line along the river's edge in this image. The spillway is designed to reduce pressure on downstream levees.

Image credit: Image Science & Analysis Laboratory, Johnson Space Center

New Orleans was originally built on high ground centered on the French Quarter (see image) and was surrounded by marshlands. Levees, drained wetlands and a sophisticated system of pumps and canals combined over time to drain more of these marshlands to allow the growth of New Orleans. Growth has occurred into progressively lower elevation and wetter locations between Lake Pontchartrain and the Mississippi River.

More than a century of human intervention has increased the probability of hurricane impact on New Orleans caused by a combination of development and severe erosion of wetlands and barrier islands.

The growth of New Orleans from 1817 to current times is illustrated in the following slides.

Image credit: Adapted from NASA

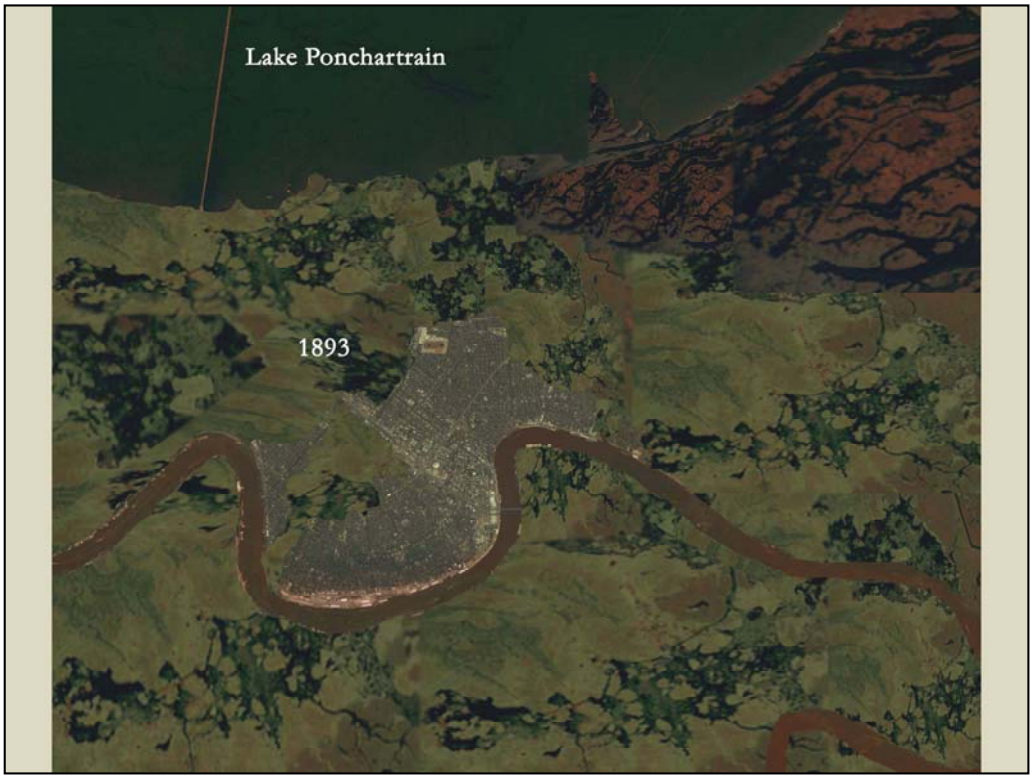


Image credit: Adapted from NASA

Image credit: Adapted from NASA

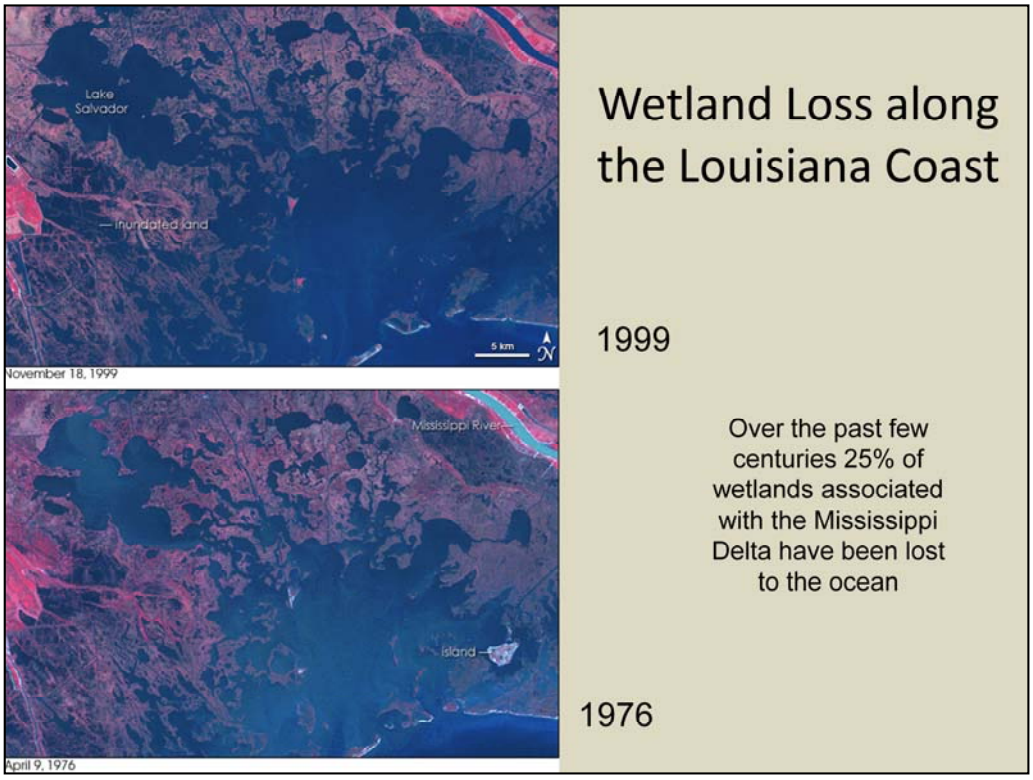
Image credit: NASA

Wetlands serve as buffers to storm surges generated by hurricanes. Quantifying the reduction of storm surges by wetlands has proven to be complex. A commonly cited reduction of "one foot for every 2.7 miles (measured inland from shoreline) of wetlands" is based on a 1963 U.S. Army Corps of Engineers report, which examined the penetration of storm surges from seven southern Louisiana storms from 1909-1957. More recent studies find that the penetration of storm surges is dependent on a number of factors including storm track, speed, duration, geometry of the shoreline, presence of barrier islands, slope of the ocean floor, vegetation type and the presence of levees. Complex mathematical models exist that take these factors into account, but most have not been tested in actual storms. Nevertheless, the loss of protective wetlands is widely viewed as a critical factor increasing the vulnerability of New Orleans to major storms. Also, New Orleans has sunk by about 0.5 m in the last 60 years. This appears to be primarily due to compaction of peat layers in the Mississippi Delta. The subsidence rate is over 10 mm per year (Tornquist, T.E., et al. 2008).

Over the past few centuries 25% of wetlands associated with the Mississippi Delta have been lost to the ocean (Blum and Roberts, 2009). Nearly 5000 km^2 of coastal islands and wetlands have disappeared since the 1930s. Each year about 65-90 km^2 are lost. Subsidence also causes sea level rise and shoreline erosion.

Subsidence – the natural process in which wetlands soils compress and sink over time

Image credit: Dr. Terry McTigue, National Oceanic and Atmospheric Administration/Department of Commerce



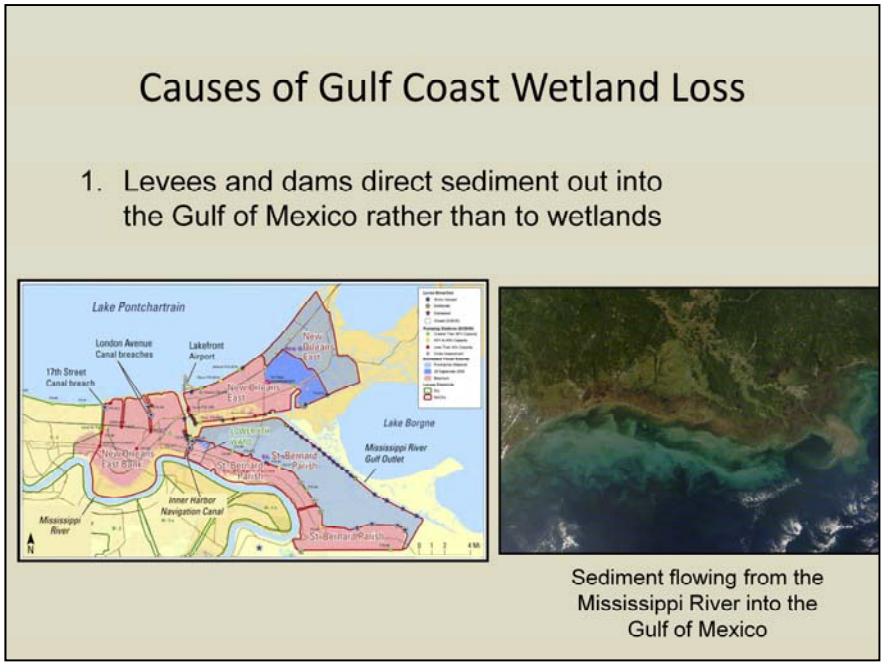
Coastal wetlands absorb the impact of a storm surge or a river flood by providing a break over which the water loses its destructive energy. Thus, the loss of wetlands increases the risk of damage from storms. Louisiana has the highest rate of coastal wetland loss in North America. Rates have been estimated at 25-35 square miles (16,000-22,000 acres) per year, which is the equivalent of an area the size of a football field every 30 minutes. Over the past 70 years, almost 1500 square miles of marsh have been lost. In a recent survey of 17 wetlands using Landsat satellite imagery, Jim Coleman, a coastal geologist at Louisiana State University, found that all had declined dramatically in recent years. Louisiana's coastal wetlands, shown in this pair of Landsat images, are among those that are steadily disappearing.

Lafourche Parish, Louisiana, for example, shown in the left portion of these images, has lost 40 to 50 percent of its land. The loss is apparent by comparing the lower 1976 image to the top image, taken in 1999. Much of the land to the south of Lake Salvador has been inundated with water. Lake Salvador has also expanded, and the land that once jutted into the lake in many places had disappeared by 1999. Wetland loss is apparent in many other regions as well. Bodies of water in Jefferson Parish, top center, are larger in 1999, and an island in the lower right corner of the image has vanished entirely.

NOTE: A number of studies have been published since 2000 that attempt to estimate the rates of wetland loss along the Louisiana Coast. These estimates range from 5500 – 25,600 acres per year depending on methodology and wetland definitions.

For a more detailed discussion of the rates of wetland loss in the Mississippi Delta, see Bourne (2000) and Dahl (2006).

Image credit: NASA Earth Observatory



Wetland loss can be attributed to both natural and human causes. Unlike inland regions where most wetland loss is due to draining or filling for agriculture, residential development or industry, Louisiana is losing its wetlands to the ocean. The soil in wetlands naturally compresses and sinks over time in a process called subsidence. Under normal conditions, the growth of plants and the infusion of fresh sediment from river floodwater offset subsidence. However, over the past 50 years, wetlands are sinking into the ocean faster than they are building up.

Although the causes for subsidence along the Gulf Coast continue to be studied, human activities appear to be contributing in the following ways:

1. A decline in fresh sediment from regular river floods. Since floods along the Mississippi River are extremely destructive to human infrastructure, a system of levees and dams has been constructed to regulate the flow of water in the river and prevent floods. The map on left shows those areas in New Orleans that are protected by this flood protection system – New Orleans East Bank, New Orleans East, and St. Bernard's Parish. Pink shading indicates those areas that flooded after Hurricane Katrina in 2005 as a result of levee breaches. Levees along the lower Mississippi cut off the tributaries of the Mississippi that would ordinarily deliver sediment to the coastal wetlands of the Mississippi Delta. Consequently, the levees direct water and sediment further out to the Gulf of Mexico instead of allowing it to be distributed over the wetlands (illustrated in satellite image on right). It is estimated that the levees direct over 100 million tons of sediment each year deep into the Gulf. Additionally, the Mississippi River Gulf Outlet was straightened and channelized by the Army Corps of Engineers and now empties the majority of Mississippi River flow 50 km out into the Gulf.

Image credits:

Left - USGS
Right - NASA

2. Canals cut into coastal wetlands allow saltwater intrusion

3. Sea level rise due to climate change

Oil gas extraction rig among eroding wetlands in coastal Louisiana

Image shows an oil gas extraction rig among eroding wetlands looking towards the Gulf, southeast of Houma in coastal Louisiana.

2. The oil and gas industry has dredged extensive networks of canals into the wetlands to improve access to drilling rigs and to provide shipping channels. In addition to physical damage to the wetlands, these canals provide a way for salt water to seep into freshwater wetlands (**saltwater intrusion**), creating an environment where wetland plants cannot survive. The result is the creation of large open areas of shallow muddy water that lack submersed aquatic or emergent vegetation.

3. Sea level rise due to climate change – elevated sea levels “drown” coastal wetlands.

Given our current level of understanding of the causes of subsidence and wetland loss along the Gulf Cost, the Environmental Protection Agency estimates that one-third of coastal Louisiana will have vanished into the Gulf of Mexico by 2050.

Image credit: Tim Carruthers, IAN Image Library (ian.umces.edu/imagelibrary/)

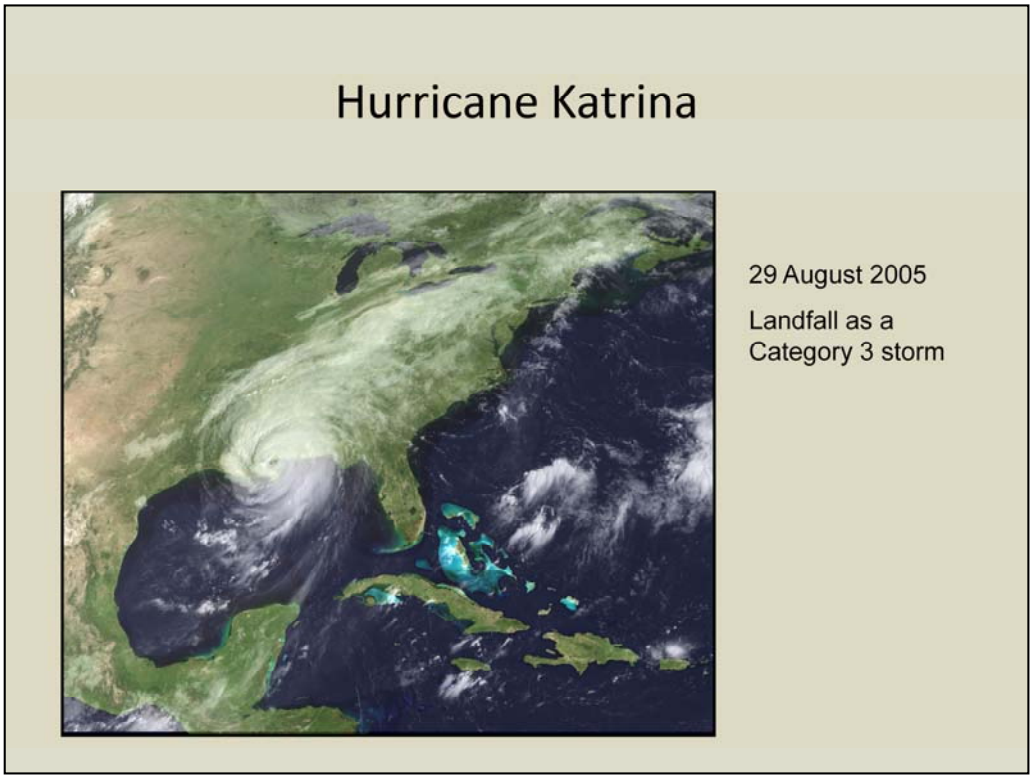
Like the coastal wetlands, barrier islands in the Gulf provide a thin line of protection for the mainland against incoming storms by absorbing energy from the strongest waves. The north-south oriented Chandeleur Islands, for example, are located approximately 100 kilometers east of New Orleans where they form a thin protective wall between the open sea and Louisiana's St. Bernard Parish.

Image credit: NASA Earth Observatory

Against this backdrop of eroding wetlands and a city built below sea level – enter Hurricane Katrina.

The 2005 hurricane season was unusually active – 28 named storms made their way across the Atlantic. Most expended their energy out at sea or lost strength before they could do significant damage on land. One of these storms, however, left its mark in U.S. history. This image, taken one day before landfall in Louisiana shows Katrina at its strongest – a category 5 hurricane with sustained winds of over 135 miles per hour. Katrina is centered over the Gulf of Mexico, the U.S. Gulf Coast can be seen towards the top of the image and the Yucatan Peninsula can be seen in the bottom half of the image.

Image credit: NASA



On August 29, 2005 Hurricane Katrina, after passing over the Caribbean and Florida and crossing the Gulf of Mexico, moved ashore over southeast Louisiana and southern Mississippi. As an extremely dangerous Category 4 storm, with high winds, a powerful storm surge, and heavy rains, Katrina crossed the Gulf of Mexico. By the time Katrina made landfall as a category 3 storm, it had already triggered extensive flooding. This NOAA satellite image shows the storm as it moved over southern Mississippi on the morning of 29 August. The eye of the storm was due east of New Orleans, Louisiana. Katrina moved north into Mississippi and ultimately into much of the eastern United States and Canada. By mid-afternoon on August 29, Katrina had weakened to a Category 1 hurricane with winds of 95 mph.

Image credit: GOES Project Science Office

At its worst, Katrina flooded coastal communities, overwhelmed levees and left more than 80% of New Orleans underwater. More than 1800 people lost their lives to the storm, mostly as a result of flooding. Damage estimates exceeded $125 billion.

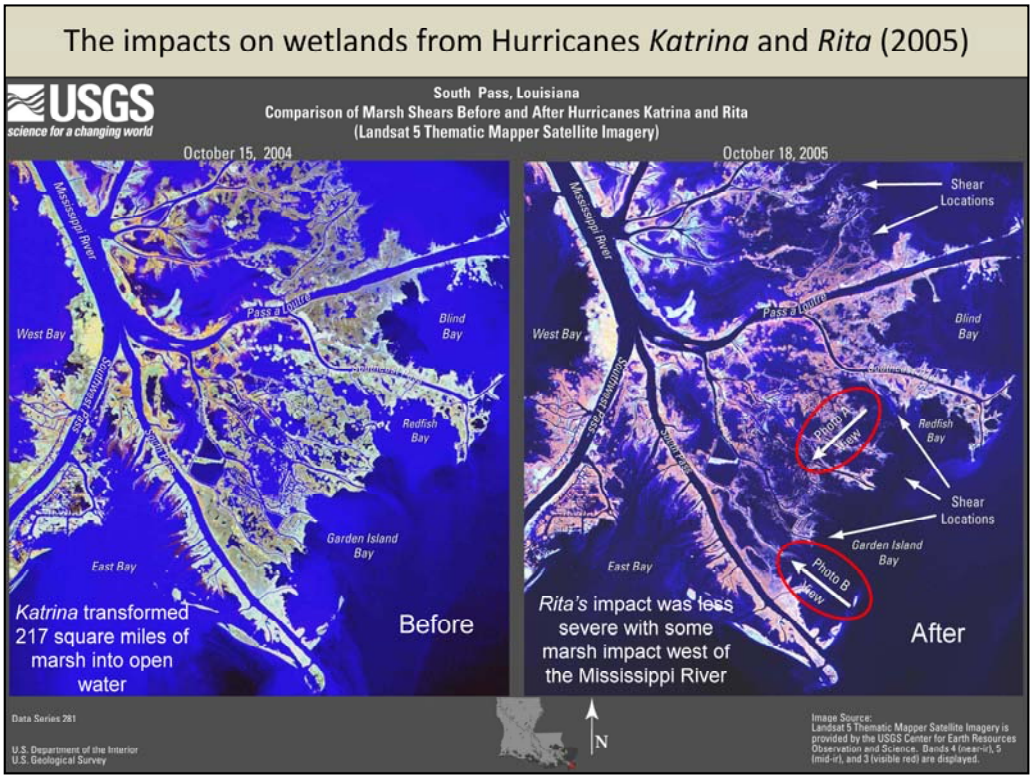
About one month later, Katrina was followed by Hurricane Rita, which took a path to the west of New Orleans and inflicted far less damage.

While the human tragedy and the damage to the U.S. economy and infrastructure rightfully took center stage during the storm and its immediate aftermath, eventually there were questions about what damage the storm had done to the natural world and what role humans had played in worsening the effects of the storm.

Photos show a sampling of Katrina-caused damage to human infrastructure.

Image credits:

Top left – failed levee: David Helvarg, Blue Frontier Campaign/Marine Photobank
Top center – flood damage: David Helvarg, Blue Frontier Campaign/Marine Photobank
Top right – fishing boats on levee: David Helvarg, Blue Frontier Campaign/Marine Photobank
Bottom left – New Orleans flooded: US NAVY
Bottom right – damage to Hard Rock Casino: David Helvarg, Blue Frontier Campaign/Marine Photobank



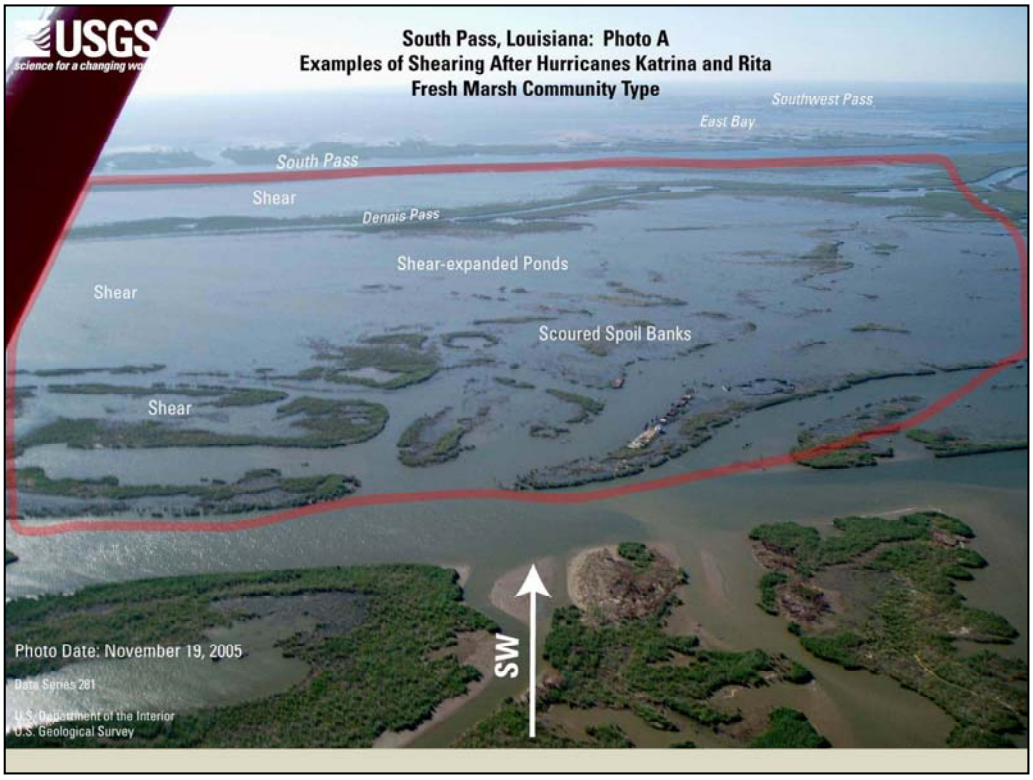
Katrina and Rita transformed 217 square miles (562 km^2) of marsh into open water in coastal Louisiana. Estimates are based on an analysis of Landsat Thematic Mapper ™ satellite data by the U.S. Geological Survey. Although some marsh may recover, indications are that much of the loss will be permanent. Most of the loss east of the Mississippi River (St. Bernard and Plaquemines parishes) was due to the effects of Katrina's storm surge. Approximately 39 square miles adjacent to Breton Sound were converted to open water as a result of marsh loss or submergence. An additional 47 square miles were lost throughout the Pontchartrain, Pearl River, Barataria, and Terrebonne basins. The Mississippi Delta itself incurred 14 square miles of loss.

Freshwater and intermediate marshes (71% of loss) were more affected than brackish and saline marshes (20% of loss), which appear to be more resistant to the impacts of storms.

Rita's impact was less severe and marsh loss was predominantly west of the Mississippi River to the Texas border.

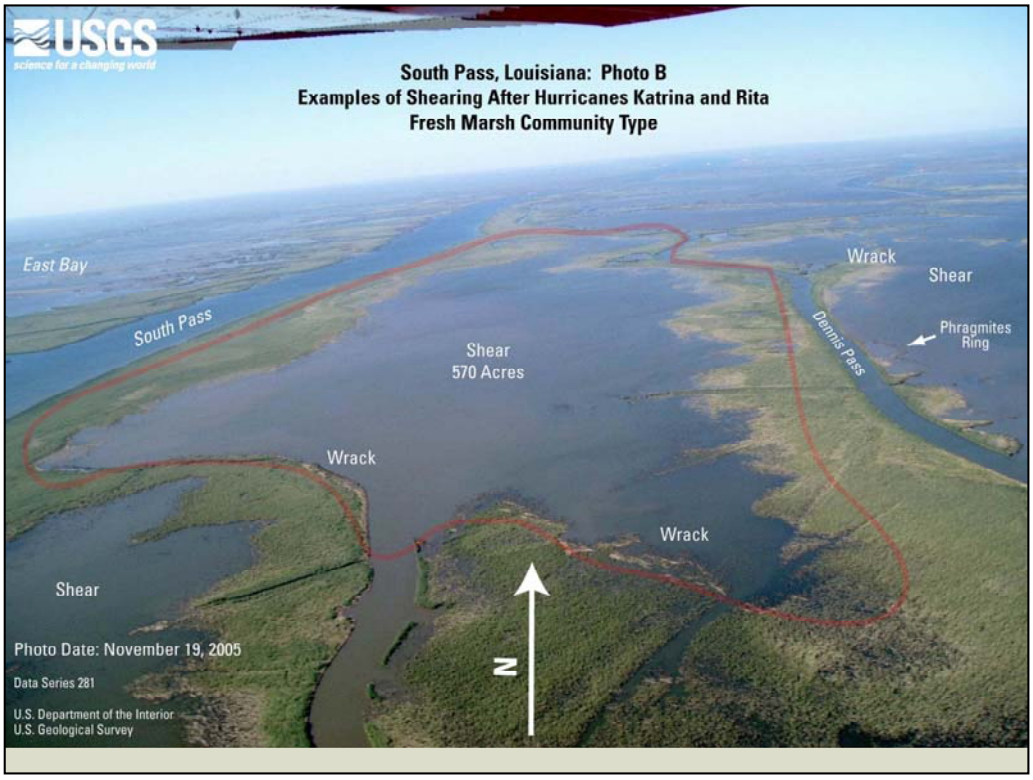
Although satellite imagery was used to estimate the impacts of Hurricanes Katrina and Rita, these estimates were verified by examination of aerial photography and field inspection of some sites. The views of two oblique aerial photographs are indicated on this image as "Photo A View" and "Photo B View." These two aerial photographs are shown in the images that follow.

Image credit: USGS



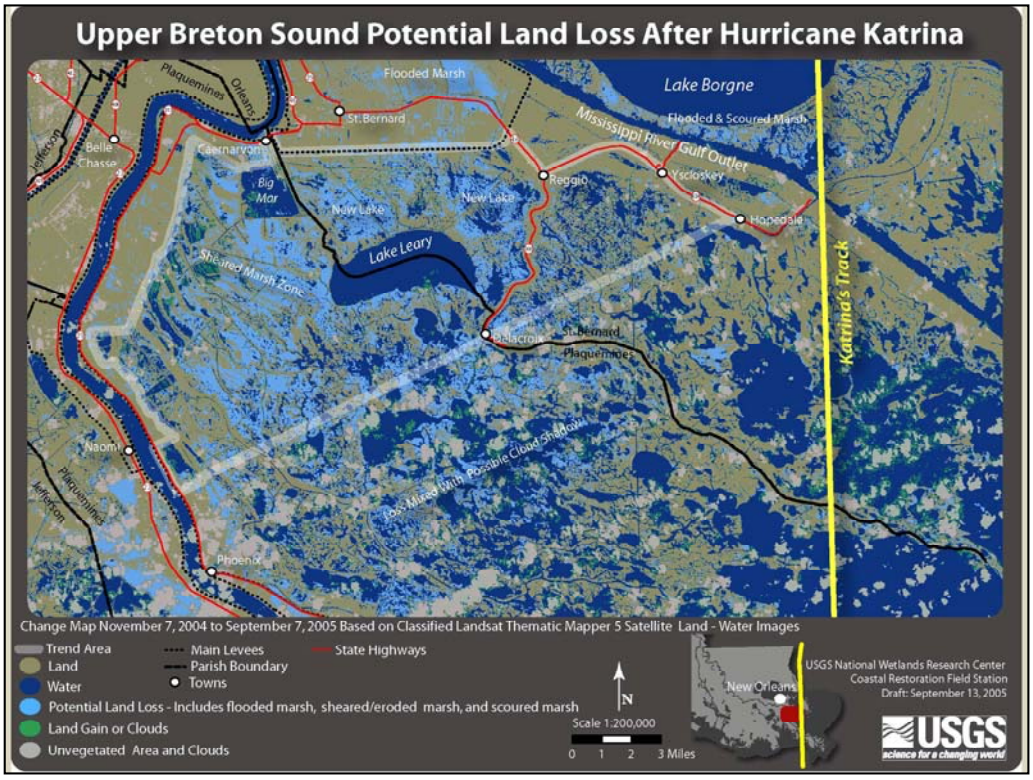
Sheared marshes are indicated as newly open and persistent water areas.

Image credit: USGS



A large area of sheared mash can be seen in this image along with “wrack” – newly deposited organic debris. The “Phragmites Ring” is the remnant of an area initially occupied by common reedgrass, an invasive wetland species.

Image credit: USGS

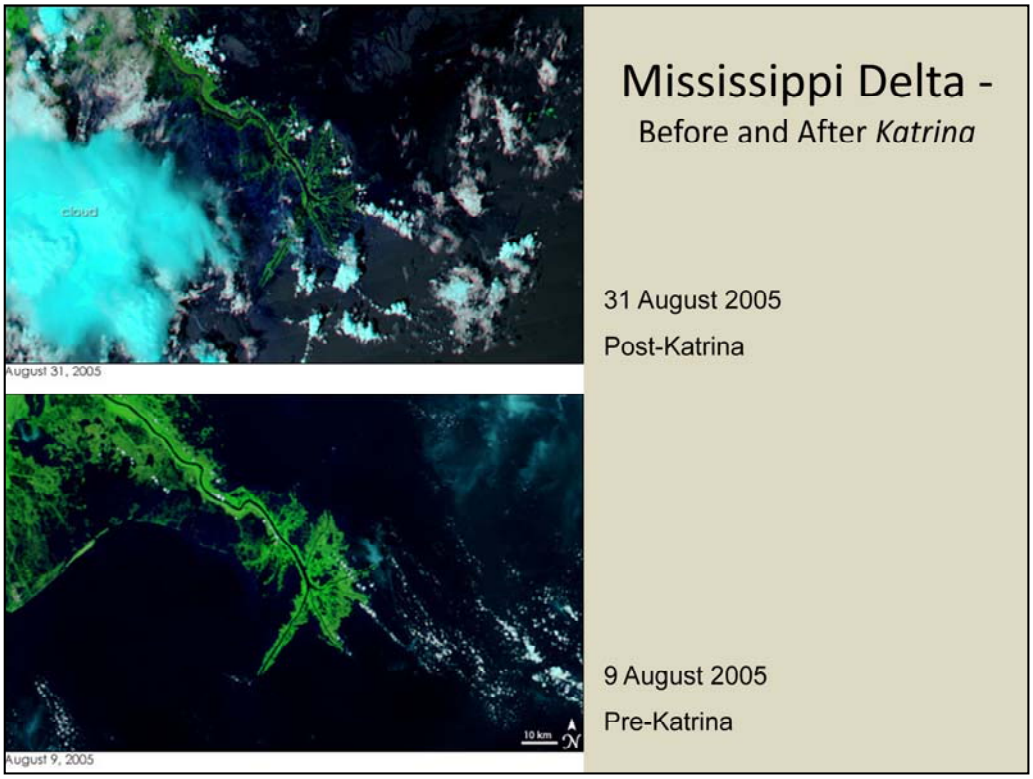


This image was generated from Landsat satellite imagery by comparing features present pre-Katrina (November 2004) to those present post-Katrina (September 2005). Differences between the images represent areas of potential land loss. The area shown is one of the areas hardest hit by Katrina – the upper portion of Breton Sound southeast of New Orleans. About 25% of this 13-square mile area was converted to open water. Future observations after several growing seasons will be required to determine how much of this loss is permanent. The marsh area contains large sheared areas, scoured marshes and significant shoreline erosion (shown in light blue in image). **Sheared areas** are those areas of persistent new bodies of water that occur after the hurricane where marsh vegetation is either partially or completely removed. **Scoured marshes** are those in which marsh vegetation is either partially or completely removed.

This same area had already lost 21 square miles (16%) of its land area between 1956 and 2004. This wetland loss and additional losses attributable to Katrina potentially reduce Louisiana's natural protection from future storms.

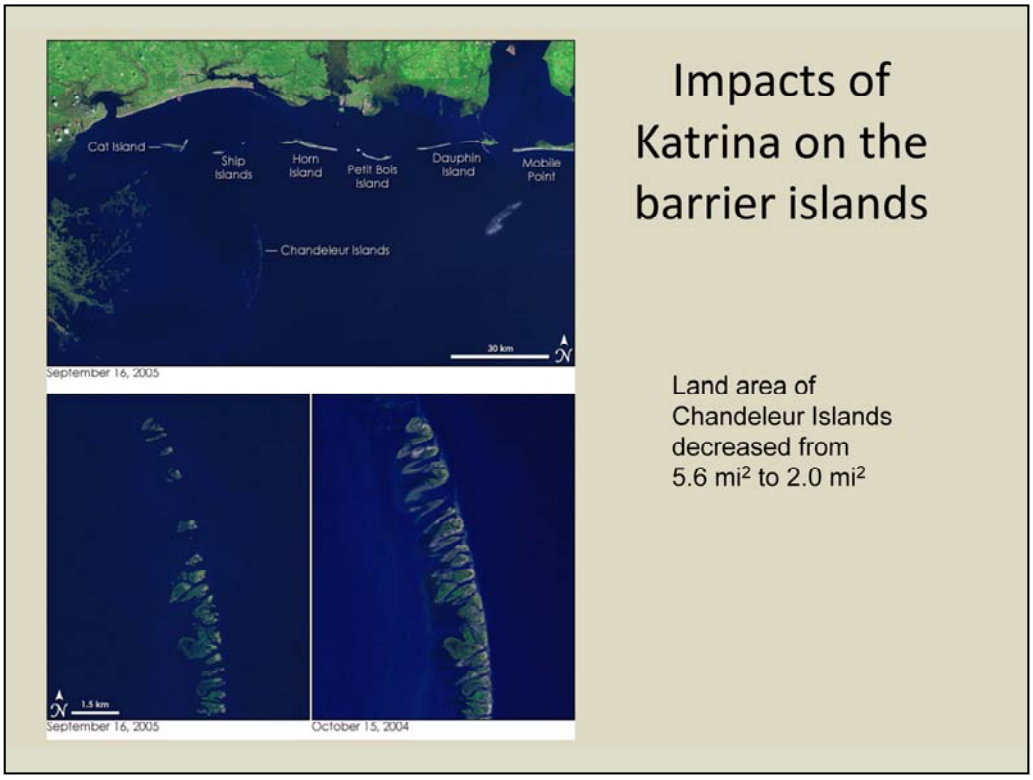
Katrina's track is highlighted in yellow. Light blue in the image indicates areas of potential land loss due to flooded, eroded and scoured marsh. Dark blue in the image is open water – some of this will likely become new lakes. Levees are represented by dotted lines

Image credit: USGS National Wetlands Research Center



The Mississippi River enters the Gulf of Mexico through the wetlands of Louisiana. Over millennia, the river has deposited sediment into the Gulf, slowly building the delta seen here. The delta changed dramatically when Hurricane Katrina blew ashore. The top image (31 August) of the Mississippi River delta shows the effects as much of the green area (mostly coastal wetlands) is under water. Some of the changes seen in the delta are a result of temporary flooding brought on by the hurricane's powerful storm surge and heavy rains. Areas where the storm washed away sections of wetland are likely permanent losses.

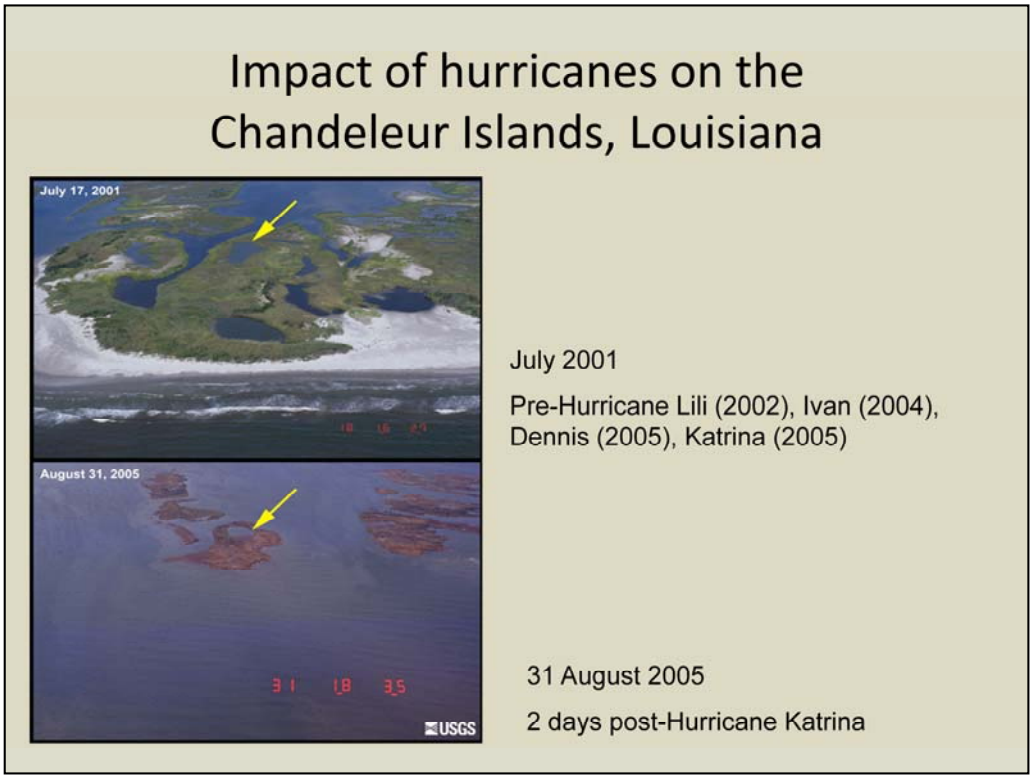
Image credit: NASA



Hurricane Katrina's strong winds, storm surge, and waves left the barrier islands heavily scoured, reduced in size and, in some cases, obliterated. The land area of the Chandeleur Islands (shown in detail in the lower photos) decreased from 5.6 mi^2 (14.5 km^2) before Katrina to 2.0 mi^2 (5.2 km^2) after Katrina. These Landsat images of the barrier islands document the impact. The top image, taken on September 16, 2005, shows the Mississippi and Alabama coast line and the thin line of barrier islands that bore the full force of Katrina. The lower images show pre-Katrina (October 2004) and post-Katrina (September 2005) views of the northern section of the Chandeleur Islands. Note the diminished size of the island chain in the post-Katrina image on the left. The other barrier islands shown in the top image were also impacted by Katrina. The Ship Islands are now significantly smaller than they were in 2004, and Dauphin Island has been cut in two.

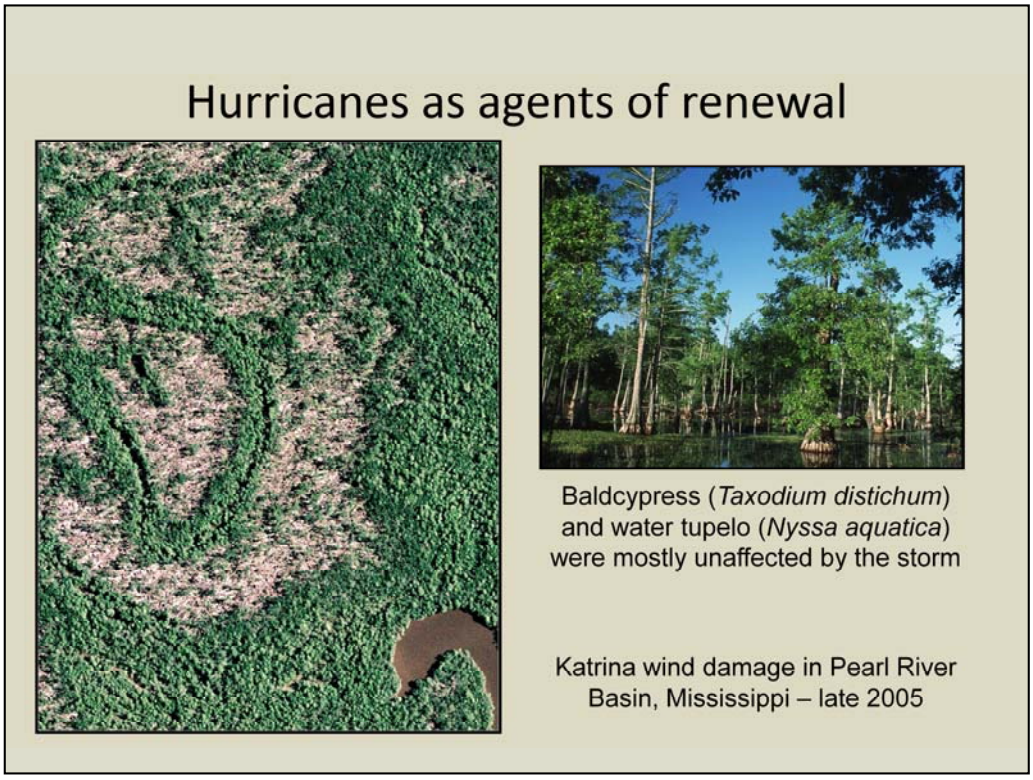
Although barrier islands are constantly building, eroding, and shifting under the normal actions of wind and waves, major storms like Katrina can have a large and lasting impact. These impacts on the barrier islands presumably have reduced their buffering effect against future storms and have increased the vulnerability of coastal areas.

Image credit: Jesse Allen, Earth Observatory, using data provided courtesy of Laura Rocchio, NASA Landsat Project Science Office



These “before and after” photos show the nearly complete destruction of the islands in recent hurricane seasons. The top image was taken in July 2001, before Hurricanes Lili (2002), Ivan (2004), Dennis (2005), and Katrina (2005). Katrina was the strongest and closest in proximity to the Chandeleur Island chain. The bottom image was taken on August 31, 2005, two days after Hurricane Katrina made landfall on the Louisiana and Mississippi coastline. Katrina’s storm surge and large waves submerged the islands, stripped sand from the beaches, and eroded large sections of the marsh. Today, there are few recognizable landforms left on the Chandeleur Island chain. Yellow arrows in the images indicate the same location.

Image credit: US Geological Survey



Despite the damage to human structures, barrier islands, and coastal wetlands, it is important to note that not all wetland types were negatively impacted. Many Gulf Coast species are adapted to periodic major disturbances such as hurricanes. Intact wetlands that are not compromised by other stressors (pollution, fragmentation, climate change, etc.) have the capacity to quickly regenerate from even major disturbances. Surviving plants quickly re-grow and plant propagules such as seeds and rhizomes quickly begin the process of recovery.

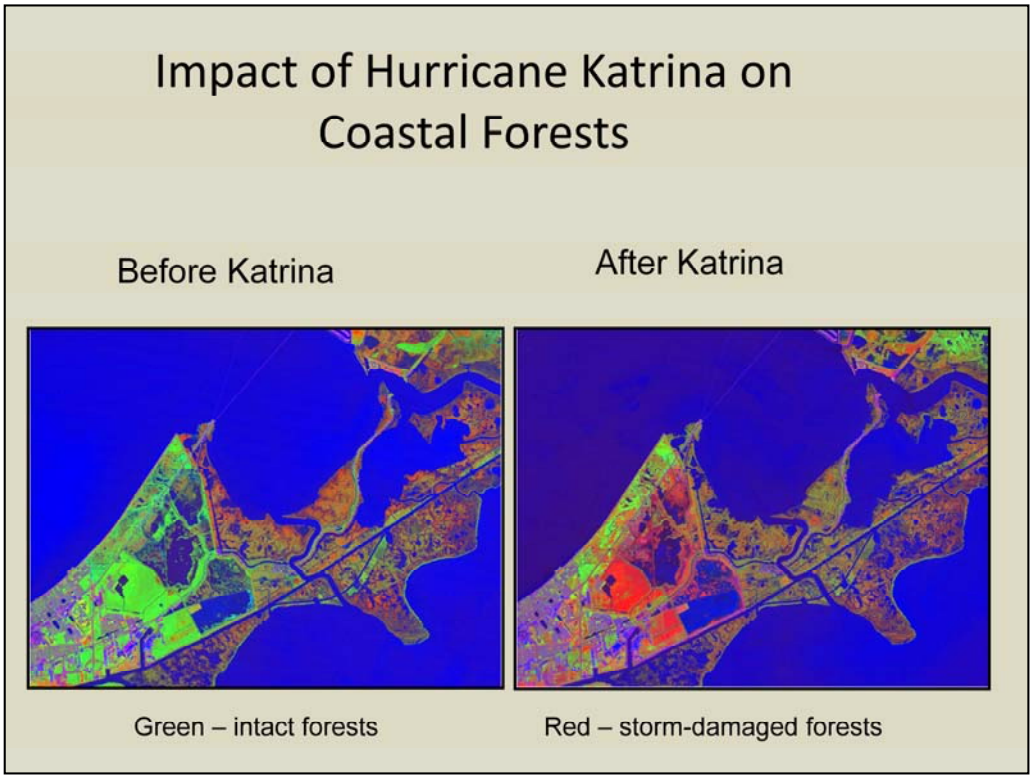
Baldcypress swamps, for example, sustained some damage to subdominant tree and shrub species, but dominant trees such as baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) were mostly unaffected. Recruitment of tree seedlings into new open areas created by the hurricane appear to be dominated by baldcypress and water tupelo. Thus, the net effect of the hurricane in this wetland type was to transform a mixed forest into one dominated by these species.

This late 2005 aerial photgraph shows an area of forest in the Pearl River Basin, which extends from central Mississippi to the Louisiana border. Note the unevenness of the impact of Hurricane Katrina. Intact forest remains immediately adjacent to wide swaths of fallen trees. Baldcypress and tupelo trees were more resistant to Katrina's winds than oak, maple, and sweetgum.

Coastal freshwater marshes, on the other hand, can be severely impacted by hurricanes as saltwater gets pushed into these environments. Plant species adapted to freshwater conditions will not grow or germinate well in brackish conditions.

See SWS Research Brief No. 2009-0002 (June 2009) for details.

Image credits:
Left - Photograph courtesy Louisiana State University Hurricane Katrina and Rita Cooperative Clearinghouse.
Right - Photo by Lynn Betts, USDA Natural Resources Conservation Service



The damage inflicted on Gulf Coast forests is captured on these before- and after-Katrina Landsat satellite images. The Interstate 10 bridges that cross Lake Pontchartrain near New Orleans can be seen in the top portion of the image. The Bayou Sauvage National Wildlife Refuge is seen in the lower left. Intact forests before the storm are in bright green. Red areas after the storm indicate heavy tree mortality.

Image credit: U.S. Geological Survey

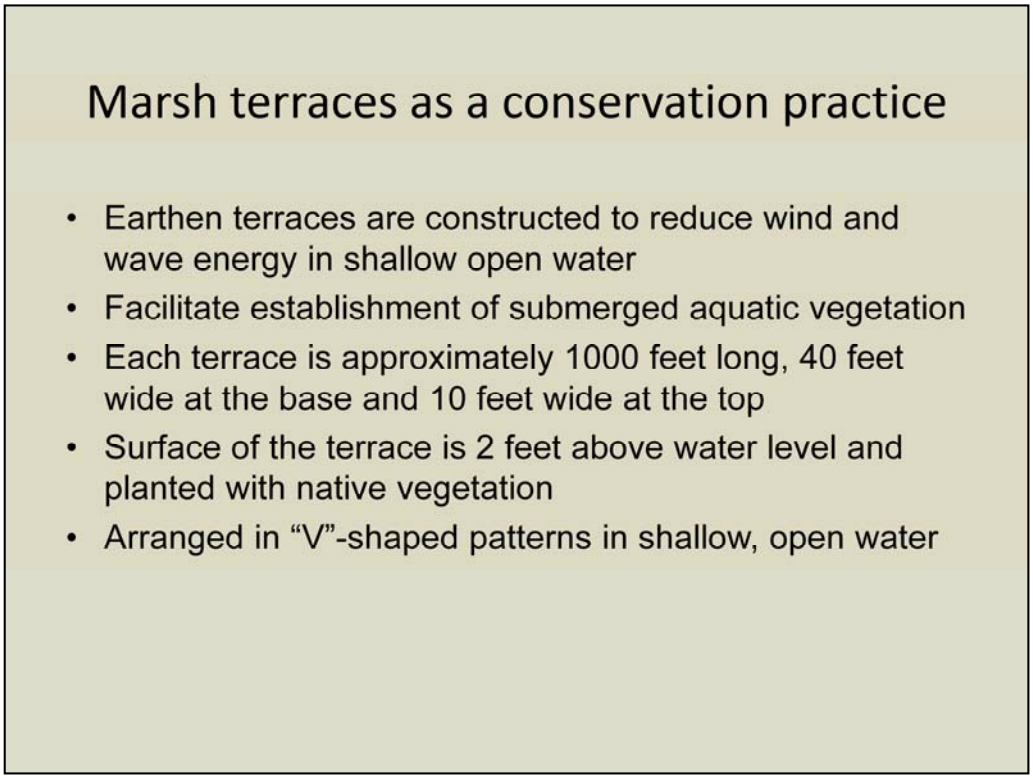
New Orleans and other Gulf Coast cities are obviously interested in reducing the impact from future storms like Katrina. Most effort has centered on improving the levee system to be able to withstand a direct hit from stronger hurricanes. The Army Corps of Engineers is responsible for maintaining the levee system and is making improvements on an on-going basis. Restoring wetlands would also provide benefit as wetlands have been shown to buffer the coast from storm surges. Most restoration experts note that restoration of Louisiana's wetlands will require re-establishing the connection between the Mississippi River and its delta (See Day, et al. 2007). It is unclear at this time whether the state of Louisiana will be willing to make the difficult choices required to restore its coastal wetlands. Tremendous political pressure is exerted by those interests that benefit from canal construction, logging of cypress swamps and the construction of newer and better levees.

Among the proposals to restore wetlands in the Gulf is one plan that diverts the Mississippi River to build new land and wetlands. This restoration effort relies on the input of Mississippi River sediment to build new wetlands. Unfortunately, the sediment load of the Mississippi is believed to be significantly lower than historic levels. Blum and Roberts (2009) estimate that the sediment load of the Mississippi is 50% lower than historic levels as a result of dam, reservoir and levee construction in the basin. These authors estimate that without additional sediment load, an additional 10,000-13,500 km^2 will be submerged by the year 2100 due to a combination of subsidence and sea level rise. To sustain the current level of wetlands, an additional 18-24 billion tons of sediment would be required, an amount that cannot be drawn from the basin in its current state. Further drowning of these wetlands appears to be inevitable.

A restoration plan first developed in 1998 by Louisiana and federal agencies, dubbed "Coast 2050," attempts to protect over 10,000 km^2 of Gulf Coast marshes, swamps and barrier islands. If fully implemented, this restoration project would be nearly twice as big as the Florida Everglades effort. The plan diverts a portion of the Mississippi River with new pipelines, canals and pumps and the river will then deliver more sediment to the bayous south of New Orleans. Some levees below New Orleans would also be opened, increasing the amount of sediment and freshwater flow to marshes. It would also close the Mississippi Gulf Outlet, which has contributed to the loss of thousands of hectares of cypress swamp due to salinization and allowed the entry of storm surges up the Mississippi River. The current web of oil and gas access channels would also be filled and wetlands restored. Wetlands and barrier islands would be restored over time as sediment builds and will be replanted with wetland grasses where necessary. Some barrier islands will also be replenished with dredged material.

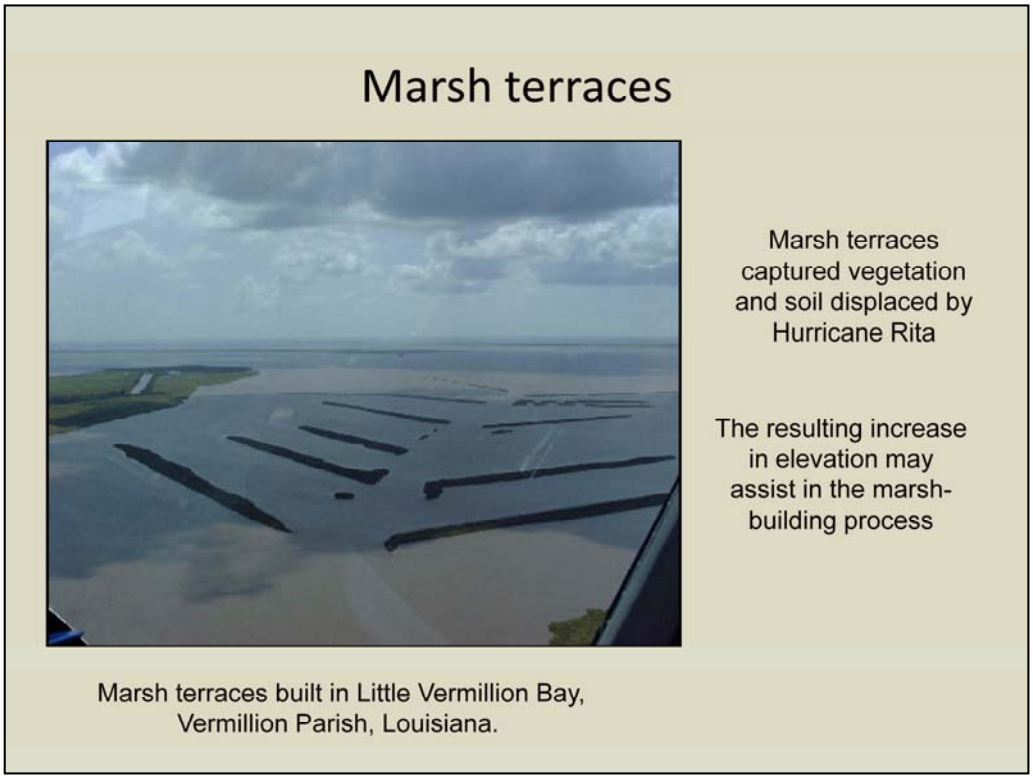
The plan got qualified support from the National Academy of Science in late 2005. But (as of 2006) Congress balked at the $14 B price tag and allocated only $3.6 B for levees and $71 million for wetland restoration.

See Katrina video cited in *Resources* for details.



A different type of wetland restoration effort in the Gulf involves the management of hydrology and salinity regimes by re-establishing historic patterns. Various control structures are built to accomplish this, including perimeter levees, water control structures and canal plugs. Once perimeter protection is established, earthen terraces (**marsh terraces**) may be constructed to reduce the impact of wind and waves on wetlands threatened by erosion. By reducing wave energy, the substrate becomes more stable and submerged aquatic vegetation can more easily become established. Water clarity also improves, allowing more sunlight to reach the underlying soils and further encouraging the growth of aquatic vegetation. Once vegetation is established, more sediment is likely to get trapped and the resulting wetlands increase in size.

Individual terraces are approximately 1000 feet long, 40 feet wide at the base and about 10 feet wide at the top. The surface of the terrace is about 2 feet above water level and planted with native vegetation. They are built in shallow water, typically only a foot or two deep. Terraces are arranged in a "V"-shaped pattern to create calm water on the downwind side of the terraces regardless of wind direction.



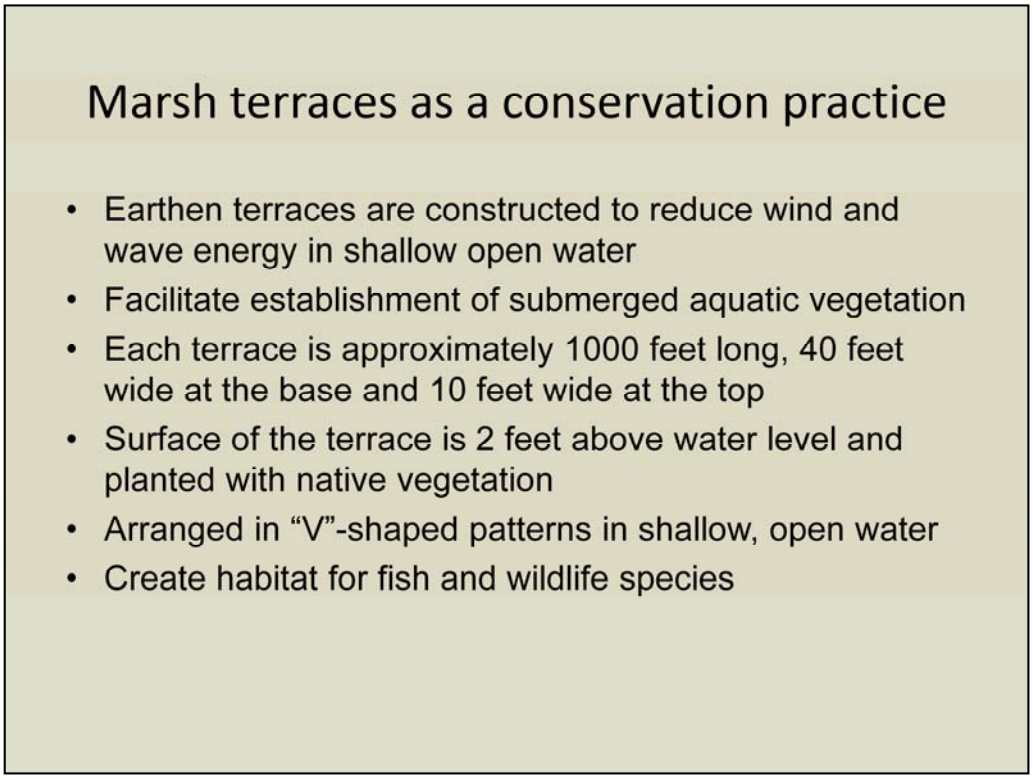
This is an image of marsh terraces built in the spring of 2005 on private lands within the Cameron Creole Watershed, Louisiana.

Although some areas of marsh were ripped up by Hurricane Rita, the terraces constructed in interior marshes were not significantly impacted. Some of the displaced vegetation and its attached soil were captured by terraces and deposited into damaged marsh areas. This soil and organic debris may increase marsh elevations and allow establishment of emergent vegetation that will aid in the marsh building process in these damaged marshes.

Image credit: NOAA Fisheries Service, John Foret and Joy Merino

These terraces in Vermillion Bay, Louisiana were constructed to trap sediment and reduce shoreline erosion, which occurs in this area at a rate of approximately 8 feet per year. A network of channels was dredged to beneficially distribute freshwater and sediment in the bay. Dredged materials were then used to construct 42,000 feed of earthen terraces. The terraces are about 25 feet wide and 4 feet above mean sea level, creating approximately 57 acres of new marsh. Margins of the terraces were planted with smooth cordgrass (*Spartina alterniflora*).

Image credit: NOAA Fisheries



Marsh terraces on the Louisiana coast have been built since the early 2000s by private organizations such as *Ducks Unlimited* in cooperation with the U.S. Fish and Wildlife Service. Marsh terraces have been shown to create habitat that supports commercially important marine species such as shrimp, red drum and blue crabs, as well as other wetland-dependent fish and wildlife species.

Hurricanes and Gulf Coast Wetlands – a summary

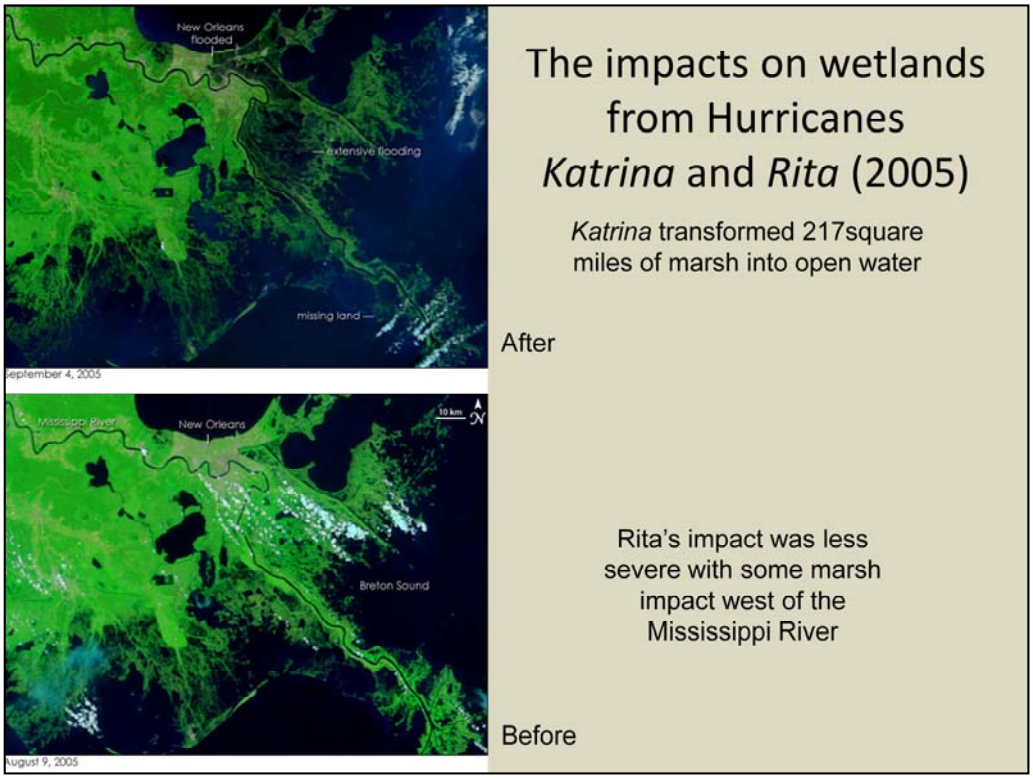
- The Gulf Coast is vulnerable to damage from hurricanes due to its location, elevation and loss of wetlands and barrier islands
- Wetlands and barrier islands provide significant protection against major storms
- Wetlands have decreased in area due to natural and human-caused events
- Hurricanes result in the loss of additional wetlands and barrier islands, some of which is likely permanent
- Wetland restoration will require additional sediment input, which the current system cannot provide
- The “Coast 2050” wetland restoration plan proposes to alter the hydrology of the Mississippi River Delta to reverse wetland loss

Photo Credits

- IAN Image Library (ian.umces.edu/imagelibrary/): Tim Carruthers
- Louisiana State University Hurricane Katrina and Rita Cooperative Clearinghouse.
- Marine Photobank: David Helvarg, Blue Frontier Campaign, ESA Envisat
- NASA/courtesy of nasaimages.org
- Jesse Allen, Earth Observatory, using data provided courtesy of Laura Rocchio, NASA Landsat Project Science Office
- NASA Earth Observatory
- NASA/GSFC/LaRC/JPL, MISR Team
- Image Science & Analysis Laboratory, Johnson Space Center
- GOES Project Science Office
- National Oceanic and Atmospheric Administration/Department of Commerce: Dr. Terry McTigue, NOAA Fisheries
- U.S. NAVY
- USDA Natural Resources Conservation Service: Lynn Betts,
- U.S. Geological Survey: National Wetlands Research Center

Additional Slides

The following slides are provided as additional evidence of the impacts of Katrina on wetlands

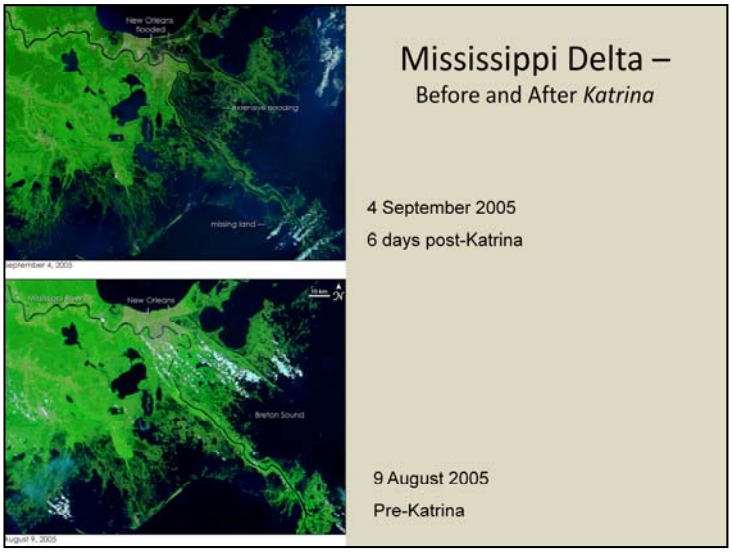


Katrina and Rita transformed 217 square miles (562 km^2) of marsh into open water in coastal Louisiana. Estimates are based on an analysis of Landsat Thematic Mapper ™ satellite data by the U.S. Geological Survey. Although some marsh may recover, indications are that much of the loss will be permanent. Most of the loss east of the Mississippi River (St. Bernard and Plaquemines parishes) was due to the effects of Katrina's storm surge. Approximately 39 square miles adjacent to Breton Sound were converted to open water as a result of marsh loss or submergence. An additional 47 square miles were lost throughout the Pontchartrain, Pearl River, Barataria, and Terrebonne basins. The Mississippi Delta itself incurred 14 square miles of loss.

Freshwater and intermediate marshes (71% of loss) were more affected than brackish and saline marshes (20% of loss), which appear to be more resistant to shearing.

Rita's impact was less severe and marsh loss was predominantly west of the Mississippi River to the Texas border.

Image credit: NASA



These “before and after” images of southeastern Louisiana provide a clear view of extensive flooding in the wetlands southeast of New Orleans. Flooded areas are black against bright green vegetation in these false-color images taken on 4 September (top) and 9 August 2005 (bottom). The images demonstrate how coastal wetlands function to protect inland regions from the destructive storm surge of powerful hurricanes such as Katrina. The wetlands act as a sponge, soaking up water that pounds the coast during the storm. After the storm, the wetlands retain water, which is why widespread flooding is still evident six days after the storm had passed. If the wetlands had not been there, the storm surge could have penetrated much further inland. By contrast, there were no wetlands to buffer New Orleans from Lake Pontchartrain, so the storm-churned lake was able to burst through the levees that separated it from the city.

Wetland loss in coastal Louisiana is a rising concern among scientists. The United States Geological Survey reports that Louisiana lost 1,900 square miles of land between 1932 and 2000, with an average 34 square miles of land disappearing every year. Though many things contribute to wetland loss, one of the primary reasons wetlands are disappearing is water use. Canals and levees prevent the regular floods along the Mississippi River that would otherwise carry sediment to the wetlands. Meanwhile, the daily ebb and flow of the ocean washes away bits of land. Since the sediment is not replaced by regular floods, the ocean gradually eats away at the wetlands until they disappear. As the top image demonstrates, without wetlands, inland cities would be more prone to storms. Though extensive flooding is evident in the wetlands, is not yet known what long-term impact Katrina had on Louisiana’s wetlands.

Image credit: NASA

These satellite images in the wake of Hurricane Katrina illustrate the flooding of New Orleans. The top image was taken on August 30, 2005. Early news reports said that as much as 80 percent of the city was flooded after levees failed to hold Katrina's massive storm surge back. The flooding was getting worse as water slowly seeped into the city from Lake Pontchartrain.

On 27 August, New Orleans looked like a tan and green grid sandwiched between the lake shore and the river in the lower image. Three days later, dark pools of water covered the eastern half of the city, and a large section of Lake Pontchartrain ballooned into the region immediately west of the city. Widespread flooding was visible elsewhere in the top image. Lake Pontchartrain and Lake Maurepas had nearly blended into a single body of water, separated only by a narrow strip of land. Dark smudges lined the rivers flowing into both lakes, a sign that water covered the ground around them.

These false color images accentuate the contrast between flooded and un-flooded areas. Water is black or dark blue where it is colored with mud, vegetation is bright green, and clouds are light blue and white.

Image credit: NASA

Wetlands and Hurricanes - Resources

Arnold, G. (ed.) 2006. After the storm: Restoring America's Gulf Coast wetlands. Environmental Law Institute, Washington, D.C. 67 pp.

Barras, J.A. 2007. Satellite images and aerial photographs of the effects of Hurricanes Katrina and Rita on coastal Louisiana. U.S. Geological Survey Data Series 281. http://pubs.usgs.gov/ds/2007/281

Barras, J.A. 2007. Land area changes in coastal Louisiana after hurricanes Katrina and Rita. U.S. Geological Survey. 16 pp. http://pubs.usgs.gov/circ/1306/pdf/c1306_ch5_b.pdf

Blum, M.D. and H.H. Roberts. 2009. Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. Nature Geoscience 2:488-491.

Boesch, D.F., et al. 2006. A new framework for planning the future of coastal Louisiana after the hurricanes of 2005. Univ. of Maryland Center for Environmental Science Cambridge, MD, 48 pp.

Bourne, J. 2000. Louisiana's vanishing wetlands: Going, going… Science 289:1860-1863.

Costanza, R., W.J. Mitsch, and J.W. Day. 2006. A new vision for New Orleans and the Mississippi Delta: Applying ecological economics and ecological engineering. Frontiers in Ecology and the Environment 4:465-472.

Day, J.W., et al. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. Science 315:11679-1684.

Ducks Unlimited. 2010. Marsh terraces as a conservation practice. 4 pp. www.ducks.org/Louisiana/LouisianaConservation/1724/MarshTerracesasaConservationPractice.html

Farris, G.S., et al. (eds.) 2007. Science and the storms: The USGS response to the hurricanes of 2005. U.S. Geological Survey Circular 1306. 283 pp. http://pubs.usgs.gov/circ/1306/

This is one of the most comprehensive assessments of the impacts of Hurricanes Katrina and Rita on the Gulf Coast, including their impacts on wetlands.

Mallin, M.A., et al. 2002. Impacts and recovery from multiple hurricanes in a Piedmont-coastal plain river system. BioScience 52:999-1010.

This publication is a reflection by 18 authors on the aftermath of Hurricanes Katrina and Rita on the Gulf Coast.

Tornquist, T.E., et al. 2008. Mississippi Delta subsidence primarily caused by compaction of Holocene strata. Nature Geoscience 1:173-176.

Wetlands and Hurricanes - Video Resources

Hurricane Katrina: A NASA Satellite Video Retrospective. NASA Earth Observatory 2010.
http://www.nasa.gov/mission_pages/hurricanes/features/katrina-retrospective.html

This 10-minute NASA video takes a retrospective look at Katrina five years after the event. It provides some background for discussions on the relationship between wetlands and hurricanes.

The day the Big Easy drowned. 2006. DVD 52 min.
www.films.com

This video examines the science and engineering behind the flooding of New Orleans following Hurricane Katrina in 2005.

The Lost City of New Orleans. 2006. DVD 50 min.
www.films.com

This video also examines the reasons behind the flooding of New Orleans following Hurricane Katrina in 2005.

McKee, K.L. 2010. Coastal Louisiana: Impacts of hurricanes on salt marsh and mangrove wetlands. U.S. Geological Survey. 7 minutes.
www.lacoast.gov/new/Ed/Videos.aspx

This brief video describes research being conducted by the USGS and university partners on the effects of hurricanes on marsh and mangrove wetlands in the Mississippi Delta. Both damaging and renewing effects of hurricanes are discussed.

McKee, K.L. 2010. Effects of sea level rise on coastal wetlands in the Mississippi River delta. U.S. Geological Survey. 7 minutes.
www.lacoast.gov/new/Ed/Videos.aspx

This video describes attempts to better understand the effects of sea level rise and other aspects of global climate change on coastal wetlands in the Mississippi River delta. Field and laboratory experiments are described that quantify how plant productivity contributes organic matter to soil building, which helps to compensate for sea level rise.

SoLa – Louisiana Water Stories. 2010. Oceans 8 Productions. 60 min. DVD and on-line

This video examines a wide variety of environmental issues in southern Louisiana. It is conveniently segmented into the following topics:

- Wetlands and hurricanes
- Decline of commercial fishing
- Impacts of oil and gas industry on environmental quality

Video notes and approximate time markers are provided to instructors who might be interested in selecting only a portion of the video.

0:00

Wetlands and Hurricanes

- Louisiana State University professor describes southern Louisiana as a biologically diverse ecosystem on a low coastal floodplain.
- Despite the overall appeal of the region, flooding continues to be a major issue.
- The origins of New Orleans and its levee system are described.
- In 1927, a major Mississippi River flood devastated the area and the 1927 Flood Control Act resulted, mandating flood control.
- In 1965, Hurricane Betsy flooded large parts of new Orleans. The government responded by constructing a hurricane protection system that interfered with sediment flow and the wetland building process. Wetlands are "starved to death."
- Wetlands are the main protection from the storm surge associated with hurricanes.
- Hurricane Katrina's impacts are described. Severe impacts occurred despite being only a Category 3 storm at landfall.

0:10

- Ex-Louisiana State University professor was named to head the Louisiana Hurricane Center. His post-storm evaluation of Hurricanes Katrina and Rita found that the U.S. Army Corps of Engineers was to blame for "shoddy engineering" of hurricane protection system of levees and canals. He was terminated after the publication of the report, claiming that, "We are setting ourselves up for a major catastrophe."
- The destruction of cypress swamps also played a major role in Katrina's impacts. The role of coastal wetlands in reducing storm surge is estimated – storm surges are lowered 6 feet for every one mile of cypress swamp.
- Southern Louisiana ports, especially New Orleans, are critical to the economic engine of the region.
- "Wetlands protect the levees; levees protect us."
- Rates of current wetland loss and projected future losses in the region are estimated.
- Dean Wilson, "Waterkeeper" describes the Atchafalaya Basin (1.4 million acres) as an area of unparalleled biodiversity. The ecosystem is dominated by trees, unlike the better known Florida Everglades, which is dominated by grass (marshlands).
- The role of hollow trees as refuges during floods is described.
- Canals for oil and gas industry have been cut through wetlands.
- Illegal logging of cypress swamps continues today and is documented by aerial survey (2000-2006 logging rates are estimated).

0:20

- June 2008 - Governor of Louisiana, Bobby Jindal states that no major oil spills (>100,000 gallons) have occurred in the Gulf of Mexico, but the Louisiana Department of Environmental Quality estimates that 9 million gallons of oil have spilled in the Gulf.
- One incident involving an oil barge collision with another vessel is described.

Importance of Commercial Fishing

- "Blessing of the Fleet" – conducted by local clergy as a blessing for a safe and abundant harvest.
- Small-scale, family-based fishing as a way of life in the Gulf is described, but is now seen as an industry "in its twilight" due to conflicting interests (fishing vs. oil and gas), global imports of seafood products, larger commercial fishing vessels, declining values of product and increasing costs.

0:30

- Gulf of Mexico Dead Zone expert describes impact of water quality on fishing industry. Cause of Dead Zone is known to be fertilizer applied for corn crop in Midwest (from 31 states). Poor water quality has an impact on the economic base of coastal communities.
- Cited as an example of abuse and neglect of natural resources in addition to poor overall environmental quality – air, water, hazardous waste.
- Louisiana Environmental Network – an environmental group trying to increase awareness of environmental issues in southern Louisiana.

0:40

Impacts of oil and gas industry on environmental quality

- Petrochemical industry is a major employer of Louisiana residents.
- "Super Fund" site described that resulted in closing the entire subdivision and razing all of the houses.
- "Better living with chemistry" has contributed to environmental contamination. Pipelines and canals have contributed to environmental degradation and many have been abandoned. Associated habitat destruction had contributed to the collapse of local fisheries.
- Fisheries sustain the community – a national treasure. Estuary provides rearing habitat for commercially-important fish.

0:50

- Oil and gas companies have strong influence on decision-making in southern Louisiana. The industry accounts for $70 billion per year and employs 320,000 people. But, people get very little of the value of the resource in part because of decline in tax rate from 40% in past to 15% now.
- Gulf of Mexico oil spill – April 2010
- Environmental impacts of spill described - burning of oil as a strategy for cleanup, impact on coastal communities.
- "The oil industry owns Louisiana. Most of us are in denial – we are addicted to oil."

0:60 END

General and Comprehensive Resources

The following resources cover a broad range of wetlands-related topics. Several are comprehensive web sites that contain a variety of information on wetlands that may be relevant to instructors. More detailed descriptions of the content of these web sites are provided in a separate section entitled "Detailed Descriptions of Comprehensive Resources" that follows. These resources have been identified with an asterisk (*) in the list below. More specific resources that cover one or few aspects of wetlands are provided in the module that is most relevant to those topics.

Association of State Wetland Managers (*)
www.aswm.org

The Association of State Wetland Managers is a nonprofit membership organization established to promote and enhance protection and management of wetland resources, to promote application of sound science to wetland management and to provide wetland training and education.

Batzer, D.P. and R.R. Sharitz. 2007. Ecology of freshwater and estuarine wetlands. Univ. of Calif. Press. 581 pp.
www.ucpress.edu

This is a comprehensive undergraduate text in wetland ecology. It is appropriate for a course devoted entirely or primarily to wetlands. Otherwise, it would be a useful reference for instructors who incorporate wetlands topics into a broader course in ecology.

Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998-2004. U.S. Fish and Wildlife Service, Washington, D.C. 112 pp.
http://www.fws.gov/wetlands/StatusAndTrends/

Environmental Protection Agency (*)
www.epa.gov/wetlands

The EPA wetlands site provides some good introductory information on wetlands. Wetlands definitions, types, status and trends, functions and values and wetlands management (including mitigation) and protection are all covered.

Hammer, D.A., ed. 1989. Constructed wetlands for wastewater treatment. Lewis Publishers, Inc., Chelsea, MI . 831 pp.

Kusler, J.A. and T. Opheim. 1996. Our national wetland heritage: A protection guide, 2nd ed. Environmental Law Institute, Washington, D.C. 149 pp.

This is a comprehensive guide to the protection and restoration of wetlands by local governments, private citizens, conservation organizations and landowners.

Maltby, E. and T. Barker (eds.). 2009. The wetlands handbook. Wiley-Blackwell, Inc. San Francisco, CA. 800 pp.
www.wiley.com

At $300 this text is probably only for the most serious wetlands instructors. It is a comprehensive analysis of ecosystem-based approaches to wetlands management. The emphasis is on maintaining/restoring ecological functions in freshwater wetlands.

Marks, R. 2006. Ecologically isolated wetlands. Natural Resources Conservation Service and Wildlife Habitat Council. Fish and Wildlife Habitat Management Leaflet #38. 8 pp.

This brief document is an excellent introduction to wetlands and is suitable to assign for student reading. Wetland processes and functions, ecological and economic benefits and issues associated with wetland loss and degradation are covered. As the title suggests, management issues emphasize what can be done to reduce the effects of wetland isolation.

Millennium Ecosystem Assessment. 2005. Ecosystems and human wellbeing: Wetlands and water – Synthesis. World Resources Institute, Washington, D.C.
www.millenniumassessment.org/documents/document.358.aspx.pdf

http://www.maweb.org/documents/document.358.aspx.pdf

This is a global assessment of wetlands resources with recommendations for future management.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., Inc. New York, NY. 539 pp.

Mitsch, W.J. and J.G. Gosselink. 2007. Wetlands. 4th ed. John Wiley and Sons, Inc., Hoboken, NJ.

A potential choice for a textbook for a course on wetlands, but designed for junior/senior level students and for those with some background in ecology.

Mitsch, W.J., et al. 2009. Wetland ecosystems. John Wiley and Sons, Inc., Hoboken, NJ. 285 pp.

Earlier editions of the Mitsch and Gosselink Wetlands *classic wetlands text (described above) included seven "ecosystem" chapters that described the structure and function of wetland ecosystems found in North America. In the interest of reducing the size of this text, the authors decided in the most recent edition to pull out these chapters and develop a separate text.* Wetland Ecosystems *is the result of that effort.*

National Research Council (NRC). 1995. Wetlands: Characteristics and boundaries. National Academy Press, Washington, D.C. 306 pp.

National Research Council (NRC). 2001. Compensating for wetlands losses under the Clean Water Act. National Academy Press, Washington, D.C. 158 pp.

Oregon Wetlands Explorer (*)
www.oregonexplorer.info/wetlands/

This joint project of Oregon State University, The Wetlands Conservancy and Oregon Division of State Lands is primarily designed for wetlands professionals, but educators (especially those in Oregon) will find some useful information here.

Payne, N.F. 1992. Techniques for wildlife habitat management of wetlands. McGraw-Hill, Inc., New York, NY. 549 pp.

Ramsar Convention on Wetlands
www.ramsar.org

The Ramsar site is most useful for international wetlands information. The Ramsar Convention is an intergovernmental treaty that commits its member countries to maintain the ecological character of "wetlands of international importance." The site provides digital photos and other media for instructor use including a 4-minute introductory You-tube video that introduces Ramsar and describes the value of wetlands.

Society of Wetland Scientists (*)
www.sws.org

The Society of Wetland Scientists (SWS) is the premier professional organization for wetland scientists and other professionals in the field. SWS publishes, Wetlands*, the leading journal on wetlands science and issues. Their web site has a number of resources that educators will find useful.*

Tiner, R.W. 2005. In search of swampland: A wetland sourcebook and field guide. Rutgers University Press, New Brunswick, NJ
http://rutgerspress.rutgers.edu

This resource is an excellent introduction to wetlands issues written for the "average citizen."

U.S. Army Corps of Engineers (*)
www.usace.army.mil/CECW/Pages/techbio.aspx

The Army Corps of Engineers has primary responsibility for waterways in the U.S. and is the primary agency that regulates wetlands at the federal level. As a focal point for federal wetlands management, this site has links to lots of wetlands resources with an emphasis on wetland delineation and classification, wetland functions and values, mitigation banking, and wetland plants and soils.

U.S. Fish and Wildlife Service - National Wetland Inventory (*)
www.fws.gov/wetlands

This site, maintained by the U.S. Fish and Wildlife Service, provides a wealth of useful information and tools including wetland status reports (national and regional), Google Earth with wetlands maps overlay and digitized wetlands maps.

U.S. Geological Survey – National Wetlands Research Center
www.nwrc.usgs.gov

Wetlands International
www.wetlands.org

The mission of this international conservation organization is "to sustain and restore wetlands, their resources and biodiversity for future generations." The organization uses science-based information to promote the protection and restoration of wetlands. Instructors looking for an international perspective on wetlands issues, especially those related to climate change and wetland bird conservation, will find Wetland International publications to be useful resources. The organization also produces a number of short (5-15 min.) videos available for download on their web site. Topics include the impacts of climate change on mangrove forests, wetland restoration and carbon dioxide storage in peatland forests.

Details on Comprehensive Web Sites (*)

Association of State Wetland Managers
www.aswm.org

The Association of State Wetland Managers is a nonprofit membership organization established to promote and enhance protection and management of wetland resources, to promote application of sound science to wetland management and to provide wetland training and education. Their web site has lots of resources related to all wetlands topics including:

A wetlands glossary:
http://www.aswm.org/watersheds/wetlands-and-watershed-protection-toolkit/887-wetlands-and-watershed-protection-toolkit?start=15

An excellent collection of publications that examine the relationship between wetlands and climate change:
www.aswm.org/science/climate_change/climate_change.htm

A collection of publications that examine the Gulf Oil Spill and its impact on wetlands. Includes coverage of wetland legal issues such as the Rapanos decision, "navigability," landmark legal cases,"takings." Instructors may also want to subscribe to "Wetland Breaking News" a newsletter on up-to-date wetlands issues and new publications.
http://aswm.org/wetland-science/2010-gulf-oil-spill

Environmental Protection Agency
www.epa.gov/wetlands
http://water.epa.gov/type/wetlands/index.cfm

The EPA wetlands site provides some good introductory information on wetlands. Wetlands definitions, types, status and trends, functions and values, wetlands management (including mitigation) and protection are all covered. The "Fact Sheets" are concise, 1-2 page summaries of various wetlands topics. Specific EPA sites of interest to instructors include:

This EPA wetlands module outlines the various values assigned to wetlands and describes how they are measured.
www.epa.gov/watertrain/wetlands/index.htm

This is an EPA site dedicated to wetland mitigation.
www.epa.gov/wetlandsmitigation

This EPA fact sheet is an excellent introduction to wetland mitigation banking.
www.epa.gov/owowwtr1/wetlands/facts/fact16.html

This is a short (approx 15 min.) video designed for a general audience that emphasizes the importance of providing outdoor, nearby nature, experiences for children – emphasis is on wetlands and includes interviews with wetlands scientists and environmentalists. Web site has directions for saving/ downloading video.
www.epa.gov/wetlands/education/wetlandsvideo/

A series of wetlands fact sheets on most aspects including an overview of wetland types, functions and values, threats, restoration, and monitoring and assessment.
www.epa.gov/owow/wetlands

The EPA wetlands helpline
http://water.epa.gov/type/wetlands/wetline.cfm

U.S. Fish and Wildlife Service – National Wetlands Inventory
www.fws.gov/wetlands

The U.S. Fish and Wildlife Service is the principal federal agency that provides information to the public on the extent and status of the nation's wetlands. This site provides a wealth of useful information and tools including wetland status reports (national and regional), Google Earth *with wetlands maps overlay and digitized wetlands maps. Perhaps the most useful tool is the "Wetlands Mapper," which visually displays the results of the national wetlands inventory, based primarily on an analysis of aerial photographs. Wetlands are identified, mapped and then superimposed on topographic maps. The inventory does not identify all wetlands in an area, but probably the most significant ones. The "Wetlands Mapper" allows viewing of identified wetlands either on-line or hard copy maps can be ordered for every state (see "Hard Copy Orders"). Each map is mapped as a polygon with an imbedded code that indicates the specific wetland type and other information related to this site.*

The WetlandsMapper shows the location of wetlands identified on National Wetlands Inventory (NWI) maps and integrates digital map data with other resource information. The following links provide a useful introduction to this feature:

- Wetlands Mapper Documentation and Instructions Manual (www.fws.gov/wetlands/_documents/gData/WetlandsMapperInstructionsManual.pdf)
- Frequently Asked Questions: Wetlands Mapper (www.fws.gov/wetlands/_documents/gData/QuestionsAnswersAboutNewMapper.pdf)
- Frequently Asked Questions web page (www.fws.gov/wetlands/FAQs.html)

NWI wetlands data can also be viewed with Google Earth. Instructions and a link to do so are included at the NWI web site.

This U.S. Fish and Wildlife site also includes Wetlands Status and Trends Reports, *which provide long-term trend information about specific changes and places and the overall status of wetlands in the United States. The historical database provides photographic evidence of land use and wetlands extent dating back to the 1950s. This provides an accurate record to assist in future restoration efforts.*

Status and Trends Reports available on the web site include:

- NOAA/USFWS joint report on Coastal Wetland Trends 1998-2004 (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsCoastalWatershedsEasternUS1998to2004.pdf)

- Status and Trends of Wetlands in the Conterminous United States 1998 to 2004 (Dahl, 2006) (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsConterminousUS1998to2004.pdf)
- Status and Trends of Wetlands in the Conterminous United States 1986 to 1997 (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsConterminousUS1986to1997.pdf)
- Wetlands Status and Trends in the Conterminous United States, Mid-1970's to Mid-1980's (www.fws.gov/wetlands/_documents/gSandT/NationalReports/WetlandsStatusTrendsConterminousUS1970sto1980s.pdf)
- Status and Trends of Wetlands and Deepwater Habitats in the Conterminous United States 1950's to 1970's (www.fws.gov/wetlands/_documents/gSandT/NationalReports/StatusTrendsWetlandsDeepwaterHabitatsConterminousUS1950sto1970s.pdf)

Links to other resources such as the National Wetlands Plant List and an EPA evaluation of the impact of climate change on coastal wetlands are also available.

Oregon Wetlands Explorer
www.oregonexplorer.info/wetlands/

This joint project of Oregon State University, The Wetlands Conservancy and Oregon Division of State Lands was first launched in 2009 as "a useful tool for anyone doing wetland work in Oregon." It is primarily designed for wetlands professionals, but educators (especially those in Oregon) will find some useful information here. The following are included:

1. *Statewide database of wetlands maps, hydric soils, FEMA flood zones, Wetland Reserve Program (WRP) sites, wetland mitigation banks. Local wetland inventories and recommended priority sites for conservation*
2. *A tool for rapid assessment for wetlands*
3. *Oregon-related information on various wetland topics*
4. *Wetland GIS and vegetation plot data*

Society of Wetland Scientists
www.sws.org/

The Society of Wetland Scientists (SWS) is the premier professional organization for wetland scientists and other professionals in the field. SWS publishes, Wetlands*, the leading journal on wetlands science and issues. Their web site has a number of resources that educators will find useful. Several are described below:*

This newly developed web page was designed to document the impact of the Deepwater Horizon oil spill in the Gulf of Mexico on wetlands. It includes insights from wetland scientists, links top pertinent resources and digital photographs.
www.sws.org/oilspill/

This page lists links to specific short courses in wetlands training – delineation, hydric soils, plant identification, restoration, mitigation, and constructed wetlands.
www.sws.org/training/

This is a directory of wetland-related academic programs at U.S. colleges and universities.
www.sws.org/colleges/

These "position papers" on various wetlands topics are designed to "increase public understanding of wetlands issues and to promote sound public policy." They are written by experts in the field and are based on the best available science. Topics include oil effects on wetlands, mosquito control, mitigation banking, performance standards for wetland restoration and creation, and definitions of wetland restoration. The papers are brief, well-referenced and provide excellent background for educators with a particular interest in specific wetland issues. They are also suitable to assign as student reading to provide a basis for discussions on wetland issues.
www.sws.org/wetland_concerns/

The SWS also publishes the "SWS Research Brief," which helps translate wetland research results for a non-technical audience. The research of selected wetlands scientists is highlighted in each brief. These make excellent student reading and serve to familiarize students with the process of science – how scientists formulate questions, collect data, present their findings and draw conclusions from them.
www.sws.org/ResearchBrief/

Some topics include:

- *Restoration of mangroves*
- *Invasive plants in wetlands*
- *Impact of elevated CO_2 levels on wetlands*
- *Impact of hurricane Katrina on wetlands*
- *Relationship between marshes, mosquitoes and malaria*

The SWS education page is designed with the college educator in mind and is intended "to facilitate sharing of techniques, skills, tools and ideas on and about wetlands education." See for educational resources including labs, field activities, courses, links to other web sites, etc. The Society of Wetlands Scientists also maintains a list of colleges and universities that offer courses or programs in wetland science or ecology.
www.sws.org/education/

Here are some examples of materials that college instructors will find most useful:

1. *Links to general information on wetlands*
2. *Syllabi, lab exercises and exams for wetlands courses*

NOTE: Instructors with an interest in teaching wetland concepts using digital imagery and aerial photography will find the "Wetland Education Through Maps and Aerial Photography" (WETMAAP) site to be particularly useful.

3. *Digital images collection for wetlands education*

U.S. Army Corps of Engineers
www.usace.army.mil/CECW/Pages/techbio.aspx

The Army Corps of Engineers has primary responsibility for waterways in the United States and is the primary agency that regulates wetlands at the federal level. As a focal point for federal wetlands management, this site has links to lots of wetlands resources. Those that are most relevant to this series of modules include the following:

Wetlands delineation and classification

- Corps Wetlands Delineation Manual (www.el.erdc.usace.army.mil/elpubs/pdf/wlman87.pdf)
- Regional Supplements to the Corps Delineation Manual (www.usace.army.mil/CECW/Pages/reg_supp.aspx)
- USFWS National Wetlands Inventory (www.fws.gov/wetlands/)
- Classification of Wetlands & Deepwater Habitats of the U.S. (www.npwrc.usgs.gov/resource/wetlands/classwet/index.htm)
- Recognizing Wetlands - An Informational Pamphlet (www.usace.army.mil/CECW/Documents/cecwo/reg/rw_bro.pdf)

Wetlands functions and values

- Current HGM Information and Guidebooks (http://el.erdc.usace.army.mil/wetlands/hgmhp.html)
- Hydrogeomorphic Approach to Assessing Wetland Functions (http://el.erdc.usace.army.mil/wetlands/hgmhp.html)
- National Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions (www.usace.army.mil/CECW/Documents/cecwo/reg/hydro_geo.pdf)
- Wetland Functions & Values - A Report by the National Science Foundation, 1995 (www.usace.army.mil/CECW/Documents/cecwo/reg/wet_f_v.pdf)
- Consequences of Losing or Degrading Wetlands
- U.S. Environmental Protection Agency Wetlands Information Website http://water.epa.gov/type/wetlands

Mitigation banking

- Federal Guidance for the Establishment, Use and Operation of Mitigation Banks (http://water.epa.gov/lawsregs/guidance/wetlands/mitbankn.cfm)
- National Wetland Mitigation Banking Study: Technical and Procedural Support to Mitigation Banking Guidance, 1995 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/WMB-TP-2.pdf)
- National Wetland Mitigation Banking Study: Model Banking Instrument, 1996 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/WMB-TP-1.pdf)
- National Wetland Mitigation Banking Study: The Early Mitigation Banks: A Follow-up Review, 1998 (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/iwrreports/98-WMB-WP.pdf)

- National Wetlands Mitigation Action Plan (www.usace.army.mil/CECW/Documents/cecwo/reg/Mit_Action_Plan.pdf)
- IWR - Wetlands and Regulatory (www.iwr.usace.army.mil/index.php?option=com_content&view=category&layout=blog&id=7&Itemid=3/publications.cfm)

Plants and soils

- NRCS Soils Website (www.soils.usda.gov/)
- Field Indicators of Hydric Soils in the U.S. ftp://ftp-fc.sc.egov.usda.gov/NSSC/Hydric_Soils/FieldIndicators_v7.pdf
- National List of Vascular Plant Species that Occur in Wetlands:
    - 1996 (www.usace.army.mil/CECW/Documents/cecwo/reg/plants/list96.pdf)
    - 1988 (www.usace.army.mil/CECW/Documents/cecwo/reg/plants/list88.pdf)
    - National Wetland Plant List (NWPL) https://rsgis.crrel.usace.army.mil/apex/f?p=703:1:2631898853215485
- NRCS Plants Database (www.plants.usda.gov/java/)
- Center for Aquatic and Invasive Plants - University of Florida (www.plants.ifas.ufl.edu/)
- Global Invasive Species Database (www.issg.org/database/welcome/)
- Interactive Key to Wetland Monocots of the U.S. (www.npdc.usda.gov/technical/plantid_wetland_mono.html)

Sources for Digital Images

Barras, J.A. 2007. Satellite images and aerial photographs of the effects of Hurricanes Katrina and Rita on coastal Louisiana. U.S. Geological Survey Data Series 281.
www.pubs.usgs.gov/ds/2007/281

Bureau of Land Management Image Library
www.blm.gov/wo/st/en/bpd.html

Most of the images in this web site are "public domain" and can be used without further authorization from the BLM.

The Integration and Application Network (IAN)
www.ian.umces.edu/imagelibrary/

The Integration and Application Network (IAN) is an initiative of the University of Maryland Center for Environmental Science. IAN emphasizes environmental problems in the Chesapeake Bay and its watershed. Although registration is required, there is no cost to download images.

The Natural Resources Conservation Service Photo Gallery
www.photogallery.nrcs.usda.gov

The Natural Resources Conservation Service Photo Gallery provides a comprehensive collection of natural resources and conservation-related photos from around the U.S. They are available for non-commercial use, free-of-charge with proper acknowledgement (described on web site).

NBII Life – Library of Images From the Environment
www.life.nbii.gov/dml/home.do

The National Biological Information Infrastructure (NBII) Library, Images from the Environment (LIFE), provides high-quality environmental images that are freely available for educational use. The collection includes images of plants, animals, fungi, microorganisms, habitats, wildlife management, environmental topics, and biological study/fieldwork. Images are annotated with background information(context, scientific names, location, habitat classifications, etc.), greatly improving their use as educational materials.

NOAA Photo Library/NERR Collection
http://www.photolib.noaa.gov/nerr/index.html
This collection includes images of estuaries in the National Estuarine Research Reserve System. Collection contains more than 1000 photos with images of landscapes, habitats, and individual specimens with descriptions.

U.S. Department of Agriculture PLANTS Database
www.plants.usda.gov

Plant images may be used for non-commercial use although copyrighted images require notification of the copyright holder.

The Society of Wetland Scientists
www.sws.org/regional/pacificNW/photo.html

The Ramsar Convention on Wetlands
www.ramsar.org/cda/en/ramsar-media-photos/main/ramsar/1-25-126_4000_0__

Has a good collection of photos from sites that have met Ramsar criteria.

U.S. Environmental Protection Agency Image Gallery
www.epa.gov/newsroom/pictures.htm

EPA maintains several collections of photographs and other images available for use by the public. Please note that while photographs and graphic materials produced by the federal government are not subject to copyright restriction, some photographs included in these collections may be copyrighted. Please observe carefully all rights and permissions information.

U.S. Fish and Wildlife National Digital Library
www.fws.gov/digitalmedia/

The U.S. Fish and Wildlife Service's National Digital Library is a searchable collection of public domain images, audio/video clips and publications. Permission is not required for use; however you are asked to give credit to the photographer or creator and the U.S. Fish and Wildlife Service.

U.S. Forest Service
www.fs.fed.us/photovideo/

USDA Forest Service's "Find-a-Photo" site allows access to thousands of copyright- free wildlife, fish, wildflower and environmental education photographs, donated by Forest Service employees, their partners and volunteers.