



# Case Study: Southwest Coastal Louisiana Conceptual Ecosystem Model Development<sup>1</sup>

by J. Craig Fischenich<sup>2</sup> and Tomma K. Barnes<sup>3</sup>

**OVERVIEW:** This case study addresses the effort and approach necessary to prepare a conceptual ecosystem model (CEM) for a typical ecosystem restoration project. It also serves as an example of the organization and level of detail for conveying the CEM in a report format. The subject model report is included as an attachment. The front matter, which precedes the attachment, summarizes information regarding approach and required resources not presented in the CEM report.

**GENERAL PROBLEM:** A CEM serves as a logical starting point in the planning process for any ecosystem restoration project and provides support throughout the process. Intended to describe functional relationships within an ecosystem, conceptual models illustrate important system processes, attributes, and cause-effect relationships; synthesize current understanding of system functions; isolate and help diagnose significant environmental challenges; and provide insight into potential outcomes of restoration actions within the project area. CEMs foster a common understanding of how a system works, what led to the degradation, and how proposed restoration actions address the problems. Developing CEMs facilitates communication among scientists, engineers, project managers, and the public; the process can be as valuable as the product in this and other regards. Development of CEMs has been recommended for all ecosystem restoration projects (US Army Corps of Engineers (USACE) 2008).

Fischenich (2008) provides detailed guidance on how to develop CEMs and describes the role and importance to ecosystem restoration projects. Dalyander and Fischenich (2010) later developed the Conceptual Ecosystem Model Construction Assistant Toolkit (CEMCAT) to help practitioners prepare CEMs. Collectively, these documents and tools guide practitioners through the CEM development process and assist with the development of supporting documentation and figures. However, neither of these previous efforts included an example of a completed CEM for a USACE project, and neither details the level of effort necessary to prepare a CEM for a typical USACE restoration project. This brief technical note was prepared to address these needs through the presentation of a typical case study: the Southwest Coastal Louisiana (SWCLA) Hurricane Protection and Coastal Restoration Project. The approach taken to develop the CEM for the SW Coastal Louisiana project and the effort required are summarized herein, and the completed product is appended as an example. At the time of preparation of this case study, the SWCLA

<sup>1</sup> This manuscript includes a report submitted to the US Army Engineer District, New Orleans presenting a conceptual ecosystem model for the subject project.

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CEM had not been subjected to a full review and should not be considered as having been approved. However, the general content and level of detail are consistent with other models that have been reviewed and approved.

**APPROACH:** The model building and development processes consist of first determining system parts, identifying relationships that link those parts, specifying the mechanisms of system interaction, and exploring model behavior. More specifically, seven individual development steps have been identified:<sup>1</sup>

1. State the model objectives
2. Bound the system of interest
3. Identify critical model components characterizing the system
4. Articulate the relationships among the components of interest
5. Represent the conceptual model
6. Describe the expected pattern of model behavior
7. Test, review, and revise as needed

Developing a conceptual model affords the restoration planning team an opportunity to investigate and clarify their understanding of the ecosystem and associated stressors, drivers, issues, and potential restoration options. For this reason, the model is best developed by a team rather than an individual, and iteration is both desirable and typically necessary. Such was the case for Southwest Coastal Louisiana; the initial model was developed by the project delivery team (PDT), stakeholders, and invited scientists and resource specialists in a workshop environment. Following an introduction in which the facilitators outlined the workshop objectives and described the process and intended product, the roughly 30 participants systematically expressed their opinions regarding the key model components. Facilitators organized the components into a rough model using a beta version of the CEMCAT and displayed the information on a projection screen. Attendees discussed relationships among the model components while facilitators took notes and represented relationships graphically. After approximately 6 hr, a rough draft model had been prepared and the meeting was adjourned.

Subsequent to the meeting, the authors compiled the notes in the form of a narrative to accompany the model diagram. They augmented the notes with additional information and literature citations, and prepared a draft of the document that is attached below. The authors also revised the figure developed during the workshop to better represent model components and linkages. This was accomplished using Microsoft PowerPoint rather than the beta of CEMCAT; the current version of CEMCAT has features that could more easily incorporate the revisions. The draft was circulated to the PDT for review and comment, and then revised by the authors.

**RESOURCE REQUIREMENTS:** Preparation for the workshop involved less than one man-week of effort by technical specialists and the Project Manager. As discussed, the workshop lasted 6 hr and involved roughly 30 individuals, and those outside the Corps were self-funded. Development of the model narrative and revisions to the model, including addressing comments from the PDT, required approximately one man-week of effort from each of two senior scientists. Collectively, the preparation and review of the attached model required about \$25 k - \$30 k, not

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<sup>1</sup> See Fischenich (2008) for additional details.

counting the contributions from non-Corps individuals participating in the workshop or providing review comments. Although the process was longer in this case due to scheduling conflicts, 3 or 4 weeks in actual time would typically be required to develop the CEM.

**EVALUATION:** The SW Coastal Louisiana CEM was conceived in a workshop environment as described above. Because the process of interaction among resource specialists is so important to the development of a useful CEM and to the establishment of a vision shared among the Corps and stakeholders, a workshop environment is recommended in the early stages of model preparation. The use of facilitators familiar with the project and possessing a deep understanding of the ecosystem significantly improves workshop flow and product quality. Preparation for the workshop can improve effectiveness given the limited time available to interact and produce a draft CEM. Useful preparatory actions include:

- Identify the preferred model type for the given need and distribute examples of that type CEM to participants ahead of the workshop to establish a common vision of the product.
- Develop a preliminary list of model components (drivers, stressors, processes, etc.,) that can expedite discussion.
- Ensure that facilitators are familiar with the ecosystem, understand key issues, and have access to and familiarity with CEMCAT (if used).
- Identify and define key terms or acronyms that might be a source of confusion to attendees and provide these prior to the meeting.
- Compile appropriate resources including maps and aerial imagery of the project site, information regarding historic conditions and change, any relevant studies or data, etc., and have this information available during meetings, should questions arise.
- Develop a questionnaire and have facilitators interview key personnel prior to the meeting to identify viewpoints and establish knowledge bases of attendees. This must be approached with care to avoid bias and undue influence.

The CEMCAT model has evolved considerably in scope and functionality since the workshop for the SW Coastal LA project. At the time of the workshop, its utility for capturing information and developing a model in real time was limited. Model enhancements make this much more streamlined now, and this tool should be useful in supporting such efforts. The process might be facilitated and simplified by developing a generic model (or models) within CEMCAT prior to the workshop. This generic model could be viewed by participants and serve as a starting point for discussions. The CEMCAT model is available at <http://cw-environment.usace.army.mil/eba/cemcat-detail.cfm?Option=Software>.

Model components within a CEM can often be appropriately expressed at different category levels depending upon the scale of analysis and the interdependencies among components in varying contexts. In other words, a component might be a stressor or a driver, an ecological effect or a stressor, etc., depending on how it is viewed. Allowing discussion of these issues is often important and useful, but part of the process will inevitably involve defining the appropriate model scale and the component characteristics. Developing more than one model (i.e. nested models) to reflect differing scales can be a useful way of tackling these issues. Multiple models (even at the same scale) might also be required in order to address different audiences. The attached example is by no means the only way of representing ecosystems. In fact, several other models have been

constructed describing important processes or sub-systems for the Chenier Plain in Louisiana. Examples of alternative depictions for this system can be found at: [http://www.clear.lsu.edu/conceptual\\_ecological\\_models/](http://www.clear.lsu.edu/conceptual_ecological_models/).

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# **Attachment**

## **Southwest Coastal Louisiana Feasibility Study**

### **Conceptual Ecological Model**

**February 2011**



**U.S. Army Corps of Engineers**  
**New Orleans District**  
**New Orleans, Louisiana**

**Coastal Protection and**  
**Restoration Authority of Louisiana**  
**Baton Rouge, Louisiana**

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## 1.0 INTRODUCTION

### 1.1 CONCEPTUAL ECOLOGICAL MODEL (CEM) DEFINITION

A conceptual model is a tentative description of a system or sub-system that serves as a basis for intellectual organization and represents the modeler's current understanding of the relevant system processes and characteristics (Fischenich 2008). These models, as applied to ecosystems (Conceptual Ecological Models or CEMs), should be simple, qualitative models, represented by a diagram which describes general functional relationships among the essential components of an ecosystem. CEMs typically document and summarize current understanding of, and assumptions about, ecosystem function. When applied specifically to ecosystem restoration projects, these models can be used as a basis for establishing the "Future-without Project Condition" and the benefits of proposed alternatives. To describe ecosystem function, a CEM usually diagrams relationships between major anthropogenic and natural stressors, biological indicators, and target ecosystem conditions.

A 2008 USACE Ecosystem Planning Center of Expertise White Paper on the certification of ecosystem output models recommended that conceptual models "be developed for all ecosystem restoration projects" (USACE 2008a). Further, they recommended that these models be reviewed as part of the normal ITR process and do not need certification". The 2008 Memorandum on Policy Guidance on Certification of Ecosystem Output Models (USACE) adopted this recommendation (USACE 2008b).

### 1.2 PURPOSE AND FUNCTION OF CONCEPTUAL ECOLOGICAL MODELS

Conceptual Ecological Models have been widely used in other regions of North America in planning several large-scale restoration projects (Rosen et al. 1995, Gentile 1996, Chow-Fraser 1998, Ogden and Davis 1999, Ogden et al. 2003). The same approach can be used for a variety of restoration scales as the elements of conceptual models are common. CEMs created for restoration programs/projects should include:

- Those physical, chemical, and biological attributes of the system that determine or express its dynamics;
- The ways in which ecosystem drivers, both internal and external, cause change, with particular emphasis on those aspects of the system where the proposed project can effect change;
- Critical thresholds of ecological processes and environmental conditions;
- Assumptions and gaps in the state of knowledge, especially those that limit the predictability of restoration outcomes or that relate to risk of unwanted outcomes; and
- Current characteristics of the system that may limit the achievement of planning objectives.

The USACE is using CEMs to provide assistance with ecosystem characterization, communication, plan formulation, and science, monitoring, and adaptive management. The CEM format utilized here follows a top-down hierarchy of information using the format established by Ogden and Davis (1999) (Figure 1). It should be noted that CEM development is an iterative process, and that CEMs developed for USACE projects during early plan formulation may be modified through the life of the project.

### 1.2.1 Model Components

The schematic organization of the CEM is depicted in Figure 1 and includes the following components:

*Drivers* - This component includes major external driving forces that have large-scale influences on natural systems. Drivers may be natural (e.g., eustatic sea level rise) or anthropogenic (e.g., hydrologic alteration) in nature.

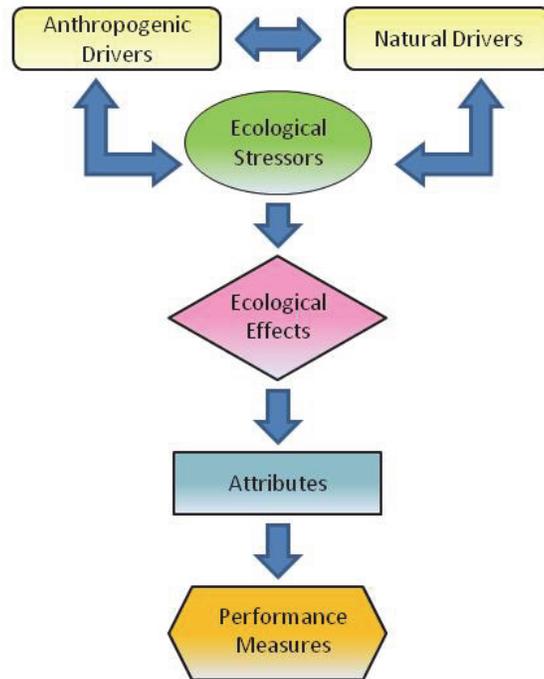
*Ecological Stressors* - This component includes physical or chemical changes that occur within natural systems, which are produced or affected by drivers and are directly responsible for significant changes in biological components, patterns, and relationships in natural systems.

*Ecological Effects* - This component includes biological, physical, or chemical responses within the natural system that are produced or affected by stressors. CEMs propose linkages between one or more ecological stressors and ecological effects and attributes to explain changes that have occurred in ecosystems.

*Attributes*- This component (also known as indicators or end points) is a prudent subset of all potential elements or components of natural systems representative of overall ecological conditions. Attributes may include populations, species, communities, or chemical processes. Performance measures and restoration objectives are established for each attribute. Post-project status and trends among attributes are measured by an appropriately scaled monitoring and assessment program as a means of determining success of a project or program in reducing or eliminating adverse effects of stressors.

*Performance measures* - This component includes specific features of each attribute to be monitored to determine the degree to which attribute is responding to projects designed to correct adverse effects of stressors (i.e., to determine success of the project).

This CEM does not attempt to explain all possible relationships or include all possible factors influencing the performance measure targets within natural systems in the study area. Rather, the model attempts to simplify ecosystem function by containing only information deemed most relevant to ecosystem monitoring goals.



**Figure 1.** Conceptual Ecological Model Schematic Diagram.

## 2.0 PROJECT BACKGROUND

### 2.1 PROJECT GOALS AND OBJECTIVES

The goal of the study is to formulate a comprehensive plan for Southwest Coastal Louisiana that provides hurricane and storm damage risk reduction and coastal restoration measures to achieve ecosystem sustainability. Specific objectives include:

- Reduce damages and economic losses from storm based flooding;
- Promote a sustainable coastal ecosystem by minimizing future land loss and enhancing wetland productivity;
- Provide and sustain diverse fish and wildlife habitats; and
- Sustain the unique heritage of coastal Louisiana by protecting historic sites and supporting traditional cultures.

The project area of the Southwest Coastal Louisiana study includes the Parishes of Cameron, Calcasieu, and Vermilion (Figure 2). This area includes approximately 4,700 square miles and a population of 117,100.



Table 1. Working Hypotheses

<b>NATURAL DRIVERS</b>	
Hurricanes and Storms	The storm surge associated with hurricanes and storms causes increased erosion and subsequently a direct loss of the ridge /Chenier barrier system.
	The storm surge associated with hurricanes and storms causes increased saltwater intrusion to the coastal system which results in reduced primary productivity.
	Increased frequency and intensity of hurricanes and storms results in fragmentation of and eventually loss of wetlands.
Relative Sea Level Rise	The combination of sea level rise and subsidence leads to an amplification of the tidal prism/amplitude which can result in wetland degradation and an eventual conversion to open water.
	The combination of sea level rise and subsidence over the long term leads to saltwater intrusion into areas that would otherwise be fresh or brackish. This will cause changes in the biological community composition and an eventual conversion of marsh habitat to open water.
	The combination of sea level rise and subsidence over the long term leads to marsh fragmentation and eventually loss of wetlands.
<b>ANTHROPOGENIC DRIVERS</b>	
Hydrologic Alteration	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have resulted in altered circulation patterns which have led to habitat conversion and changes in the biological community composition.
	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have resulted in an increased tidal prism/amplitude which has led to an increase in wetland loss.
	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have resulted in saltwater intrusion which has led to habitat conversion and changes in the biological community composition.
	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have caused an increase in flood duration which has led to habitat conversion and changes in the biological community composition.
	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have caused an increase in flood duration which has led to a reduction in primary productivity.
	Alterations in the natural hydrology of coastal Louisiana, including the creation of navigation channels and water control structures, have resulted in marsh fragmentation and eventually wetland loss.
Mineral/Sediment Extractions	Mineral and Sediment extractions from the Chenier Plain has resulted in a direct loss of the ridge and Chenier barrier system.

	Mineral and Sediment extractions from the Chenier Plain has resulted in an increase susceptibility to saltwater intrusion into areas that would otherwise be fresh or brackish. This will cause changes in the biological community composition and an eventual conversion of marsh habitat to open water.
	Mineral and Sediment extractions from the Chenier Plain has resulted in an increase susceptibility to storm surge from hurricanes and storms which could result in a direct loss of the ridge and Chenier barrier system.
Sediment Supply	A decrease in sediment supply due to alterations in the Mississippi River for flood control and navigation exacerbates shoreline erosion. This results in an increase in the loss of the ridge and Chenier barrier system and coastal wetlands.
	A decrease in sediment supply due to alterations in the Mississippi River for flood control and navigation contributes to the fragmentation and ultimately the loss of coastal marshes.

#### **4.0 CONCEPTUAL ECOLOGICAL MODEL**

The CEM developed by the team for the Southwest Coastal Louisiana Feasibility Study is presented below (Figure 3). The model depicts the series of working hypotheses formed by the team (Table 1), arranged in a conceptual diagram. Relationships expressed with thicker or bolder arrows are more certain than those represented by thinner arrows. Model components are identified and discussed in the following subsections along with further explanation of the relationships between the components.

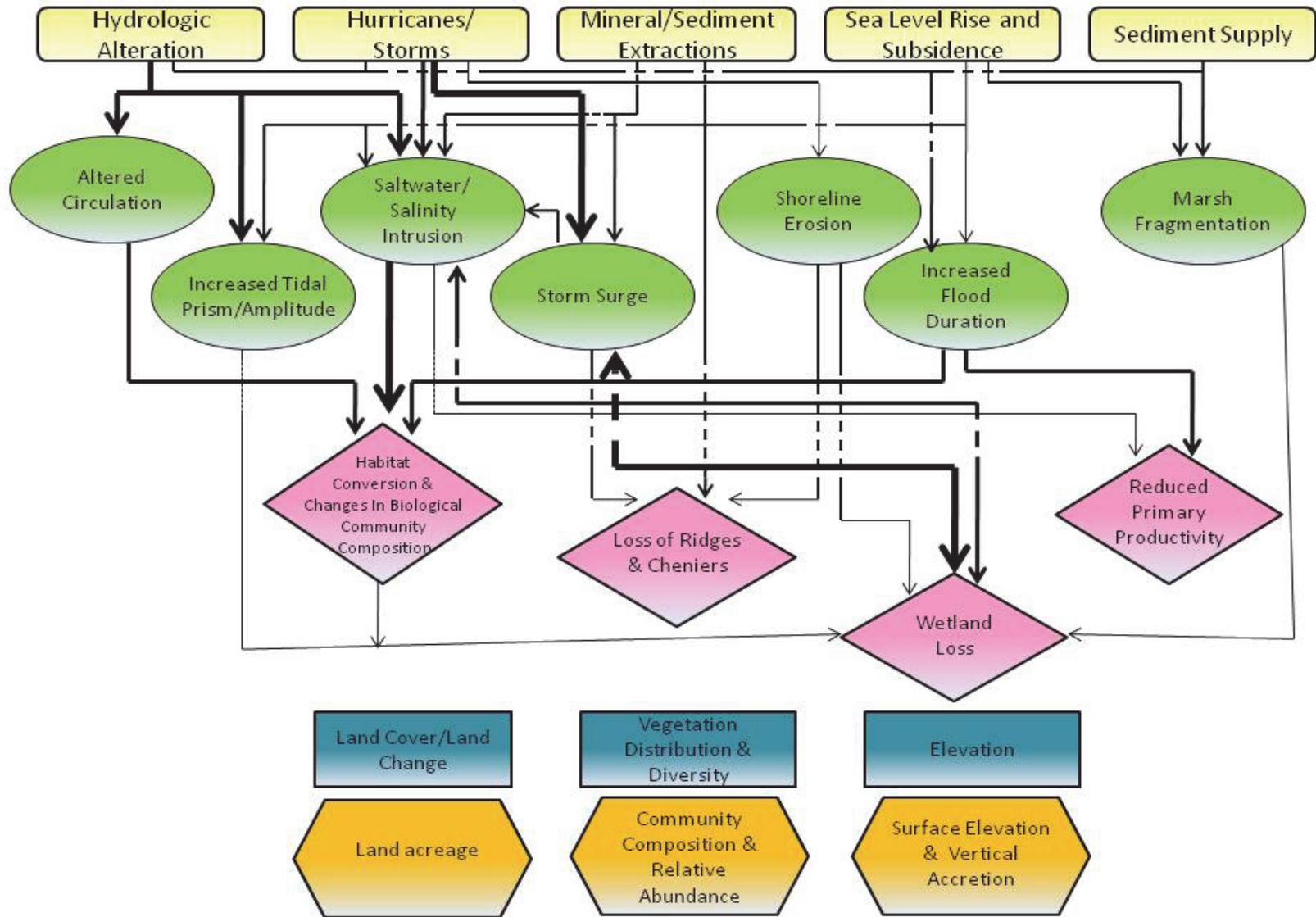


Figure 3. Southwest Coastal Louisiana Conceptual Model

## 4.1 DRIVERS

Drivers are the major external driving forces that have large-scale influences on Southwest Louisiana's coastal system. Anthropogenic drivers (e.g., hydrologic alteration) provide opportunities for finding relevant solutions to problems. For instance, hydrologic alterations can be undone through either temporary or permanent modification of channels and canals, and mineral/sediment extraction practices can be changed. Natural drivers, however, cannot be influenced directly; e.g. we cannot change the frequency or intensity of tropical storms or change how high or fast sea level rises. Some drivers are both anthropogenic and natural in nature. On a large, historical scale, sediment deposition has been determined by geological forces. On a local scale, sediments can be brought into the system from outside the system, or can be moved from where they are a hindrance (navigation channels) to where they are beneficial (marsh restoration sites).

The study team identified five main drivers that influence the project area on a large scale.

*D1: Relative Sea Level Rise (Sea Level Rise and Subsidence)*

*D2: Numerous Hurricanes and Storms*

*D3: Hydrologic Alteration*

*D4: Sediment Supply to the Chenier Plain*

*D5: Mineral and Sediment Extraction.*

### 4.1.1 Relative Sea Level Rise

Relative sea level rise (RSLR) consists of eustatic sea level rise combined with subsidence. Eustatic sea level rise is defined as the global increase in oceanic water levels primarily due to changes in the volume of major ice caps and glaciers, and expansion or contraction of seawater in response to temperature changes. The International Panel on Climate Change (IPCC) estimates that average eustatic sea level rise since 1961 has been 1.8 mm per year, and since 1993, 3.1 mm per year (IPCC 2007). Additionally, there is a projected rise between 182 and 610 mm in the next century (IPCC 2007). In coastal Louisiana, this rise in sea level is exacerbated by rapid changes in land elevation.

Subsidence is the decrease in land elevations due to compaction of Holocene deposits, consolidation of sediments, and faulting. Anthropogenic activities such as sub-surface fluid extraction and drainage for agriculture, flood protection, and development are also contributors to land elevation decreases. Forced drainage of wetlands results in lowering of the water Table resulting in accelerated compaction and oxidation of organic material. Areas under forced drainage can be found throughout coastal Louisiana and the study area. Each process produces a range of subsidence rates dependent on local environmental factors and each process occurs across a unique set of scales (Reed and Yuill 2009). The mean subsidence rate for coastal Louisiana is 11 mm (0.43inches) per year (Berman 2005).

This combination of sea level rise and rapid subsidence, as well as natural and man induced erosional processes, has resulted in extensive wetland loss in coastal Louisiana. Rates for RSLR along coastal Louisiana are currently estimated to be between 1 to 1.2 m/century (USACE 2004). These are the highest rates of RSLR along the contiguous United States.

RSLR affects project area marshes by gradually inundating marsh plants. Marsh soil surfaces must vertically accrete to keep pace with the rate of relative sea level rise. Changes in land elevation vary spatially along coastal Louisiana; however, in areas where subsidence is high and riverine influence is minor or virtually nonexistent, wetland habitats sink and convert to open water.

Land elevations increase as a result of sediment accretion (riverine and littoral sources) and organic deposition from vegetation. Vertical accretion in most of the study area, however, is insufficient to offset subsidence. The combination of subsidence and eustatic sea level rise is likely to cause the landward movement of marine conditions into estuaries, coastal wetlands, and fringing uplands (Day and Templet 1989; Reid and Trexler 1992).

#### **4.1.2 Hurricanes and Storms**

The Gulf Coast region is affected by tropical and extra-tropical storms. These atmospherically driven storm events can directly and indirectly contribute to coastal land loss through: 1) erosion and breaches from increased wave energies; 2) removal and/or scouring of vegetation from storm surges; and 3) storm induced saltwater intrusion into interior wetlands. These destructive processes can result in the loss and degradation of large areas of coastal habitats in relatively short periods of time (days and weeks versus years). Since 1893, over 130 tropical storms and hurricanes have struck or indirectly impacted Louisiana's coastline. On average, a tropical storm or hurricane affects Louisiana every 1.2 years. The most recent tropical cyclones to affect the study area were Hurricanes Katrina and Rita, which occurred in August 2005 and September 2005, respectively, and Hurricanes Gustav and Ike, which occurred in September 2008. Storm surge and wave fields associated with the 2005 storms eroded 527 km<sup>2</sup> of wetlands within the Louisiana coastal plain (Barras et al. 2008).

Hurricane Rita was the fourth-most intense Atlantic hurricane ever recorded and the most intense tropical storm ever observed in the Gulf of Mexico. The storm generated a surge of up to 5 meters in some areas, driving saltwater tens of kilometers inland and killing wetlands in artificially impounded areas. Rita made landfall between Sabine Pass, Texas and Johnson's Bayou, Louisiana causing extensive damage to Louisiana's southwest coastal parishes. Coastal communities in Cameron Parish were destroyed; the communities of Holly Beach, Hackberry, Creole, Grand Chenier, and Cameron were severely impacted. The Calcasieu Parish communities of Sulphur, Westlake, and Vinton also suffered significant damage and parts of the City of Lake Charles experienced 2 to 3 meter deep flooding associated with surge propagating up a ship channel. Six people lost their lives and 10,000 structures were flooded. Rita caused \$9.4 billion in damage along the Louisiana and southeastern Texas coasts.

Additional hurricane impacts to coastal environments can include sediment overwash, ripped and torn marsh, erosion of pond and lake margins, wrack (large amounts of plant debris) deposition, and lateral compression of marshes. Substantial sediment deposition associated with the passage of the storm can result in the burial of the pre-storm surface and the smothering of vegetation (Dunbar et al. 1992, Jackson et al. 1992). This same effect may occur as a result of burial by wrack. Extensive areas of marsh can be pushed against firm barriers (for example, levees and firmly grounded marsh) and can result in a ridge and trough

topography. Freshwater marsh species can experience a “burning” effect (aboveground portions of the plants are killed) if exposed to saline waters (Dunbar et al. 1992, Jackson et al. 1992, Stone et al. 1993, Stone et al. 1997). In some marsh zones, unconsolidated or weakly rooted marsh has been eroded. Storms and hurricanes, depending on strength and intensity, can also blow over, defoliate, and/or cause major structural damage to trees well beyond the coastal zone (Lovelace 1998).

#### **4.1.3 Hydrologic Alterations**

Hydrologic alterations, including navigation channels and water control structures, are the dominant sources of stress on the southwest Louisiana coastal system. These alterations cause disruptions in natural coastal hydrological processes, causing changes in circulation and tidal prism, and by increasing saltwater intrusion into the freshwater interior.

Altered hydrology is exacerbated by additional physical changes made in the watershed, which include canal, roads, and levees. Canals and associated spoil banks constructed for navigation and/or oil and gas development can be found throughout the project area. Canals impact wetlands by changing the normal hydrologic pattern. Canals deprive existing natural channels of water and allow more rapid runoff of water than the slower shallower natural channels do. This allows for greater fluctuation in the marsh and a lowering of the minimum water level, which dry the marsh (Mitsch and Gosslink 2000).

These hydrologic alterations have also led to increased coastal habitat fragmentation. Hydrologic connectivity in the Chenier Plain has been disrupted by several activities, most notably the creation of navigational channels, such as the Sabine/Neches Waterway, Calcasieu Ship Channel, GIWW, Mermentau Ship Channel, and Freshwater Bayou Canal Navigational channel, and the creation of water control structures, such as the Calcasieu and Leland Bowman locks, the Freshwater Bayou Canal Lock, the Schooner Bayou Canal Structure, and the Catfish Point Control Structure. These channels have disrupted the hydrology of the region by facilitating saltwater intrusion into the historic freshwater interior.

Water control structures were subsequently constructed to reduce saltwater intrusion into the interior, but these efforts further altered drainage patterns and have led to prolonged ponding of salt water following storm events (Swenson and Turner 1987). This excessive ponding in certain types of wetland habitats can kill the vegetative and result in eventual conversion to open water (Wang 1987, Flynn et al 1995). Near total mortality of marsh vegetation in many areas has been documented as a result of high salinity following storm surge. The effects of altered drainage also eliminate soil-building processes necessary to counteract subsidence and can cause secondary indirect impacts such as accelerating erosion rates along the channel and canal banks (USACE 2004, USACE 2010).

#### **4.1.4 Sediment Supply**

The Chenier Plain was developed as the result of the interplay of three coastal plain rivers (Sabine, Calcasieu, and Mermentau Rivers), cycles of Mississippi River Delta development, and the Gulf of Mexico. During periods of active Mississippi River delta building, Gulf of Mexico currents transported fine-grained sediments (clay and silt) in an east to west direction along the Louisiana coast. When delta formation occurred in shallow waters of bays or the inner continental shelf along the western reaches of the Deltaic Plain, longshore currents

carried the fine-grained sediment west in a mudstream towards the Chenier Plain. These sediments were then brought into coastal estuaries and marshes along the gulf shoreline by tidal processes and storms which were deposited along the shore to form mudflats (Gagliano and van Beek 1970). This newly formed land was colonized by wetland vegetation, which further promoted the land-building process. Wave action and occasional storm events also deposited sand and shells onto the newly built land.

Alteration of the Mississippi River for navigation and flood control now limits the delivery of sediments onto the continental shelf and, thus, the redistribution of those sediments westward through littoral processes., with wide-ranging secondary effects. However, since 1973, delta-building processes at the mouth of the Atchafalaya River have initiated a new interval of land building via the formation of extensive mudflats along the eastern part of the Chenier Plain.

#### **4.1.5 Mineral and Sediment Extraction**

The production, refinement, and transport of oil and gas have resulted in both short- and long-term negative environmental impacts to coastal Louisiana. Recent findings have indicated that oil and gas fluid withdrawal has resulted in regional subsidence and fault reactivation causing wetland losses in coastal Louisiana (Morton et al. 2005). This induced subsidence coupled with sea level rise can lead to elevation changes, increased flooding, and eventual habitat switching and loss.

Secondary impacts result from canal construction for oil and gas extraction and subsequent associated spoil banks (Jones et al 2002). These barriers limit the exchange of water, sediment, and nutrients between the water pathways and the marsh. Hydrologic barriers such as roads, levee, and culverts obstruct the flow of water and can modify inundation patterns on either side of the barrier (Harvey et al 2010).

## **4.2 ECOLOGICAL STRESSORS**

### ***Ecological Stressors***

*ES1: Increased Flood Duration*

*ES2: Storm Surge*

*ES3: Saltwater/Salinity*

*ES4: Shoreline Erosion*

*ES5: Marsh fragmentation.*

*ES6: Increased Tidal Prism or Amplitude.*

*ES7: Altered Circulation*

#### **4.2.1 Increased Flood Duration**

Hydrologic modifications in the project area, especially the construction of roads, levees, and other similar features, have altered normal drainage patterns. This had led to a condition whereby flood durations are increased in many wetland areas. This is especially problematic in the wake of a hurricane, when highly saline storm surge waters are impounded for long periods, causing stress and eventual loss of the affected wetland communities.

#### **4.2.2 Storm Surge**

Tropical cyclone events exert a stochastic but severe stress upon the swamp habitat through salinity spikes associated with saline storm surge events. The introduction of saline storm surge water into impounded areas results in reduced biomass production and impaired health, which in turn causes increased vegetation mortality, decreased soil production and integrity, and a consequent increase in relative subsidence. Saline storm surge waters become impounded by the spoil banks, roads and levees in the area. Consequently, these periodic influxes of saline storm surge waters result in cumulative increases in salinity in impounded waters and soils in the study area. Saltwater introduction into freshwater wetlands has been demonstrated to reduce productivity for short-term periods and cause the loss of wetland vegetation altogether for longer periods of inundation.

The elevation of the storm surge within a coastal basin depends upon the meteorological parameters of the hurricane as well as the physical characteristics existing within the basin. The physical factors include the basin bathymetry, roughness of the continental shelf, configuration of the coastline, and the existence of significant natural or man-made barriers. With the loss of marsh and chenier features, storm surge can become larger at points further inland, including areas of dense development.

While the study area has periodically experienced localized flooding from excessive rainfall events, the primary cause of the flooding events has been the tidal surges from hurricanes and tropical storms. During the past eight years, the planning area has been greatly impacted by storm surges associated with three Category 2 or higher hurricanes—Lili, Rita, and Ike, which inundated structures and resulted in billions of dollars in damages to southwest coastal Louisiana.

Hurricane surge also causes significant damage to wetlands. Hurricane surge has formed ponds in stable, contiguous marsh areas and expanded existing, small ponds, and it has removed material in degrading marshes (Barras 2009). Fresh and intermediate marshes appear to be more susceptible to surge impacts (Barras 2006, Howes et al. 2010).

#### **4.2.3 Saltwater/Salinity Intrusion**

Salinity levels decline along a gradient as the saltwater moves inland from the Gulf of Mexico. Distinct zones of plant communities or vegetative habitat types, differing in salinity tolerance, exist along that gradient, with the species diversity of those zones increasing from salt to fresh environments. Saltwater intrusion changes the salinity gradient, which results in habitat changes.

The combined effects of hydrologic alterations and hurricanes in the near term as well as sea level rise and subsidence over the long term lead to saltwater intrusion into areas that would otherwise remain fresh or intermediate.

Decreased freshwater inputs and increased channelization allows tidal water to intrude farther upstream, causing significant damage to freshwater wetland systems and changing freshwater wetlands to brackish or saline marshes. This is the principal factor in the conversion of freshwater systems, and in extreme cases salt intolerant vegetation cannot

replaced the freshwater species before the marsh converts to open water (Mitsch and Gosslink 2000, Flynn et al. 1995).

Changes to the salinity gradient are caused by a number of factors, including: the construction of levees, man-made channels, and canals, and degraded wetland areas. Tropical storm events can introduce saltwater into fresher areas, damaging large amounts of habitat in a short period of time.

#### **4.2.4 Shoreline Erosion**

Shoreline erosion is a normal consequence of natural tidal processes, wind generated waves, and surge from storm events, but can be accelerated by marsh breakdown and stress from other factors such as saltwater intrusion, flooding, and relative sea level rise. When these natural causes are combined with man-made activities (navigation/access channels), inland areas are subjected to more dramatic tidal forces and wave action, increasing erosion.

In the past 100 years, the total barrier island area in Louisiana has declined 55percent at a rate of 155 acres per year (Williams et al. 1992), largely due to storm overwash and wave erosion. In many ways the bays and lakes and the banks of canals and streams are even more vulnerable to erosion than the barrier islands. The Louisiana coast has approximately 350 miles of sandy shoreline along its barrier islands and gulf beaches; however, there are about 30,000 miles of land-water interface along bays, lakes, canals, and streams. Most of these consist of muddy shorelines and bank lines, and virtually all are eroding. In many instances, rims of firmer soil around lakes and bays and natural levees along streams have eroded away leaving highly organic marsh soils directly exposed to open water wave attack.

#### **4.2.5 Increased Tidal Prism or Amplitude**

Tidal currents in Louisiana are relatively small, due to the small tidal amplitude. In the absence of wind, density effects and barometric pressure gradients, these currents reach magnitudes of approximately 10 – 15 cm/s (0.3 - 0.5 ft/s). Although small in magnitude in open coastal waters, tidal currents can reach speeds of approximately 50 cm/s (1.7 ft/s) at estuary and barrier island inlets, depending on the inlet dimensions. Generally, tidal exchange between back-barrier bays and the Gulf of Mexico has increased along the delta plain since at least the 1880s due to widespread conversion of wetlands and salt marsh to open water areas.

#### **4.2.6 Altered Circulation Patterns**

Circulation of coastal waters depends on driving forces such as tides, wind, and atmospheric pressure. Along the complex Louisiana coast, circulation mechanisms go beyond these driving forces to include high rainfall; the large volume of fresh water introduced by the Mississippi and Atchafalaya Rivers; currents induced by density differences and mixing processes of these two masses of water; and local shoreline and bathymetric features such as the Mississippi River mouth, barrier islands, marshes, inlets, bays, and so forth. More locally, the loss of wetlands coupled with the effects of canals, ridge gapping, and other landscape alterations can significantly alter circulatory patterns.

#### **4.2.7 Marsh Habitat Fragmentation**

Habitat fragmentation is the disruption of continuous blocks of habitat into less contiguous habitat. Climate change, hydrologic alterations, and diminishing sediment supply

individually in combination cause coastal degradation and habitat fragmentation in Louisiana. These impacts are frequently worsened by human intervention at various scales.

Two components of climate change that will continue to affect ecosystem connectivity are sea level rise and the increased frequency and intensity of storm events (Hitch and Leberg 2008). Impacts are and will continue to be exacerbated by human activities that have modified water and sediment delivery from watersheds to the coastal systems. Relative sea level rise is the key factor contributing to the fragmentation of coastal marshes, however. Inundation, resulting from sea level rise and subsidence, cause conversion of vegetated surfaces to open water thus decreasing the amount of available wetland habitat.

Marshes of the project area provide habitat and a food source for fish and wildlife species. Marsh loss implies an imbalance between sea level and marsh accretion rates. The primary factor in the latter is a decrease in or lack of sediment supply (Blum and Roberts 2009). Additionally, dredging of channels has increased water depths thereby strengthening tidal currents, enhancing erosion, and trapping sediments that would otherwise be deposited on the marsh surfaces in deeper areas.

### 4.3 ECOLOGICAL EFFECTS

#### *Ecological Effects*

*EE1 Wetland Loss*

*EE2 Decreased Primary Productivity*

*EE3 Habitat Conversion and Changes in Biological Community Composition*

*EE4 Loss of Ridges and Cheniers.*

#### **4.3.1 Wetland Loss**

Wetland loss in the project area due to vegetation changes can be the result of gradual decline and eventual complete loss of marsh vegetation due to inundation and saltwater intrusion, or it can result suddenly from storm surge events. As marsh vegetation is lost, underlying soils are more susceptible to erosion and are typically lost as well, leading to deeper water and precluding marsh regeneration. Significant accretion of sediments is then required in order for marsh habitat to reestablish.

The accelerated loss of Louisiana's wetlands has been ongoing since at least the early 1900s with equal harmful effects on the ecosystem and possible future negative impacts to the economy of the region and the Nation (LCA 2004). The LCA Study (2004) estimated coastal Louisiana would continue to lose land at a rate of approximately 6,600 acres per year over the next 50 years. It is estimated that an additional net loss of 328,000 acres may occur by 2050, which is almost 10 percent of Louisiana's remaining coastal wetlands.

Wetland degradation and loss are the result of both natural factors and anthropogenic activities, producing conditions where wetland vegetation can no longer survive and wetlands are lost (Barras et al. 2003, Barras et al. 1994; Dunbar et al. 1992). These factors have been described at length above. Perhaps the most serious and complex problem in the study area is the rate of land and habitat loss. The Louisiana coastal plain contains one of the largest expanses of coastal wetlands in the contiguous United States and accounts for 90 percent of

the total coastal marsh loss in the nation (USACE 2004). Across much of the Louisiana coast, wetland loss and shoreline erosion continue largely unabated, resulting in accelerated coastal land loss and ecosystem degradation.

#### **4.3.2 Reduced Primary Productivity**

Decreased productivity in vegetative communities in the study area is thought to be a biological response to the lack of nutrients and sediment inputs, and saline stress from flooding following storm surge.

There has been a reduction in frequency of nutrient and sediment rich water pulses into and across the wetlands as a result of flood protection and water control structures, and channelization for navigation and oil and gas infrastructure. Instead, the nutrient rich water is delivered directly into the coastal bays or into the Gulf of Mexico, and often as a result, coastal wetlands lack the required nutrients necessary to maximize productivity. Increased productivity results in higher organic soil formation, which then leads to increased stem densities, sediment deposition, and vertical accretion.

Salinity-induced stress decreases primary production and biomass in freshwater marshes (Smart and Barko 1980, Linthurst and Seneca 1981, Pezeshki et al 1987, McKee and Mendelsohn 1989, Spalding and Hester 2007) and therefore organic matter production and vertical accretion rates are compromised following saltwater intrusion. Maintaining a balanced position in the coastal landscape requires that marshes accrete vertically as sea level rises and the marsh surface sinks because of subsidence. In coastal Louisiana, the amount of sedimentation required to keep pace with sea level rise is high compared to other regions of the United States (Stevenson et al. 1986).

#### **4.3.3 Habitat Conversion and Changes in Biological Community Composition**

Habitat conversion can be the result of several drivers acting independently or collectively. The conversion of habitat (especially from land to open water) can make an area more susceptible to storms and erosion as well as altering the type of fauna expected to occur in the area. Freshwater marsh can be susceptible to saltwater intrusion. The effects of invasive species can damage or displace native vegetation.

Coastal marshes also provide habitat for a variety of vertebrate wildlife including fish, birds, mammals, and reptiles. Teal (1986) stated that one of the most important functions of coastal marshes was to provide habitat for migrant and resident bird populations. Some wildlife species inhabiting tidal marshes are also important game animals, valuable furbearers, and provide recreational opportunities for birdwatchers, nature enthusiasts, and wildlife photographers (USACE 2010).

The majority of species that utilize the wetlands have neither commercial nor recreational value, but simply are ecologically important members of the ecosystem. Many of the organisms that use the marsh ecosystem are highly mobile and serve as a transfer mechanism for nutrients and energy to adjacent terrestrial or aquatic ecosystems. Some of the larger vertebrates, including the muskrat and nutria, consume large amounts of forage and, at high densities, can have significant impacts on marsh vegetation structure (USACE 2008).

Tidal marshes provide forage habitat, spawning sites, a predation refuge, and a nursery for resident and nonresident fishes and macrocrustaceans. These organisms use tidal marshes or adjacent subtidal shallows either year round or during a portion of their life history. These organisms are consumed by nektonic and avian predators and are considered to represent an important link in marsh-estuarine trophic dynamics (USACE 2008).

#### **4.3.5 Loss of Ridges and Cheniers**

The Chenier Plain of SW Louisiana consists of multiple shore-parallel, sand rich ridges that are balanced on and physically separated from one another by relatively finer grain, clay-rich sediments. Cheniers are unique and critical components of the local environment. They support diverse wildlife and, because of their location along important migration pathways, are especially significant for migrating birds, as well as providing natural protection against salt water intrusion, storm surge, and flooding (Providence Engineering Group, 2009).

Formed over thousands of years by the deltaic processes of the Mississippi River and other streams, the chenier ridges of southwest Louisiana run laterally to the modern shoreline and rise above the surrounding marshes ( Gould and McFarlan 1959, Byrne et al. 1959). These ridges range from 2 to 15 ft thick and from 100 to 1,500 ft wide, with some ridges extending along the coast for a distance of up to 30 miles. Live oak and hackberry are dominant canopy species, and others common species are red maple, sweet gum, water oak, green ash, and American elm.

Cheniers have been severely impacted by human activities such as deforestation for conversion to cattle pasture or development. They have also been threatened by coastal erosion and wetland loss resulting from salt water intrusion, subsidence, hurricanes, debris from oil and gas infrastructure by storms, navigation channels, and invasive species.

### **4.4 ATTRIBUTES AND PERFORMANCE MEASURES**

#### **Attributes and Associated Performance Measures**

##### *A1 Land Cover/ Land Change*

*Performance Measures: Relative Change in Land Cover*

##### *A2 Vegetation Distribution and Diversity*

*Performance Measures: Community Composition and Relative Abundance*

##### *A3 Elevation*

*Performance Measures: Surface Elevation and Vertical Sediment Accretion*

#### **4.4.1 Land cover**

Land cover has been identified as a key indicator of project success with respect to preventing habitat conversion and future land loss. Comparison of pre-project land cover characteristics with post-project land cover characteristics would serve to determine if the current trend in habitat conversion and land loss within the study area experiences a post-project decline or ceases altogether. Additionally, post-project land cover analysis would determine if areas within the study area that had previously gone through a conversion undergo post-project recovery.

Spatial analysis has been identified as an appropriate assessment tool for the determination of the response of land cover to the proposed project. Spatial analysis generally involves comparative analysis of pre- and post-project aerial or satellite imagery to determine relative changes in land cover within the study area. Some challenges persist with discriminating vegetation types using remote imagery alone, and field verification might be required.

#### **4.4.2 Vegetation Distribution and Diversity**

Plant distribution and diversity has been identified as a key indicator of project success with respect to preventing, reducing, or reversing wetland loss in the study area. Comparison of pre-project vegetation monitoring data with post-project vegetation monitoring data would serve to determine if plant communities within the study area change in response to project actions and features.

Relative abundance is a measure of the abundance or dominance of each species present in a sample. Relative abundance can be used to document the degree of impact in an area by measuring both species dominance and evenness. Relative abundance can be used to assess ecosystem health by comparing plant density before and after project implementation. The Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) as described in Steyer et al. (1995) will be utilized to measure relative abundance.

Post-project stabilization of relative abundance within the study area would be an indication of significant project success, while a post-project reduction in the rate of decline of relative abundance would be an indication of moderate project success. Conversely, no change in the rate of decline of relative abundance post-project would indicate that the project did not succeed in increasing vegetation productivity.

#### **4.4.3 Elevation**

Ground surface elevation has been identified as a key indicator of project success with respect to increasing sediment and nutrient load within the study area. Comparison of pre-project elevations with post-project elevations would serve to determine if sediment input and soil accretion is occurring within the study area in response to project features. A post-project decrease in the rate of elevation decline would implicitly indicate the introduction of nutrients and sediment into the marshes as a result of the project. Two performance measures have been identified for this attribute, including surface elevation table (SET) measurements and feldspar marker horizon measurements.

Surface Elevation Table (SET) measurements provide a constant reference plane in space from which the distance to the sediment surface can be measured by means of pins lowered to the sediment surface. Repeated measurements of elevation can be made with high precision because the orientation of the table in space remains fixed for each sampling. Elevation change measured by the SET is influenced by both surface and subsurface processes occurring within the soil profile.

Feldspar marker horizon measurements involve the placement of a cohesive layer of feldspar clay on the ground surface. Soil borings are extracted at the marker horizon location periodically to measure the amount of soil deposition and/or accretion that has occurred above the horizon since placement. Significant quantities of soil atop marker horizons are

indicative of soil building within the area, which in turn indicates an increase in relative elevation. A post-project stabilization of elevation as evidenced by SET measurements or documented soil accretion atop a marker horizon within the study area would be an indication of project success, while a post-project decrease in the rate of decline in elevation would be an indication of moderate project success. Conversely, no change in the rate of elevation decline post-project within the study area would indicate that the project did not succeed in offsetting subsidence and, by extension, habitat conversion and future land loss.

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