SYSTEM-WIDE ASSESSMENT AND MONITORING PROGRAM (SWAMP) FRAMEWORK

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BACKGROUND

The State of Louisiana and its partners have allocated considerable resources and have made long-term commitments to the restoration and management of wetland and aquatic resources in the coastal zone. Early project-specific monitoring efforts through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) program in the early 1990s quickly became challenging as adequate reference areas were difficult to identify, and monitoring parameters were not consistent among projects. As a result, CWPPRA developed the Coastwide Reference Monitoring System-*Wetlands* (CRMS-*Wetlands*) to address these challenges and provide a pool of reference sites by which to evaluate the effectiveness of individual projects, effectiveness of the overall program, and to provide a means to assess overall landscape change.

Although CRMS-*Wetlands* provides valuable data on wetlands, a more comprehensive, systematic monitoring program is needed to satisfy the state's coastal protection and restoration modeling and assessment needs. In 2005, the Louisiana Coastal Area (LCA) study proposed expanding CRMS-*Wetlands* to the System-Wide Assessment and Monitoring Program (SWAMP). The proposed expansion was expected to include programmatic monitoring of barrier islands implemented by CPRA under the Barrier Island Comprehensive Monitoring Program (BICM) and be an extension of monitoring estuarine to open water areas.

CPRA has recognized that going forward, SWAMP must be expanded to include the elements described above and to ensure that it satisfies all the monitoring needs of the coastal protection and restoration program. WI, with guidance and input from CPRA, was tasked to develop a monitoring and assessment framework to outline the components of a coastwide monitoring system that will be needed to support the state's coastal protection and restoration program. The framework presented here identifies the important parameters needed to support the restoration and protection program and to document the overall ecological condition of the coastal system. The parameters and their role within the framework shown in Appendix 1 is described in a series of tables grouped to simplify access the definitions.

THE NEED FOR COASTWIDE MONITORING

Monitoring is an integral component of large-scale landscape management programs to improve the understanding of the system's state and track the system's response to management interventions. Although it is frequently discussed in terms of ecosystem management (Lyons et al. 2008; Williams 2011), monitoring of social, economic and physical aspects of systems is also critical where management addresses issues beyond the ecosystem to more fully understand interdependencies among ecosystem, social, and economic dynamics. For example, program goals may include providing protection from flooding or other natural disasters for communities and would thus require data collection efforts targeting specific protection measures, communities' characteristics, etc. Whether for restoration or protection programs, well-designed monitoring programs are essential for adaptive management to support future management decisions. In order for monitoring to be effective in the context of decision making, there must be a strong connection between the monitoring design and decision structure (Lyons et al., 2008). Consequently, managers must anticipate how monitoring information will be used and be engaged in identifying key indicators as well as defining the indicators' roles in the decision process (Lyons et al., 2008; Nichols & Williams, 2006). In addition to decision making, long-term data are also useful for evaluating responses to climate change, providing baseline data, improving biological understanding, and comparing against model-based predictions (Lindenmayer & Likens, 2009; Nichols & Williams, 2006).

The State of Louisiana, through CPRA, is tasked with planning, designing, and implementing coastal protection and restoration projects for the coastal system. CPRA responsibilities include project planning, engineering and design, construction, operations, maintenance, and monitoring of coastal restoration and protection projects, as well as damage assessments. The wide-ranging responsibilities of CPRA require a variety of data collection and assessment efforts. While the ongoing monitoring and assessment of wetland systems and barrier islands through CRMS-*Wetlands* and the BICM, respectively, has proven to be of value, other aspects of system dynamics, including offshore and inland water-body boundary conditions, nontidal freshwater habitats, riverine conditions, risk status, and protection performance, are not presently the subject of the coordinated monitoring program. In addition, monitoring of some key aspects of the system is undertaken by other agencies or entities. A collaborative framework for monitoring can help avoid duplication, leverage limited funding, and ensure support for long-term data collection.

SWAMP has been conceived to ensure a comprehensive network of coastal data collection activities to support the development, implementation and management of the coastal protection and restoration program. The SWAMP framework for data collection presented here focuses on CPRA's portfolio of interests, and needs to be routinely reassessed to ensure it supports efficient program operations and is responsive to changing coastal conditions. Once SWAMP is fully functional it will support CPRA's mission by providing support for evaluating project and program performance, data for detecting system change, and information for damage assessments, flood risk management, and modeling.

The SWAMP framework for systems monitoring is designed to enable efficiency in data collection and use, consistency across CPRA programs, leveraging of existing data collection activities, and transparency in assessment of CPRA and other coastal activities. Data management will be essential to ensure the utility of SWAMP and to ensure data needed for Adaptive Management (AM) and other purposes can be obtained. A fully functioning SWAMP would support CPRA activities by providing data that could be used to:

- document the drivers (natural and anthropogenic) and their effect on the system;

- provide early warning indication of changes in the system state;
- monitor the effects of natural or anthropogenic disasters;
- reduce uncertainties regarding changing conditions or system state;
- evaluate performance of coastal protection and restoration programs and projects;
- improve, validate, and calibrate numerical models;
- support planning, engineering, and designing activities.

This document provides a framework for identifying the important parameters needed to support the restoration and protection program and to understand the overall system condition.

APPROACH

Identifying the parameters needed to understand system dynamics requires acknowledgement of what causes change to the system. An influence diagram approach was employed to illustrate how the main drivers of system change influence specific system characteristics and identify the key parameters required to understand system change. The diagrams are designed to illustrate general relationships between drivers and system responses and are not intended to serve as comprehensive conceptual models. This approach does function as a guide for identifying important key parameters (e.g., those that reflect a number of system change mechanisms) and understanding in a holistic sense the potential impacts on system dynamics from a variety of drivers. Influence diagrams were developed separately for the restoration and protection monitoring frameworks, although common drivers exist between the two. For the restoration monitoring framework, drivers were grouped into two broad categories: system processes and human activities (Figure 1). System processes include geological processes, surface water and groundwater inputs, and atmospheric and oceanic processes. Human activities include restoration activities—as proposed in the 2012 Coastal Master Plan—and ecosystem utilization. For the protection monitoring framework, the focus was on drivers that influence risk for the coastal environment including flooding threats (i.e., physical processes similar to those identified in the restoration framework), defenses, and community and asset vulnerabilities (Figure 2). Physical processes are system attributes that can impact flooding threats, such as geological, atmospheric, and oceanic processes. Defenses are measures undertaken to reduce flooding risk and include structural features and nonstructural approaches. Vulnerabilities refer to community assets and strategic infrastructure that are at risk for flooding from storm events.

The SWAMP framework was not designed to be an inventory of all existing monitoring efforts. Concurrent with the framework was the development of a monitoring inventory that is designed to catalog active, long-term monitoring efforts along the coast[1]. Since the framework provides details of which parameters need to be monitored to detect change within the coastal system, it can then be matched with the inventory to identify where there are unmet needs and how future monitoring initiatives can be informed by existing monitoring efforts. The next steps on accomplishing this integration is described in the Path Forward.

[1] For more information on the System-wide Assessment and Monitoring Program Geographic Information Systems Data Inventory, contact info@thewaterinstitute.org.

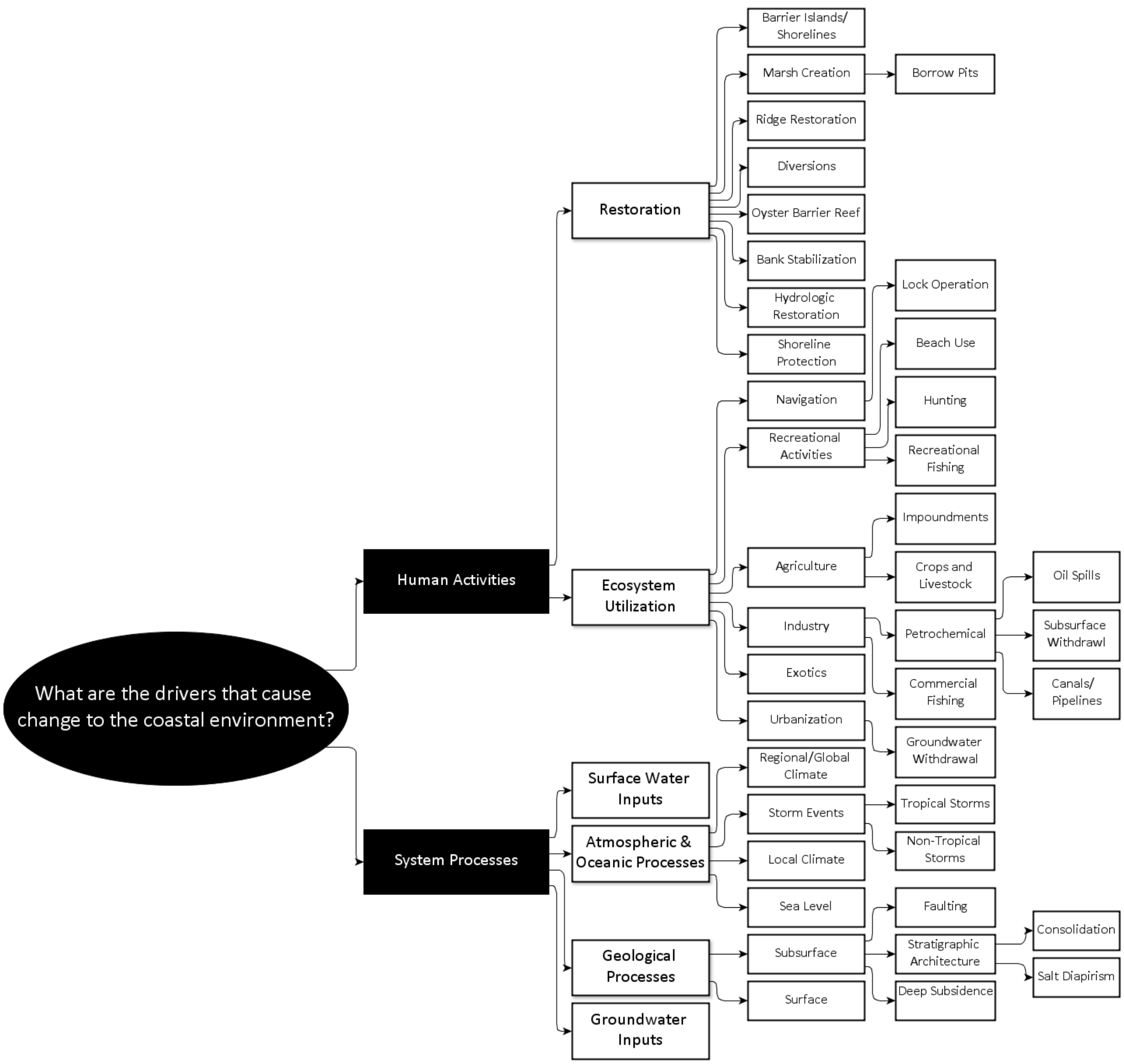

Figure 1. Drivers of coastal change identified for the restoration framework.

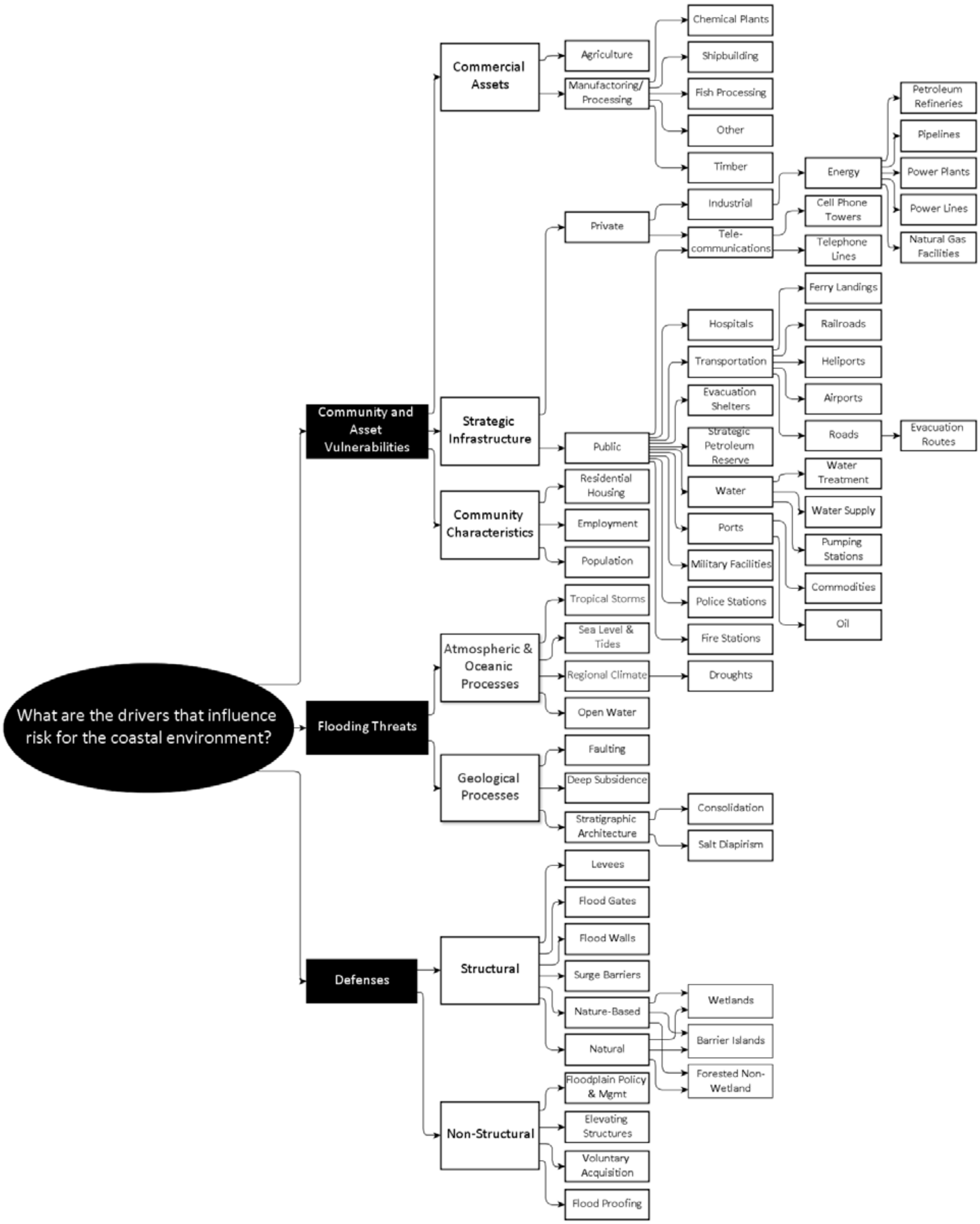

Figure 2. Drivers of coastal change identified for the protection framework.

RESTORATION AND PROTECTION MONITORING FRAMEWORKS

The monitoring frameworks focus on ecosystem and built-system responses to system dynamics, management interventions, and human activities. The scope of the framework covers the Louisiana coastal zone and immediate boundary areas. The 2012 Coastal Master Plan objectives were used as a guide in generating the key parameters, and as a result, the restoration framework's primary focuses are landscape and higher trophic dynamics, while the protection framework's focus is risk reduction from storm surge flooding. The drivers of system change identified as relevant to coastal restoration and protection are explained below. Atmospheric/oceanic and geological processes were included in both the restoration and protection framework but are only described once in this section. The parameters needed to track the system response to these drivers are provided in table format in the succeeding sections. The full diagram is provided in Appendix I.

DRIVERS OF SYSTEM CHANGE

Atmospheric and Oceanic Processes

Atmospheric and oceanic processes serve as drivers of coastal environmental change through their generation of weather, as defined by climatic variables, and extreme weather events, e.g., storms, as well as through control of oceanic boundary conditions, e.g., waves and currents. Atmospheric and oceanic processes also affect sea level over long time periods by causing eustatic sea level rise, and over shorter periods during storm surges. These processes affect local weather patterns by influencing the hydrological and energy balance through the introduction of precipitation and solar heat (Wallace & Hobbs, 2006). Local gradients in temperature—controlled by the insolation and radiation of heat energy—create wind such as land-sea breezes. Atmospheric and oceanic processes play a role in regional/global climate by creating, in part, persistent atmospheric circulation cells and jet streams which are responsible for the movement of large air masses at the continental spatial scale. These same atmospheric circulation patterns also help drive large-scale oceanic circulation patterns. In the Gulf of Mexico, circulation is primarily driven by warm easterly winds (Elliott, 1982).

Geological Processes

Geological processes drive environmental change at a range of spatial and temporal scales throughout coastal Louisiana, both on the surface and in the subsurface. The important subsurface processes are faulting, crustal flexure (e.g., deep subsidence), salt diapirism, and sediment consolidation (Morton et al., 2002; Yuill et al., 2009). These processes are governed by the spatial distribution of the production and release of geopressure, which originates from crustal dynamics or sediment loading, and the stratigraphic architecture of the regional subsurface environment (Jones, 1969; Jackson & Talbot, 1986). Stratigraphic architecture refers to the composition and spatial distribution of the subsurface material (i.e., basement rock and sedimentary deposits). The character of this material within a location dictates how influential a geological process may be at that location. For example, density controls how buoyant a material may be within the surrounding material or how compressible it is under a set load through time. In coastal Louisiana, subsurface geologic processes may produce subsidence, which is an influential process of environmental change that leads to increased relative sea level rise and wetland land loss (Gagliano et al., 1981).

Surficial geological processes in coastal Louisiana generally include the erosion, transport, and deposition of sedimentary material; surface exposure of pre-Holocene deposits is rare in coastal

Louisiana. These processes are driven by flowing water (including river flows, currents, tides, and waves) or wind and result in the lowering or raising of the elevation of earth's surface.

Surface Water and Groundwater Inputs

The flow of water into coastal Louisiana has an important influence on its morphology and ecosystem condition. Flowing water on the earth's surface (surface water) and within the subsurface (groundwater) is a primary mode of transport for nutrients and pollutants. Overland flow flushes nutrients and pollutants into channelized flow—rivers and canals—from nonpoint sources. When surface water infiltrates the soil and becomes groundwater, it will often transport the contained constituents into the groundwater.

The amount of surface water flowing into the system plays a direct and obvious role in the amount of water available for plant and animal consumption and utilization. Overland flow and channelized (i.e., river) flow entrain sediment and play import roles in soil erosion and aggradation and water turbidity. Over long periods, the amount of flow in an area controls the evolution of river networks and landscape denudation rates.

Ecosystem Utilization

Recreational and economically important activities are widespread across the coast and result in various types of coastal change. Beach use, hunting, and recreational fishing are common activities that have implications for fish and shellfish, wildlife, and barrier island/shoreline habitats. Agriculture and industries, including petrochemical and commercial fishing, are important drivers of change for coastal habitats, fish, and wildlife. Navigation—including lock operations—affects hydrologic patterns and river channels. The introduction of exotics, such as water hyacinth, zebra mussel, and Chinese tallow, have the potential to wreak havoc on the environment by out-competing native organisms, clogging waterways, or destroying habitats[2]. In addition, urbanization has important implications for the quantity and quality of both surface water and groundwater inputs.

Restoration

The 2012 Coastal Master Plan included approximately 95 restoration projects that were grouped into nine categories: barrier island/headland restoration, hydrologic restoration, marsh creation, oyster barrier reefs, ridge restoration, sediment diversion, channel realignment, bank stabilization, and shoreline protection. The goals of these projects were to build, sustain, and maintain land, restore hydrologic patterns, stabilize shorelines, and/or attenuate wave energies. In addition, these projects are also designed to meet the overall objectives of the master plan, which included providing suitable habitats for an array of commercial and recreational activities and harnessing the natural processes of the system to promote a sustainable ecosystem (CPRA, 2012).

Defenses

The 2012 Coastal Master Plan included approximately 15 structural measures. Structural measures include earthen levees, concrete flood walls, flood gates, and pumps. The U.S. Army Corps of Engineers (USACE) also proposed surge barriers and nature-based and natural features to reduce flood risk (USACE, 2013). The 2012 Coastal Master Plan also included a coastwide nonstructural program.

[2] http://is.cbr.tulane.edu/index.html

Nonstructural measures refer to activities that do not interfere with the flow of water. These measures are typically related to elevating or flood-proofing homes and businesses, land use planning, upgrades to building codes, and public education. The protection measures collectively included in the 2012 Coastal Master Plan are designed to the meet the objectives of reducing economic losses from storm-surge flooding, sustaining the cultural heritage of the region, and providing a viable working coast (CPRA, 2012).

Community and Asset Vulnerabilities

Hijuelos and Reed (2013) identified socio-economic performance measures to support the development of report cards and AM. The performances measures were related to supporting a resilient community, encouraging a robust and resilient economy, improving quality of life, and reducing flooding and storm surge damages. These measures require monitoring of community characteristics related to population, employment, and residential housing. Vulnerable assets are strategic infrastructure and commercial assets vital to sustaining the community and/or economy. Strategic infrastructures include utilities, emergency facilities, and transportation, while commercial assets include manufacturing, processing, and agricultural businesses.

Parameters Influenced by Drivers

A set of parameters were identified as necessary to track the system's response to drivers of change using professional judgment and examination of previous reports and monitoring efforts. Approximately 100 parameters were identified for the restoration framework and 35 parameters for the protection framework. Parameters are measurable attributes of the system and do not included indices, ratios, classifications, or other types of calculations that are performed on raw datasets. For organizational purposes, the restoration parameters were placed into one of the following categories: atmospheric, land, water, river, groundwater, fish and wildlife, and intermediate responses (Tables 1-7). The protection parameters were organized into: flooding threats and defenses, and strategic infrastructure and commercial assets (Tables 8-9). The tables below are designed to serve as a guide for the influence diagram (Appendix I) and the two should be used together to understand the monitoring needs for coastal Louisiana. The tables are structured to provide a definition for each parameter and list the "inputs" and "outputs" from the diagram[3]. The type of measurement typically associated with the parameter (e.g., concentration, area, length, etc.) is provided as well, except for the case of those labeled as "intermediate responses." An intermediate response is not a quantifiable parameter. It was used as a classification scheme in the influence diagram to represent multiple parameters at once and simplify the graphic representation of the connections. For example, Estuarine Water Quality is classified as an intermediate response, as it in itself is not a quantifiable metric. It instead represents quantitative parameters including turbidity, dissolved oxygen, and others (Figure 3). Due to the fact that numerous drivers affect turbidity, dissolved oxygen and the other identified water quality parameters, connections were drawn directly to the Estuarine Water Quality box, instead of each individual parameter. This reduces the overall number of connections in the influence diagram and simplifies the presentation.

[3] Supporting references are only provided in instances where the framework uses a specific interpretation of parameter use. Where the parameters reflect conventional terminology and common usage, supporting references are not included.

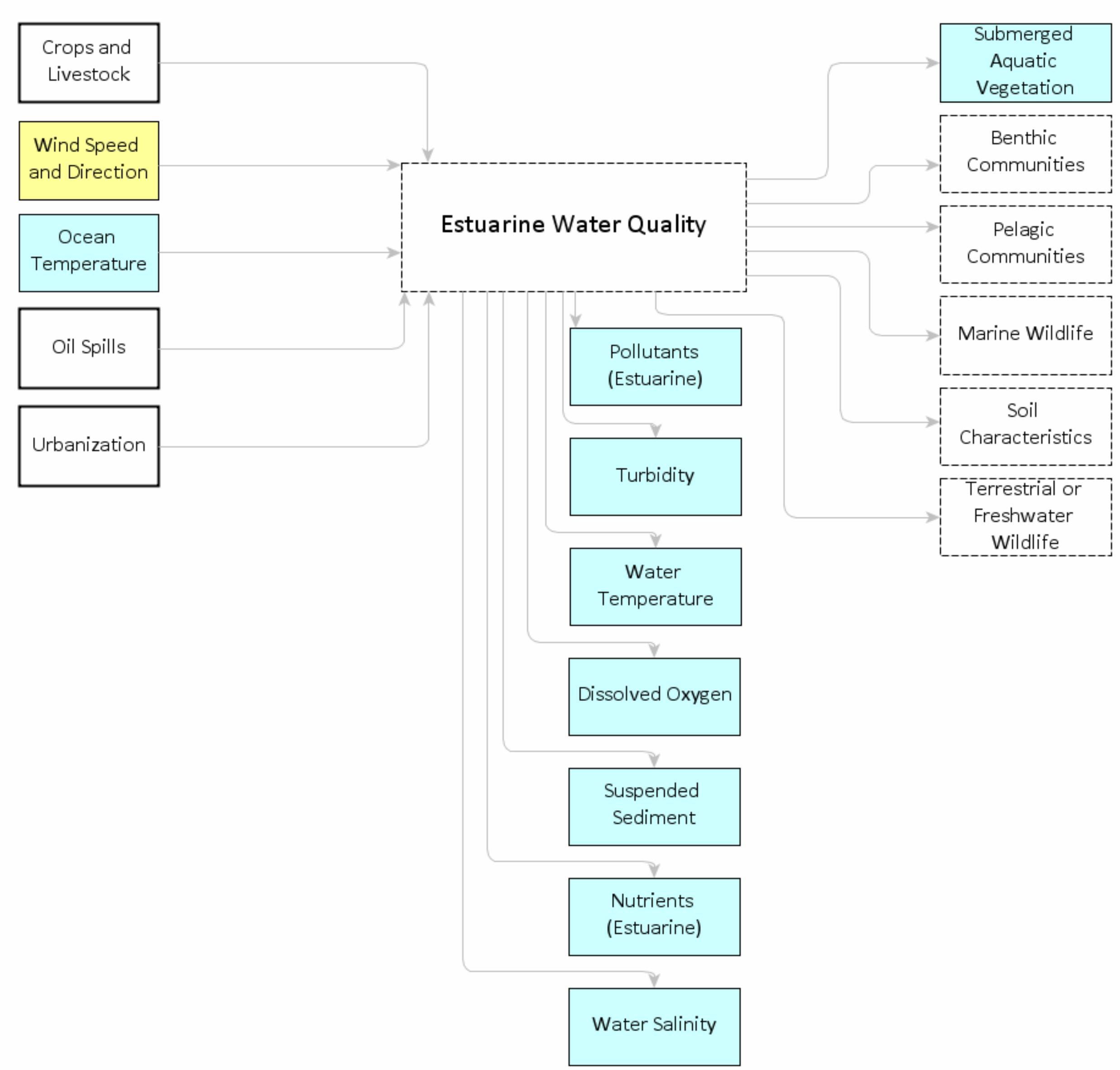

Figure 3. The diagram is a subset of the restoration influence diagram designed to focus on estuarine water quality in order to illustrate the role of the "intermediate response," signified by the dashed-outlined box. Estuarine water quality is meant to represent seven parameters: pollutants, turbidity, water temperature, dissolved oxygen, suspended sediment, nutrients, and salinity. The arrows leading into estuarine water quality are drivers (solid-outlined white boxes) and other parameters (colored boxes) that influence the seven estuarine water quality parameters. Likewise, the arrows leaving estuarine water quality indicate the influence of the seven parameters collectively on other parameters or intermediate responses. The coloring scheme was used to categorize parameters in the full diagram found in Appendix I.

Table 1. Atmospheric parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

	Parameter	Description	Inputs	Outputs
1	Air temperature	Air temperature is a property of local climate. An increase in air temperature may lead to the expansion of terrestrial subtropical or tropical species, and increases in evapotranspiration and water temperature.	• Regional/global climate • Local climate	• Estuarine Water temperature • Evapotranspiration • Expansion of subtropical/tropical species
2	Atmospheric Carbon Dioxide	Carbon dioxide is a naturally occurring chemical compound found in the earth's atmosphere. It is a primary component of the carbon cycle and is required by vegetation for photosynthesis. The excess production of carbon dioxide is a driver of global warming (greenhouse effect) and ocean acidification when dissolved in sea water. Increases in atmospheric carbon dioxide concentration may enhance vegetative growth and productivity of C3 plants, including subtropical mangrove species (McKee & Rooth, 2008).	• Regional/global climate	• Expansion of subtropical/tropical species • Wetland primary Productivity
3	Evapo-transpiration (ET)	ET refers to the transformation of terrestrial liquid water to atmospheric gaseous water due to evaporation and plant transpiration. In general, ET reduces the amount of surface and subsurface (shallow/rhizosphere) water. Because direct measurements of ET can be difficult to collect (e.g., using a lysimeter), potential evapotranspiration (PET) is a more typically used metric and defines the total amount of liquid water that could be consumed (i.e., the water demand) by regional vegetation and evaporated by solar energy. PET is estimated from environmental parameters such as land cover, temperature, and wind.	• Air temperature • Forested non-wetland types • Solar radiation • Wetland vegetative types • Wind speed and direction	• Groundwater quantity • Surface water quantity

Parameter		Description	Inputs	Outputs
4	Precipitation	In this context, precipitation refers to rainfall associated with local weather, tropical and winter storms. Precipitation is a major component of the hydrologic cycle and influences the quantity of both surface water and groundwater. Precipitation depth defines the amount of terrestrial water introduced during a precipitation event. Precipitation intensity influences the amount of precipitation that is converted to runoff.	• Local climate • Tropical storms • Non-tropical storms	• Surface water quantity • Groundwater quantity
5	Solar radiation	Solar radiation, or insolation, refers to the amount of solar energy that reach's the surface of the earth. Insolation is shortwave electromagnetic energy and produces light and heat.	• Local climate	• Evapotranspiration • Dissolved oxygen • Wetland primary productivity • Pelagic primary production
6	Wind speed and direction	Winds associated with local weather, winter and tropical can influence estuarine water elevation by increasing or decreasing water levels, depending on their speed and direction. Wind may contribute to mixing of the water column, thereby influencing estuarine water quality. Wind is an important driver of evapotranspiration. It creates waves in estuarine water bodies and on the continental shelf. These wave heights, periods, and directions are controlled by fetch and wind speed. Winds may negatively impact forested wetlands and non-wetlands by increasing fragmentation and reducing area, as well as indirectly impacting all coastal shorelines through wave attack. They may also damage barrier island habitats such as dune communities.	• Local climate • Tropical storms • Non-tropical storms	• Estuarine water elevation • Estuarine water quality • Evapotranspiration • Wave height, period, direction • Forested non-wetland fragmentation • Forested non-wetland area • Wetland fragmentation • Wetland area • Barrier island vegetated/ unvegetated habitats

Table 2. Land parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
7	Barrier island area (subaerial)	Barrier island area refers to the amount of exposed land area associated with a barrier island above mean sea level. Island area should be a temporally averaged value to account for the effect of tides. It can include areas of beach dune, swale, and backmarsh.	• Barrier island morphology • Barrier islands/ shorelines • Shoreline position	• Marine wildlife • Barrier island vegetated/ unvegetated habitats • Beach use • Terrestrial or freshwater wildlife • Wave height, period, direction
8	Barrier island morphology	Barrier island morphology refers to the measurement of the continuous subaqueous and subaerial surface of a barrier island sand body and associated marshes. The surface may be extrapolated from elevation data collected at known locations as a digital elevation model (DEM) or represented as a contour map. Coupling the topographic and bathymetric data permits definition of the full island dimensions and volume above the sea floor.	• Barrier island vegetated/ unvegetated habitats • Barrier islands/ shorelines • Subsidence	• Barrier island area (subaerial) • Wave height, period, direction
9	Bulk density	Soil bulk density is defined as the mass of an oven-dry sample of undisturbed soil per unit bulk (wet) volume. Bulk density is used to estimate and evaluate many physical soil properties, such as porosity, water retention, buoyancy and compressibility. It is used to convert data from weight-based to volume- and area-related data, e.g., from a mass of sediment deposited to a vertical increment of elevation change.	• Soil characteristics	See "Soil Characteristics" in Table 7 for output
10	Forested non-wetland area	Refers to the area of nondeveloped, forested land area that is not defined as a wetland (i.e., the groundwater table is sufficiently below the terrestrial surface and the shallow subsurface soil is not saturated).	• Ridge restoration • Shoreline position • Surface elevation • Wind speed and direction	• Forested nonwetland types

Parameter		Description	Inputs	Outputs
11	Forested non-wetland fragmentation	Forest fragmentation refers to the breaking-up of forest canopy allowing greater light penetration. This can lead to the invasion of opportunistic or invasive species.	• Canals/pipelines • Wind speed and direction	• Terrestrial or freshwater wildlife
12	Forested non-wetland types	Forested non-wetland types include those found in Chenier and maritime forests, on beach ridges, natural levees, and spoil banks.	• Exotics • Forested non-wetland area • Soil characteristics	• Evapotranspiration
13	Land use/ land cover	Land use and land cover is typically monitored using remote sensing techniques that invoke processing of remotely sensed data that encompass large spatial coverage of land surface information.	• Agriculture • Urbanization	N/A
14	Organic matter and mineral content	Organic matter and mineral content of wetland soils are key determinants of marsh soil development and are often used to describe the roles of organic accumulation—derived from above- and below-ground plant material—and mineral sediment deposition. Soil organic matter content (usually expressed as percent weight) is the net result of plant biomass production (either through root rhizome production directly into the soil or through litter fall from aboveground production) and decomposition. Both processes will vary with plant communities and other aspects of wetland dynamics, including soil inundation, drainage, redox potential, and other biogeochemical processes. Mineral content of soils (expressed as percent weight) depends upon sediment deposition on the marsh surface as well as compaction processes that reduce porosity and increase bulk density.	• Soil characteristics	See "Soil Characteristics" in Table 7 for output

Parameter	Description	Inputs	Outputs
15 Redox potential	Redox potential, or oxygen reduction potential, reflects the degree of electrochemical reduction in wetland soils. In wetland soils, oxidation occurs not only through uptake of oxygen but when hydrogen is removed. Redox potential is thus a quantitative measure of the tendency of a soil to oxidize or reduce substances.	• Soil characteristics	See "Soil Characteristics" in Table 7 for output
16 Shoreline position	Shoreline position is monitored to detect horizontal change in position of the average interface between land and sea. The shoreline is measured along some defined datum within the intertidal zone, such as the mean high tide. Differential changes in shore elevation or sea-level elevation, when the change causes net land loss or land building, result in the horizontal displacement of the shoreline.	• Bank stabilization • Barrier islands/ shorelines • Canals/pipelines • Oil spills • Shoreline protection • Wave height, period, direction	• Barrier island area (subaerial) • Forested non-wetland area • Wetland area
17 Soil contaminants	Soil contaminants may enter from point and nonpoint sources and include heavy metals, hydrocarbons, and toxic chemicals. Wetland soils in particular have the capacity to process pollutants, but degrading wetlands or excessive concentration of pollutants may limit the soil's ability to handle contaminants.	• Soil Characteristics • Oil spills • Pollutants (estuarine) • Pollutants (river)	See "Soil Characteristics" in Table 7 for output
18 Soil pH	Soil pH is a measure of the acidity or alkalinity of soil and is measured in pH units. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. The pH scale includes values from 0 to 14 with pH 7 as neutral. As the amount of hydrogen ions in the soil increases, the soil pH decreases, thus becoming more acidic. Soil pH influences the solubility of nutrients. It also affects the activity of micro-organisms responsible for breaking down organic matter and most chemical transformations in the soil.	• Soil characteristics	See "Soil Characteristics" in Table 7 for output

	Parameter	Description	Inputs	Outputs
19	Soil salinity	Soil salinities change more slowly than open water salinities. Soil salinity is influenced by tidal cycle as well as wind direction, seasonal changes to freshwater input, and climatic cycles, but variation is dampened compared to variation in salinity of the overlying water. Soil salinity measurements involve extracting interstitial water from a sediment sample by centrifugation or by using field collection tubes.	• Soil characteristics	See "Soil Characteristics" in Table 7 for output
20	Subsidence	Subsidence refers to the vertical displacement of a geologic horizon relative to a geodetic datum. Typically, coastal subsidence is a term used in reference to the net lowering of the earth's surface.	• Faulting • Consolidation • Salt diapirism • Deep subsidence • Subsurface withdrawal • Groundwater withdrawal	• Barrier island morphology • Surface elevation
21	Surface elevation	Surface elevation is the height of the land surface relative to a datum. Common datums include mean sea level, NAVD88, WGS84. The elevation of land relative to nearby water levels is a determinant of inundation of wetlands. Land elevation also dictates the area of land that can be inhabited by forested nonwetland communities.	• Bank stabilization • Marsh creation • Ridge restoration • Subsidence • Surficial accretion • Surficial erosion	• Forested non-wetland area • Inundation
22	Surficial accretion	Surficial accretion refers to the deposition of materials on a surface. Vertical accretion of wetlands is critical in order to keep pace with relative sea-level rise and includes both organic and inorganic accumulation on the marsh surface.	• Diversions • Surface • Suspended sediment • Wetland primary productivity	• Surface elevation • Wetland fragmentation
23	Surficial erosion	Surficial erosion is the process by which soil particles are removed from the surface by wind, water, or other forces.	• Diversions • Surface • Wave height, period, direction	• Surface elevation • Wetland fragmentation

Parameter		Description	Inputs	Outputs
24	Vegetative types (barrier islands)	The general distribution of vegetation on the surface of a barrier island is controlled by the subaerial morphology of the island, the stability of the island in space, and the local soil characteristics. In turn, vegetation can trap sand and increases the resistance of the barrier island to erosion by wind, waves, and overwash.	• Barrier island vegetated/ unvegetated habitats	N/A
25	Wetland area	Wetland area quantifies the amount of land composed of emergent wetland vegetation (see wetland vegetative types). Wetlands serve a multitude of functions from buffering storms, filtering nutrients, pollutants, and sediments, and supporting fish, shellfish, and wildlife. Wetland loss is a critical issue in coastal Louisiana.	• Herbivory • Inundation • Marsh creation • Shoreline position • Wetland primary productivity • Wind speed and direction	• Marine wildlife • Terrestrial or freshwater wildlife
26	Wetland fragmentation	Wetland fragmentation refers to the breaking up of wetland area into smaller patches and results in increases in the amount of marsh edge. Marsh edges are often cited as important habitats for fish and shellfish (Zimmerman et al., 2000), but increasing fragmentation can lead to alterations to hydrologic patterns, increased erosion, and marsh collapse.	• Canals/pipelines • Marsh creation • Surficial accretion • Surficial erosion • Wind speed and direction	• Marine wildlife • Terrestrial or freshwater wildlife • Benthic communities • Pelagic communities
27	Wetland primary Productivity	Wetland plants accumulate energy through fixation of sunlight; this energy is called primary production. The rate at which this energy accumulates is called primary productivity. Measurements of aboveground and belowground biomass over time can be used to evaluate primary productivity.	• Atmospheric Carbon Dioxide • Inundation • Nutrients (estuarine) • Oil spills • Soil characteristics • Solar radiation	• Surficial Accretion • Wetland area

Parameter		Description	Inputs	Outputs
28	Wetland vegetative types	Plant communities play a central role in shaping wetland ecosystems. Both the species and plant growth forms define habitat conditions for other organisms. The plant species that comprise a wetland also shape hydrology and edaphic conditions through processes such as evapotranspiration, and frictional resistance to water flow, thus affecting sedimentation and erosion rates. In Louisiana, a number of emergent vegetation "types" have been recognized in coastal wetlands (Visser et al. 1998, 2000), including: Mangrove, Oyster grass, Salt grass, Needle rush, Brackish mixture, Paspalum, Wire grass, Scrub-shrub, Bullwhip, Roseau cane, Bulltongue, Cattail, Saw grass, Cut grass, Maiden cane, Delta splay, Thinmat, Wax myrtle, and Swamp forest .	• Exotics • Expansion of subtropical/ tropical species • Inundation • Marsh creation • Soil characteristics	• Evapotranspiration • Terrestrial or freshwater wildlife

Table 3. Water parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
29	Dissolved oxygen	Dissolved oxygen is a measure of how much gaseous oxygen is present in liquid water. Most forms of aquatic life require a specific range of dissolved oxygen concentrations for respiration, outside of which can be harmful. Dissolved oxygen enters surface water due to the absorption of atmospheric oxygen or from primary production. Dissolved oxygen is removed from surface water by the respiration of aquatic animals or by the decomposition of submerged organic matter.	• Estuarine water quality • Solar Radiation	See "Estuarine Water Quality" in Table 7 for output

Parameter		Description	Inputs	Outputs
30	Estuarine water elevation	Water elevation refers to the height of the water surface relative to a common datum.	• Diversions • Hydrologic restoration • Impoundments • Surface water quantity • Tidal regime/ exchange • Tropical storms • Winds speed and direction	• Wave height, period, direction • Inundation • Benthic communities • Pelagic communities • Submerged Aquatic Vegetation
31	Estuarine water temperature	Average temperature of the water at a point within an estuary.	• Air Temperature • Estuarine water quality	• Pelagic primary production • See "Estuarine Water Quality" in Table 7 for additional outputs
32	Inlet hydrodynamics	Inlet currents influence the flow and sediment discharge passing through a coastal inlet, between the sea (e.g., the Gulf of Mexico) and an enclosed body of water, such as a bay. Currents often change direction due to tides or seasonal flow patterns so it is often useful to use temporally averaged values to estimate the net movement of water and sediment. Measuring flow and sediment at an inlet location helps constrain the total exchange of flow and sediment between estuarine and oceanic sources because adjacent land masses act as barriers to the flow.	• Diversions • Hydrologic restoration • Tidal regime/ exchange	• Coastal and estuarine sediment transport

Parameter		Description	Inputs	Outputs
33	Inundation	Inundation is the height of water above a wetland surface such that occurs with tides, storm surge, or wind-driven events. The duration and depth of flooding or drying can be an important influence on vegetation.	• Estuarine water elevation • Surface elevation	• Soil characteristics • Wetland vegetative types • Wetland area • Wetland primary Productivity
34	Nutrients (estuarine)	Estuarine nutrients are an important characteristic of estuarine water quality. Multiple sources can contribute nutrients to estuaries and wetlands including land-based point and non-point, atmospheric, surface water, and groundwater inputs. Common nutrients include nitrogen and phosphorus in both organic and inorganic forms (Glibert et al., 2010).	• Estuarine water quality • Marsh creation • Nutrients (river) • Submerged aquatic vegetation	• Pelagic primary production • Wetland primary productivity
35	Ocean temperature	Ocean temperature is a function of regional and global climate dynamics. An increase in ocean temperature associated with global warming has implications for the expansion of tropical or subtropical species, primary production, estuarine water quality, and the formulation of offshore hypoxia.	• Regional/global climate	• Estuarine water quality • Expansion of subtropical/tropical species • Offshore hypoxia • Pelagic primary production
36	Pollutants (estuarine)	Estuarine pollutants are a characteristic of estuarine water quality. It refers to anthropogenically sourced organic or inorganic compounds that have an adverse effect on the environment. Pollutants may enter estuaries from surface water and riverine inputs that are polluted by urban, agricultural, and industrial runoff. Examples of pollutants include solvents and detergents, petroleum components, chlorides, and heavy metals.	• Estuarine water quality	• Soil contaminants • See “Estuarine water quality” in Table 7 for related outputs

Parameter		Description	Inputs	Outputs
37	Sediment composition	Sediment composition commonly refers to the grain-size distribution of a sediment sample. The grain-size distribution is typically summarized in terms of summary statistics, such as median grain size, or in terms of a classification scheme, such as the Unified Soil Classification System (USCS). Grain size is measured as the intermediate diameter of a sediment grain. Additionally, the amount of organic material in a sediment sample is sometimes measured because of its relevance to the hydraulic properties of the soil and its shear strength.	• Barrier islands/ shorelines • Coastal and estuarine sediment transport	N/A
38	Submerged Aquatic Vegetation (SAV)	SAV are aquatic plants found in shallow water rooted in mud/sand substrates. SAV serves as critical habitat for fish and invertebrates during many stages of their life cycle and are an important foraging ground for birds. SAV also traps suspended sediments and nutrients and can sequester carbon. Their productivity and growth is influenced by estuarine water characteristics including light, salinity, temperature, nutrients, and water depth. SAV is typically monitored using remote sensing techniques. Individual sites may be periodically assessed on the ground to look at species composition.	• Estuarine water quality • Estuarine Water Elevation	• Benthic communities • Pelagic communities • Nutrients (estuarine) • Suspended sediments
39	Suspended sediment	Suspended sediment quantifies solid-phased (inorganic plus organic) materials suspended in the water column. Data are produced by measuring the dry weight of all sediment from a known volume of water-sediment mixture (Gray et al., 2000).	• Coastal and estuarine sediment transport • Estuarine water quality • Submerged aquatic vegetation	• Surficial accretion • Turbidity
40	Turbidity	Turbidity is a characteristic of estuarine water quality that quantifies the clarity of the water. Suspended sediments, nutrients, pollutants, and organisms can impact the turbidity of the water.	• Estuarine water quality • Suspended sediment	• Pelagic primary production

Parameter		Description	Inputs	Outputs
41	Water Salinity	Salinity refers to the amount of dissolved salts in the water reported as mass per unit volume, calibrated refraction, or as a unit-less measure.	• Estuarine water quality • Hydrologic restoration • Impoundments • Lock operation • Tidal regime/ exchange	• See "Estuarine water quality" in Table 7 for output
42	Wave height, period, direction	Wave height is the distance measured from trough to the wave crest. Wave period is the time it takes for one wave cycle to pass a fixed point. Wave direction refers to the direction in which a wave propagates.	• Barrier island area (subaerial) • Barrier island morphology • Barrier island vegetated/ unvegetated Habitats • Estuarine water elevation • Oyster barrier reef • Shoreline protection • Wind speed and direction	• Shoreline position • Surficial erosion • Coastal and estuarine sediment transport • Offshore hypoxia • Benthic communities

Table 4. Groundwater parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
43	Groundwater flux rates	In saturated soils, groundwater flux is estimated by the permeability and porosity of the soil and the viscosity and hydraulic head of the fluid. Groundwater flux is typically estimated by looking at time series or spatially distributed measurements of piezometers that intrude into the water table.	• Groundwater quantity	See “Groundwater quantity” in Table 7 for output
44	Groundwater nutrients	Excessive nutrient enrichment in groundwater can adversely affect plant and animal health, as it feeds into surface water or is withdrawn at well locations. Typical nutrients found in groundwater include nitrogen, nitrate, ammonia, orthophosphate, and phosphorus. Nutrients are often supplied to groundwater from the infiltration of agricultural runoff.	• Groundwater quality	See “Groundwater quality” in Table 7 for output
45	Groundwater pollutants	Groundwater pollutants refer to anthropogenically sourced organic or inorganic compounds that have an adverse effect on the environment. Groundwater pollutants often enter groundwater reservoirs through the infiltration of urban and industrial runoff. Examples of typical groundwater pollutants include solvents and detergents, petroleum components, chlorides, and heavy metals.	• Groundwater quality	See “Groundwater quality” in Table 7 for output
46	Groundwater elevation	This parameter refers to the vertical distance between the surface of the groundwater table at a specific point and a geodetic datum.	• Groundwater quantity	See “Groundwater quantity” in Table 7 for output

Table 5. Fish and wildlife parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
47	Benthic biomass/ density	Benthic biomass is commonly used metric to evaluate benthic communities. It refers to the quantity of benthic organism in a given geographic area.	• Benthic communities	See "Benthic communities" in Table 7 for output
48	Benthic Contaminants/ Sediments	Contaminants in the benthos refer to the concentration of pesticides, polychlorinated biphenyls (PCBs), trace elements, and other pollutants that may negatively impact benthic communities.	• Benthic communities	See "Benthic communities" in Table 7 for output
49	Benthic diversity	Benthic diversity quantifies the number of individuals of each species present.	• Benthic communities	See "Benthic communities" in Table 7 for output
50	Benthic primary Productivity	Benthic primary productivity is the rate of organic carbon production by benthic organisms. Benthic primary productivity plays a major role in secondary productivity or production of pelagic communities.	• Benthic communities	See "Benthic communities" in Table 7 for output
51	Bird counts	The diverse habitat types of coastal Louisiana support a range of birding populations including resident marsh birds, migratory songbirds, waterfowl, and wading birds, among others. Bird counts are often conducted in a fixed location in which the number of individuals by species is counted for a fixed amount of time.	• Terrestrial or freshwater wildlife	See "Terrestrial or freshwater wildlife" in Table 7 for output
52	Bird nesting pairs	Bird nesting pairs or the nests themselves can be used to quantitatively assess successful breeding.	• Terrestrial or freshwater wildlife	See "Terrestrial or freshwater wildlife" in Table 7 for output
53	Bycatch	Bycatch refers to incidental take by a fishery. It is typically quantified by measuring the total weight by species.	• Commercial fishing • Recreational fishing	• Marine wildlife • Pelagic communities
54	Contaminants (fish)	Examination of fish tissues for contaminants such as mercury, pesticides, PCBs), algal toxins, and trace elements may be necessary periodically as this would occur with an oil spill or when high levels of pollutants are suspected.	• Fish population condition	See "Pelagic communities" in Table 7 for output

Parameter		Description	Inputs	Outputs
55	Fecundity	Fecundity is the potential reproductive capacity of fish and is of particular importance for fish stock management. Fecundity is estimated by removing the ovaries from females, weighing the total eggs, and counting a subset.	• Fish population condition	See "Pelagic communities" in Table 7 for output
56	Fish Density	Fish density is one parameter for quantifying pelagic communities. The measurement refers to the number of individuals of a particular species in a given geographic location.	• Pelagic communities	See "Pelagic communities" in Table 7 for output
57	Harmful algal blooms	Harmful algal blooms (HABs) are the result of excessive algal production by particular algal species, such as *Pseudo-nizschia* spp., that can produce harmful toxins, clog fish gills, or cause hypoxia. It should be noted that not all algal blooms can lead to these harmful effects. However, detecting HABs is often achieved by observing these detrimental impacts.	• Pelagic primary production	• Benthic communities • Offshore hypoxia • Pelagic communities
58	Herbivory	Herbivory is the consumption of plant materials by wildlife. Nutria are invasive herbivores that consume large quantities of plant material leading to a change in wetland plant communities and sometimes in wetland loss and fragmentation. Other native herbivores, e.g., muskrats, are also common in Louisiana. Monitoring herbviroy may be conducted by measuring the areal extent of consumption.	• Terrestrial or freshwater wildlife	• Wetland area
59	Mammal density (marine)	Some marine mammals, including bottlenose dolphins, are found in coastal bays of Louisiana. Their density can be measured by calculating the number of individuals in an area.	• Marine wildlife	See "Marine wildlife" in Table 7 for output
60	Mammal density (terrestrial/ freshwater)	Mammals including muskrat, otters, and other wildlife serve an important ecological role as upper-tropic level species. Their density can be measured by calculating the number of individuals in an area.	• Terrestrial or freshwater wildlife	See "Terrestrial or freshwater wildlife" in Table 7 for output

Parameter		Description	Inputs	Outputs
61	Pelagic primary production	Pelagic primary production is the total quantity of carbon produced by primary producers within open water areas. Production by can be estimated by measurements of chlorophyll *a* while productivity can be estimated from photosynthetic and respiration rates.	• Estuarine water temperature • Nutrients (estuarine) • Nutrients (river) • Ocean temperature • Solar Radiation • Turbidity	• Benthic communities • Harmful algal blooms • Pelagic communities
62	Reptile density (freshwater)	Reptile density, e.g. alligators, serves an important ecological role as upper-trophic level species, but also supports a large economic industry. Their density can be measured by calculating the number of individuals in an area.	• Terrestrial or freshwater wildlife	See "Terrestrial or freshwater wildlife" in Table 7 for output
63	Reptile density (marine)	Reptile density in this context refers to sea turtles. The coastal waters serve as important foraging, developmental, and migratory habitat for sea turtles. Sea turtles are also protected by the Endangered Species Act. Their density can be measured by calculating the number of individuals in an area.	• Marine wildlife	See "Marine wildlife" in Table 7 for output
64	Reptile nests (freshwater)	Quantifying reptile nests, e.g., alligator, provides a measure of reproductive success.	• Terrestrial or freshwater wildlife	See "Terrestrial or freshwater wildlife" in Table 7 for output
65	Reptile nests (marine)	Reptile nesting grounds, e.g., sea turtles, are found on barrier islands and shorelines beaches, although nesting populations of sea turtles are not abundant in Louisiana. Quantifying the number of nests provides a measure of reproductive success.	• Marine Wildlife	See "Marine wildlife" in Table 7 for output
66	Fish Size	Length and weight measurements are used to develop morphological condition indices to assess energy reserves and ultimately overall health of the fish population.	• Fish Population Condition	See "Pelagic communities" in Table 7 for output

Parameter		Description	Inputs	Outputs
67	Threatened and endangered species	Species are designated as endangered or threatened under federal and state statutes. Their presence should be monitored by calculating the number of individuals in an area.	• Marine wildlife • Borrow pits • Pelagic communities • Terrestrial or freshwater wildlife	N/A

Table 6. River parameters identified in the restoration framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
68	Borrow Pit Morphology	In coastal Louisiana, the term "borrow pit" refers to the empty volume within the earth's surface due to mining. Where the mining occurs in subaqueous environments, the borrow pit will be full of water. Borrow sediment is typically removed by dredging to provide fill material for land-building restoration projects. Monitoring of the bathymetry and elevation of borrow pits is necessary to track infilling rates.	• Borrow pits	N/A
69	Bedload	Bedload refers to the transport of sediment grains along the bed of a river channel. The grains roll or saltate along the bed, pushed by the tractive forces of fluid flow.	• Riverine water particulate load	N/A
70	Discharge	Discharge is a general measurement of the amount of water volume transported within a river channel (i.e., through a channel cross section per unit time). Discharge is typically reported as cubic feet or meters per second. Discharge is often calculated by multiplying metrics of flow velocity by the cross-sectional area of the flow.	• Surface water quantity	• Offshore hypoxia • River channel elevation

Parameter		Description	Inputs	Outputs
71	Mineral suspended load	Mineral suspended load refers to the mineral sediment that is transported in suspension within river flow and is differentiated from bedload, which is transported in contact with the channel bed. While the suspended load is contained within the entire depth profile of the river flow, concentrations tend to be greater near the channel bed than the water surface, logarithmically increasing with flow depth, on average. Mineral sediment is typically composed of finely weathered rock.	• Suspended load	N/A
72	Nutrients (river)	Excessive nutrient enrichment in rivers can adversely affect plant and animal health, as it feeds into surface water or is discharged into the Gulf. Typical nutrients found in rivers include nitrogen forms of nitrate and ammonia, phosphorus (e.g.,phosphate), and silica. Nutrients are often supplied from agricultural runoff, municipalities, industries, and atmospheric deposition in the watershed.	• Riverine water dissolved load	• Nutrients (estuarine) • Pelagic primary production • Offshore hypoxia • Benthic communities
73	Offshore hypoxia	Bottom-water hypoxia occurs when the concentration of dissolved oxygen decreases to a low level (< 2 ppm) that can no longer support most living aquatic organisms. In the northern Gulf, bottom-water, hypoxic events are largely linked to river discharge and nutrient concentrations coupled with characteristics of the ocean itself (e.g., temperature and wave dynamics, stratification).	• Discharge • Harmful algal blooms • Nutrients (river) • Ocean temperature • Wave height, period, direction	N/A
74	Organic matter suspended load	Organic matter suspended load refers to the amount of organic, i.e., non-mineral, material transported within the full depth profile of flow. The total amount of organic matter in flow consists of a particulate and a dissolved fraction and commonly consists of pollen, plant debris and exudates, and charcoal. The fluvial transport of organic material is an important pathway within the carbon cycle.	• Suspended load	N/A

Parameter		Description	Inputs	Outputs
75	Pollutants (river)	Riverine pollutants refer to anthropogenically sourced organic or inorganic compounds that have an adverse effect on the environment. Pollutants in a river may include pesticides, industrial by-products, trace metals, and chlorinated hydrocarbons.	• Riverine water dissolved load	• Benthic communities • Pelagic communities • Soil Contaminants
76	River channel elevation	River channel elevation refers to the distance between the river channel bed surface and a vertical datum, such as mean sea level or NAVD88. River channel elevation is typically reported for channel thalweg (i.e., the lowest point of the channel bed within a channel cross section) or averaged over the channel bed for a channel cross section or channel reach. Temporal changes in river channel elevation are used to estimate the amount of sediment that is deposited or eroded at the river channel bed for alluvial fluvial systems.	• Discharge • Navigation • Diversions	N/A
77	River stage	River stage refers to the surface elevation of flow within a river channel. River stage is a point measurement. For practical considerations it is typically reported as a temporally averaged value, e.g., reported hourly or daily. River stage is often used to derive flow discharge.	• Surface water quantity	N/A

Table 7. Intermediate Responses identified in the restoration framework to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
78	Barrier island vegetated/ unvegetated habitats	This intermediate parameter describes barrier island habitats including those that are vegetated and unvegetated.	• Barrier island area (subaerial) • Barrier islands/ shorelines • Beach use • Wind Speed and Direction	• Barrier island morphology • Terrestrial wildlife • Vegetative types • Wave Height, Period, Direction
79	Benthic communities	Benthic communities are those that reside on the sea floor surface or bottoms of rivers, streams, and lakes, and include bivalves, polychaetes, and crustaceans. They are influenced by water quality characteristics and the presence of submerged aquatic vegetation and marsh edges and the construction of oyster barrier reefs. They may be detrimentally impacted by pollutants, HABs, and bottom-water hypoxia.	• Estuarine water elevation • Estuarine water quality • Harmful algal blooms • Nutrients (river) • Oil spills • Oyster barrier reef • Pelagic primary production • Pollutants (river) • Submerged aquatic vegetation • Wave height, period, and direction • Wetland Fragmentation	• Benthic Biomass/density • Benthic contaminants/ sediments • Benthic diversity • Benthic primary productivity • Pelagic communities

Parameter		Description	Inputs	Outputs
80	Coastal and estuarine sediment transport	Coastal and estuarine sediment transport entrains and moves sediment along the sea bed, either in the longshore (e.g., parallel to the shore) or cross shore (e.g., perpendicular to the shore) direction. Coastal and estuarine sediment transport is primary driven by ocean currents occurring near the sea bed and is also influenced by wind, waves, and tides. Unlike fluvial sediment transport, the coastal transport direction is highly variable and may reverse direction over short time periods due to tides. Coastal and estuarine sediment transport is the primary process influencing beach and barrier island evolution.	• Inlet hydrodynamics • Tidal regime/ exchange • Wave height, period, direction	• Suspended sediment • Sediment composition
81	Estuarine water quality	Water quality is an important attribute of estuaries that encompasses general water characteristics including salinity, turbidity, suspended sediments, dissolved oxygen, nutrients, and pollutants. These parameters have wide implications for benthic and pelagic communities, marine wildlife, soil properties of adjacent wetlands, and the productivity of submerged aquatic vegetation. The key drivers that dictate water quality conditions are human-related activities and oceanic and atmospheric processes.	• Exotics • Wind speed and direction • Ocean temperature • Riverine water quality • Groundwater quality • Crops and livestock • Urbanization • Oil spills • Surface water Inputs • Diversions • Oyster barrier reef	• Submerged aquatic vegetation • Dissolved oxygen • Pollutants (estuarine) • Estuarine water temperature • Nutrients (estuarine) • Water salinity • Suspended sediment • Turbidity • Pelagic communities • Benthic communities • Marine wildlife • Soil characteristics

Parameter		Description	Inputs	Outputs
82	Expansion of subtropical/ tropical species	The expansion of indigenous species, such as mangroves, may occur with changes in global climate. Tracking of the expansion requires vegetative surveys that document vegetation types and their distributions.	• Air temperature • Atmospheric Carbon dioxide • Ocean temperature	• Wetland vegetative types
83	Fish population condition	Condition indices are used to assess the overall health of the population by examining presence of contaminants in fish tissues or collecting information on length and weight.	• Pelagic communities	• Contaminants • Fish Size • Fecundity • See "Pelagic communities" in Table 7 for related output
84	Groundwater quality	Groundwater quality refers to the general quality of ground water volume, which will reflect the presence and amount of different natural constituents and contaminants.	• Crops and livestock • Groundwater inputs • Urbanization	• Estuarine water quality • Groundwater nutrients • Groundwater pollutants • Riverine water quality
85	Groundwater quantity	Groundwater quantity characterizes the amount of water below the earth's surface.	• Evapotran-spiration • Groundwater inputs • Groundwater withdrawal • Precipitation	• Groundwater elevation • Groundwater flux rates

Parameter	Description	Inputs	Outputs
86 Marine wildlife	Marine wildlife is an intermediate response used to describe marine mammals and reptiles such as dolphins and sea turtles. (Note that birds are included in terrestrial wildlife.)	• Barrier island area (Subaerial) • Bycatch • Estuarine water quality • Wetland area • Wetland fragmentation	• Mammal density (marine) • Reptile nests (marine) • Reptile density (Marine) • Threatened and endangered species

Parameter	Description	Inputs	Outputs
87 Pelagic communities	Pelagic communities are those that reside in the water column, e.g., fish. In Louisiana, they play an important role in the recreational and commercial fishing industries. Restoration activities may influence their distribution by increasing the amount of edge habitat, improving estuarine water quality, or promoting primary production. Their movement may be influenced by physical features such as the operations of locks. Oil spills, river pollutants, HABs, and bottom-water hypoxia may affect populations, depending on the area impacted.	• Barrier islands/ shorelines • Benthic communities • Bycatch • Commercial fishing • Estuarine water elevation • Estuarine water quality • Exotics • HABs • Lock operation • Oil spills • Oyster barrier reef • Pelagic primary production • Pollutants (river) • Recreational fishing • Submerged aquatic vegetation • Terrestrial or freshwater wildlife • Wetland fragmentation	• Fish density • Threatened and endangered species • Fish population condition

Parameter		Description	Inputs	Outputs
88	Riverine water dissolved load	Riverine water dissolved load refers to the total mass of organic and mineral material (ions) carried by channelized flow in solution. The dissolved load is often measured as a concentration within a sample volume.	• Riverine water quality	• Nutrients (river) • Pollutants (river)
89	Riverine water particulate load	Riverine water particulate load refers to the total mass of organic and mineral material transported in suspension or as bedload.	• Riverine water quality	• Bedload • Suspended load
90	Riverine water quality	Riverine water quality refers to the general quality of a river water volume, which will reflect the presence and amount of different natural constituents and contaminants.	• Crops and livestock • Groundwater quality • Surface water inputs • Urbanization	• Diversions • Estuarine water quality • Riverine water dissolved load • Riverine water particulate load
91	Soil characteristics	Soil characteristics include bulk density, pH, organic matter and mineral content, redox potential, and soil salinity. These parameters have wide implications for vegetative growth and productivity. The key drivers that dictate soil conditions are estuarine water quality and inundation, along with restoration activities.	• Estuarine water quality • Inundation • Marsh creation	• Forested nonwetland types • Wetland vegetative types • Wetland primary productivity • Soil pH • Soil salinity • Bulk density • Organic matter and mineral content • Redox potential • Soil contaminants

Parameter		Description	Inputs	Outputs
92	Surface water quantity	The quantity of surface water that enters the coastal ecosystem is a function of local climate events and human activities. Surface water is a primary mode of transport for nutrients and pollutants into rivers and estuaries.	• Crops and livestock • Evapotran-spiration • Lock operation • Precipitation • Surface water inputs • Urbanization	• Estuarine water elevation • River stage • Discharge
93	Suspended load	Suspended load refers to the organic and mineral sediments that are transported in suspension within a river flow.	• Lock operation • Riverine water particulate load	• Mineral suspended load • Organic matter suspended load
94	Tidal regime/exchange	Tide is the periodic rise and fall of sea level produced by gravitational interactions of the Moon, Sun, and Earth. Tidal regimes refer to the frequency of the tidal event, while the exchange characterizes the horizontal movement of water across the estuary as a result of tidal inundation.	• Barrier islands/ shorelines • Marsh creation • Oyster barrier reef • Ridge restoration • Sea level	• Estuarine water elevation • Coastal and estuarine sediment transport • Water salinity • Inlet hydrodyamics

Parameter		Description	Inputs	Outputs
95	Terrestrial or freshwater wildlife	Terrestrial or freshwater aquatic wildlife, (e.g., birds, muskrats, alligators) serve an important ecological role as upper tropic level species, but also economically for coastal Louisiana.	• Barrier island area (subaerial) • Barrier island vegetated/ unvegetated habitats • Beach use • Forested non-wetland fragmentation • Hunting • Oil spills • Wetland area • Wetland fragmentation • Wetland vegetative types	• Bird counts • Bird nesting pairs • Herbivory • Mammal density (terrestrial/ freshwater) • Pelagic communities • Reptile density (freshwater) • Reptile nests (freshwater) • Threatened and endangered species

Table 8. Parameters associated with Flooding Threats and Defenses identified in the protection framework needed to assess system condition and dynamics for SWAMP.

Parameter		Description	Inputs	Outputs
1	Barrier island area (subaerial)	Barrier island area refers to the amount of exposed land area (i.e., the horizontal surface), attributed to a barrier island above sea level. Island area should be a temporally averaged value to account for the effect of tides. Barrier islands can attenuate and/or dissipate waves and stabilize sediments (USACE, 2013).	• Barrier islands • Surface elevation	N/A

Parameter		Description	Inputs	Outputs
2	Dune height	Dune formation and structure is a function of sediment supply, wind patterns, wave action, and relative sea level. Dunes on barrier islands can break offshore waves, attenuate wave energy, and slow inland water transfer (USACE, 2013).	• Barrier islands	N/A
3	Employment Rate	Employment rate or job growth can be used as an indicator to assess economic conditions and social vulnerability.	• Employment	N/A
4	Ethnicity	Characteristics of the community, such as ethnicity, should be tracked to ensure fairness and equality in protection measures.	• Population	N/A
5	Forested nonwetland area	Refers to the area of nondeveloped, forested land area that is not defined as a wetland (i.e., the groundwater table is sufficiently below the terrestrial surface and the shallow subsurface soil is not saturated). Maritime forest and shrub communities can attenuate and/or dissipate waves, stabilize shoreline erosion, and promote soil retention (USACE, 2013).	• Forested (non-wetland) • Surface Elevation	N/A
6	Groundwater levels	Groundwater levels can impact the stability of levees and lead to groundwater seepage.	• Levees	• Groundwater seepage
7	Groundwater seepage	Seepage of the soil can lead to subsurface erosion and threaten the stability of levees.	• Groundwater levels • Soil composition	N/A
8	High water marks	High water marks provide estimates of surge heights.	• Levees • Flood walls	N/A
9	House elevations	Tracking the elevations of houses relative to base flood elevation allows assessment of the need for/success of program for flood proofing and elevation.	• Flood proofing • Elevating structures • Surface elevation	N/A
10	Housing inventory	Housing inventory is needed to assess the number of people and structures protected by a particular defense and/or vulnerable to damage. It includes the size of the house and the number of people residing in the house.	• Residential housing • Voluntary acquisition	N/A
11	Housing values	Housing values can be used as an indicator to assess economic growth and the value of the assets under threat.	• Residential housing	N/A

Parameter		Description	Inputs	Outputs
12	Inclination	Inclination refers to tilt in the protection structure that may compromise stability.	• Surge barriers • Flood walls	N/A
13	Number flood insured	Tracking the number insured for flood damage provides an indication of the vulnerability of the community to flood damage.	• Residential housing	N/A
14	Number wind insured	Tracking the number insured for wind damage provides an indication of the vulnerability of the community to damage from wind.	• Residential housing	N/A
15	Personal income	Income can be used as an indicator to assess economic condition and social vulnerability.	• Population	N/A
16	Population age structure	The age structure of the population can aid in understanding the needs of the community and how the population may respond to a storm event. Can also help with assessing the "adaptability" of the population.	• Population	N/A
17	Population density	The population density can be used to assess changes in the community after storm events.	• Population	N/A
18	Precipitation	In this context, precipitation refers to rainfall associated with tropical storms. Precipitation depth defines the amount of terrestrial water introduced during a precipitation event. Precipitation intensity influences the amount of precipitation that is converted to runoff.	• Tropical storm events	N/A
19	Protection Structure Height	Heights of protection structures are an important measure to determine the level of flood protection a structure provides. Changes in surface elevation as a result of local subsidence may lower levee foundations and reduce heights over time.	• Surge barriers • Levees • Flood walls • Surface elevation • Flood gates	N/A
20	Scour	Scouring occurs with erosion on a levee slope that can cut into the levee base.	• Surge barriers • Levees • Flood walls	N/A

Parameter		Description	Inputs	Outputs
21	Soil composition	The composition of the soil (e.g., grain-size distribution of a sample) dictates how levee foundations are constructed. Soil types can also impact groundwater seepage.	• Surge barriers • Levees • Flood walls	• Groundwater seepage
22	Stability/movement	Stability is compromised by changes in the horizontal or vertical crest/toe alignment, and may manifest itself through evidence of cracks in the structure.	• Surge barriers • Levees • Flood walls • Flood gates	N/A
23	Subsidence	Subsidence refers to the vertical displacement of a geologic horizon relative to a geodetic datum. Typically, coastal subsidence is a term used in reference to the net lowering of the earth's surface.	• Deep subsidence • Faulting • Consolidation • Salt diapirism	• Surface elevation
24	Surface armor	Surface armor may include densely rooted vegetation, fabrics, or concrete blocks to serve as coverings on the protected side of levees/earthen embankments to reduce erosion.	• Tropical storm events • Droughts • Levees	N/A
25	Surface Elevation	Surface elevation is the height of the land surface relative to a datum. Common datums include mean sea level, NAVD88, WGS84. The elevation of land relative to nearby water levels is a determinant of inundation of wetlands.	• Subsidence	• House elevations • Forested non-wetland area • Wetland area • Structure elevation • Barrier island area (subaerial)
26	Water Elevation	Water elevation refers to the height of the water surface relative to a common datum. Common datums include mean sea level, NAVD88, WGS84.	• Sea level and tides • Open water	N/A
27	Wave height, period, and direction	Wave height is the distance measured from the trough to the wave crest. Wave period is the time it takes for one wave cycle to pass a fixed point. Wave direction refers to the direction in which a wave originates.	• Tropical storm events	N/A

Parameter		Description	Inputs	Outputs
28	Wetland area	Wetland area quantifies the amount of land composed of wetland communities (see wetland vegetative communities). Vegetative features in wetlands can break offshore waves, attenuate wave energy, slow inland water transfer and increase infiltration (USACE, 2013).	• Wetlands • Surface elevation	N/A
29	Wind speed and direction	Winds associated with local weather, winter storms, and tropical storms can influence estuarine water elevation by increasing or decreasing water levels, depending on their speed and direction. High winds can also cause damage to properties.	• Tropical storm events	N/A

Table 9. Strategic Infrastructure and Commercial Assets parameters identified in the protection framework needed to assess system condition and dynamics for SWAMP.

	Parameter	Description	Inputs	Outputs
30	Locations	The location of strategic infrastructure and commercial assets is needed for planning where risk reduction measures can provide benefit.	• Strategic infrastructure • Commercial assets	N/A
31	Presence of hazardous materials	The presence of hazardous materials in strategic infrastructure and commercial assets should be identified in order to plan where risk reduction measures can provide benefit.	• Strategic infrastructure • Commercial assets	N/A
32	Size or capacity	The size of strategic infrastructure and commercial assets is needed for planning of risk reduction measures. It includes information on the actual structure, the type of operations, facilities, and employment.	• Strategic infrastructure • Commercial assets	N/A

	Parameter	Description	Inputs	Outputs
33	Structure elevation	The elevation of the structure at its lowest floor (including the basement) is measured relative to base flood elevation. Base flood elevation is the computed elevation to which floodwater is anticipated to rise during the base flood. It can be used to track flood risk in a community and calculate flood insurance premiums.	• Strategic infrastructure • Commercial assets	N/A

PATH FORWARD

This report was designed to outline the parameters needed to understand change in the coastal system as the 2012 Coastal Master Plan and the broader coastal protection and restoration program is implemented. However, this report does not address the design of the monitoring program, such as spatial or temporal frequencies of data collection efforts, nor does it prioritize monitoring efforts. Future work will identify data gaps and monitoring needs by using this document, along with the data inventory that was developed concurrently with this document, to guide the development of an experimental design. The experimental design should be informed by statistical concepts (e.g., power analysis, probability sampling) that can aid in determining adequate sample sizes needed to detect significant change and distributing samples across the landscape. Such an assessment of monitoring needs must also be informed by knowledge of near-term project implementation in order that pre-project data collection can be conducted as appropriate.

Design of the monitoring program will also require an understanding of how the data collection efforts will be used in AM and other decision-making processes. Well-formulated and tractable questions are often cited as essential for a successful long-term monitoring program in order to justify the monitoring expense and effort (Lindenmayer & Likens, 2009). The framework represents a key step in the development of such questions with a focus on the processes driving coastal change. The nature of the implementation program is also a necessary ingredient; this integration of data needs, data availability and decision making is essential to ensure coastal restoration and protection is founded on a sound basis of data and knowledge.

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Appendix I: Restoration and Protection Conceptual Models

APPENDIX I – RESTORATION AND PROTECTION INFLUENCE DIAGRAMS

Table 1. Restoration Influence Diagram. Drivers are organized within general categories for visual purposes, only. The arrangement of individual responses was made to conform to the layout of this report and does not represent any hierarchy. The classification of responses is designated by the color scheme shown in the legend.

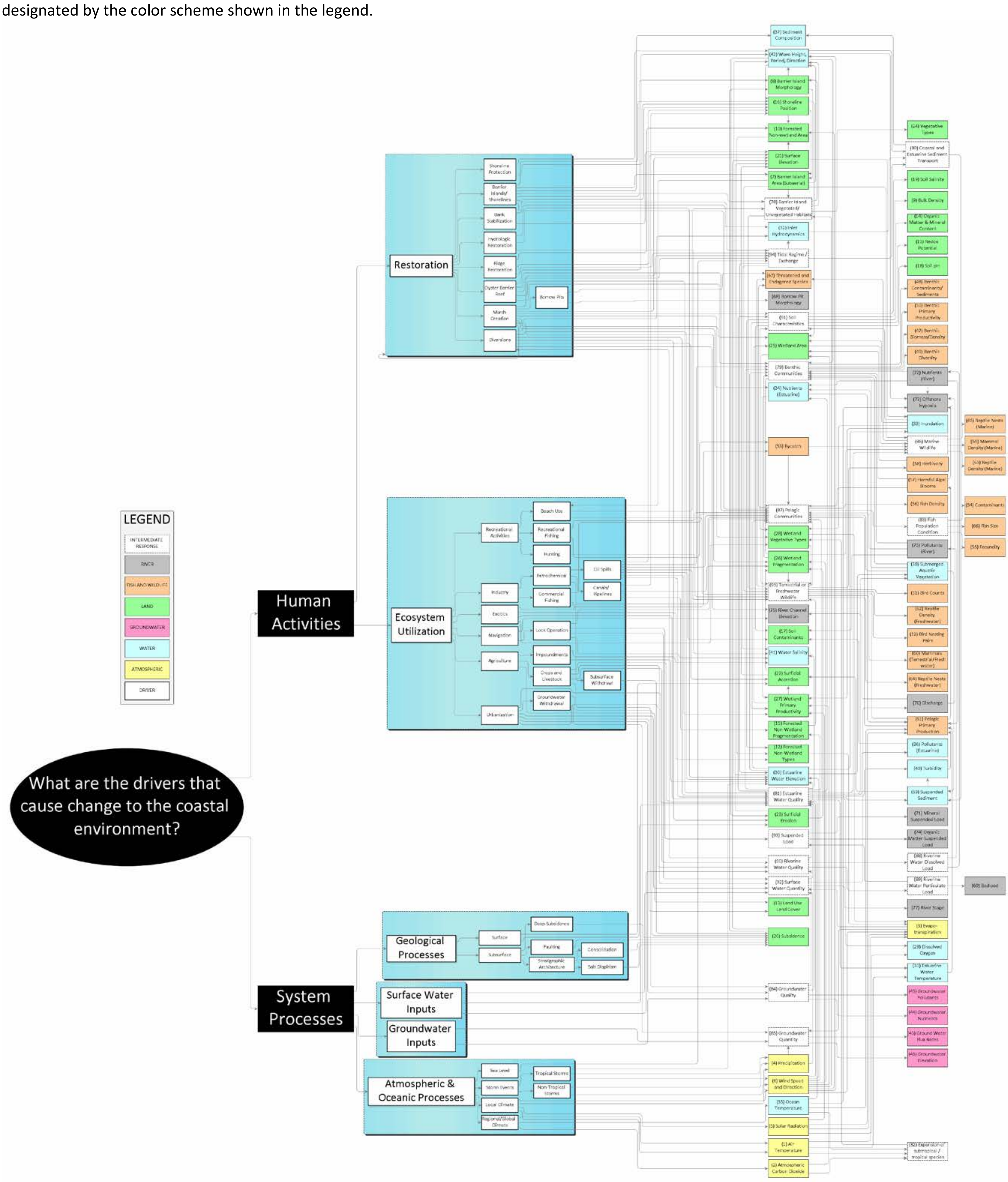

Table 2. Protection Influence Diagram. Drivers are organized within general categories for visual purposes only. The arrangement of individual responses was made to conform to the layout of this report and does not represent any hierarchy.