Monitoring and Adaptive Management Activity Implementation Plan

Quantifying Restoration Impacts on Wetland Ecosystem Health and Carbon Export

Introduction

The Deepwater Horizon (DWH) oil spill settlement in 2016 provides the Natural Resource Damage Assessment (NRDA) Trustees (Trustees) up to $8.8 billion, distributed over 15 years, to restore natural resources and services injured by the spill. As described in the DWH oil spill Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (PDARP/PEIS) (DWH NRDA Trustees, 2016), the Trustees selected a comprehensive, integrated ecosystem approach to restoration. The Final PDARP/PEIS considers programmatic alternatives, composed of Restoration Types, to restore natural resources, ecological services, and recreational use services injured or lost as a result of the DWH oil spill incident. As shown in the PDARP/PEIS, the injuries caused by the DWH oil spill affected such a wide array of linked resources over such an enormous area that the effects must be described as constituting an ecosystem-level injury. The PDARP/PEIS and information on the settlement with BP Exploration and Production Inc. (called the Consent Decree) are available at the Gulf Spill Restoration website.

Given the unprecedented temporal, spatial, and funding scales associated with the DWH oil spill restoration effort, the Trustees recognized the need for robust Monitoring and Adaptive Management (MAM) to support restoration planning and implementation. As such, one of the programmatic goals established in the PDARP/PEIS is to “Provide for Monitoring, Adaptive Management, and Administrative Oversight to Support Restoration Implementation” to ensure that the portfolio of restoration projects provides long-term benefits to natural resources and services injured by the spill (Appendix 5.E of the PDARP/PEIS). This framework allows the Trustees to evaluate restoration effectiveness, address potential uncertainties related to restoration planning and implementation, and provide feedback to inform future restoration decisions.

The Louisiana Trustee Implementation Group (LA TIG) MAM Strategy (LA TIG, 2021) has identified a need to “Contribute to maintaining and restoring ecosystem-scale condition and resilience at coastwide, basin, and subbasin scales” as a high-level objective under the Cross-Restoration Type. Under this high-level objective is the fundamental objective to “maximize the combined benefits of the various Restoration Types and approaches across the overall restoration portfolio (PDARP Section 5.5.1) (Cross-Restoration #1)”. To develop a Specific, Measurable, Achievable, Relevant, appropriate Timeline (SMART) objective, the LA TIG has identified that a MAM effort is needed to “Quantify wetland net ecosystem carbon balance at pre-spill/post-spill time scales and basin/sub-basin spatial scales, including export to nearshore Gulf of Mexico” (Cross-Restoration #1b). The MAM activity described here will include suggested activities provided in the LA TIG MAM Strategy “Within the next 5 years, targeted numerical modeling based upon available/collected data to calculate carbon capture of flora, fauna, and soils, associated with restoration portfolio; synthesize as carbon budget and calculate carbon export to nearshore marine systems”, including quantifying carbon capture of flora and soils, and export of dissolved and particulate carbon to adjacent estuarine waters. Therefore, additional activities beyond this proposal will be needed to address the remaining MAM needs to quantify faunal carbon and export to the nearshore environment (beyond estuarine boundary as defined by NOAA) and calculate carbon export to nearshore marine systems.

Purpose of this document

This MAM Activities Implementation Plan (MAIP) describes the MAM activity, "*Quantifying restoration impacts on ecosystem health and carbon export*" to address MAM priorities identified within the Louisiana Trustee Implementation Group (LA TIG) MAM Strategy for Cross Restoration Fundamental Objective #1 (LA TIG, 2021). Specifically, this document outlines a MAM activity for quantifying net ecosystem carbon balance at pre-spill/post-spill timescales and basin/sub-basin spatial scales, including export from wetlands to estuarine coastal waters adjacent to Gulf of Mexico, directly addressing most of the need identified by the LA TIG (Cross-Restoration #1b) to develop and document a SMART Objective. This MAM activity is consistent with the LA TIG MAM Strategy and the DWH Final PDARP/PEIS and partially fills an information gap for a key SMART objective related to assessing the impact of restoration activities on coastal wetland health and carbon sequestration as described above. This document provides information about the activities to be implemented and the data gaps and uncertainties they will address.

Monitoring and Adaptive Management: Quantifying impacts of restoration activities on net ecosystem carbon balance in wetlands and export to nearshore habitats.

This MAM MAIP describes a MAM activity to partially address key Cross Restoration Type knowledge gaps (i.e., MAM need) identified by the LA TIG that would need to be filled to develop associated SMART Objectives. This MAM activity is intended to support evaluation of regional restoration outcomes within the LA TIG Restoration Area; perform data collection and model development; resolve critical information gaps and uncertainties for restoration planning and informing restoration decision-making. This document provides information about the MAM activity and the data gaps and uncertainties it will address; describes the applicability to the LA TIG MAM Strategy; describes the consistency with the programmatic alternative selected by the DWH Trustees in the PDARP/PEIS, OPA, and compliance with NEPA.

This activity will collect data and develop a carbon budget model to assess the impacts of restoration activities on carbon sequestration, which will inform the approach identified in the PDARP/Cross Restoration Type: "maximize the combined benefits of the various Restoration Types and approaches across the overall restoration portfolio".

Type of Project: Targeted data collection and analysis, programmatic MAM

Restoration Type: Cross Restoration Type

Fundamental Objective: Cross Restoration Type, Fundamental Objective #1: "Maximize the combined benefits of the various Restoration Types and approaches across the overall restoration portfolio".

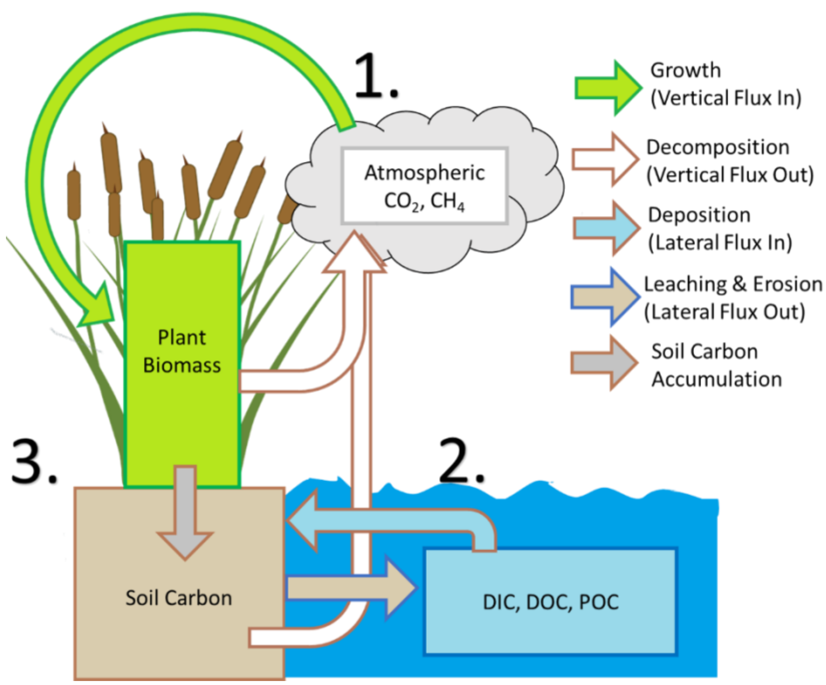
MAM SMART Objective: The proposed activity will partially satisfy the MAM need to develop SMART objective 1.b. to "Quantify wetland net ecosystem carbon balance at pre-spill/post-spill time scales and basin/sub-basin spatial scales, including export to nearshore Gulf of Mexico". The proposed MAM activity will directly quantify wetland net ecosystem carbon balance at pre-spill/post-spill time scales and basin/sub-basin spatial scales, including export of dissolved carbon to adjacent estuarine waters. The spatial extent of the proposed activity will focus on wetlands and estuarine waters and will not extend to the nearshore environment; therefore, additional future activities are needed for to address the nearshore MAM need.

MAM Activity Description

Background

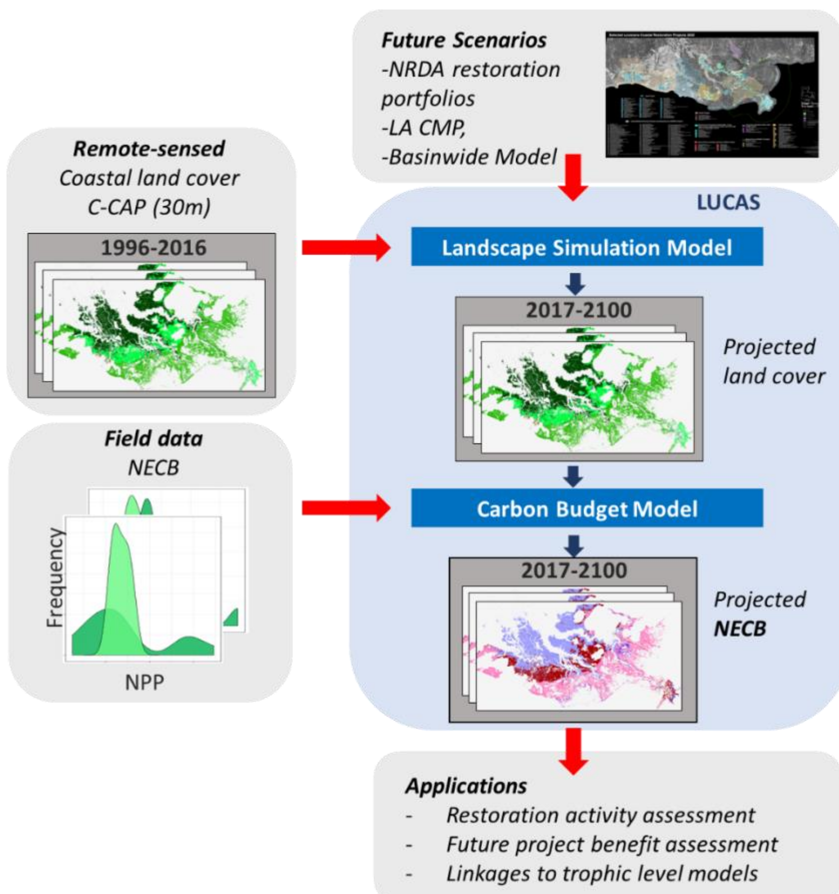
Net ecosystem carbon balance (NECB) is the sum of carbon entering the ecosystem minus the carbon leaving the ecosystem (Figure 1). NECB measures 3 primary carbon fluxes: 1. vertical gas flux, 2. lateral aquatic flux, and 3. changes to soil carbon storage, to determine whether the ecosystem is a net sink (carbon sequestration) or a net source (carbon export) of carbon. Because NECB is an integrative measure of ecosystem productivity, it serves as a strong indicator of ecosystem health. Generally, negative NECB represents a degrading system, where the majority of energy is leaving the system (carbon export). In contrast, positive NECB represents a healthy system, where energy is being stored (carbon sequestration). For coastal marshes, negative NECB is associated with increased vulnerability and a greater risk of conversion to open water. Therefore, a primary goal of restoration is to create marshes with a positive NECB that are more resilient and have high rates of carbon sequestration. To address the fundamental objective to "Maximize the combined benefits of the various Restoration Types and approaches across the overall restoration portfolio", we propose to conduct targeted data collection and model development to estimate NECB in a fresh marsh and a salt marsh ecosystem, which will provide a baseline for comprehensive assessments of restoration activities in coastal Louisiana.

Figure 1. Net Ecosystem Carbon Balance (NECB) represented by **1.** Vertical gas C fluxes, **2.** Lateral aquatic C fluxes, and **3.** Soil C storage, with export to estuarine habitats.



Furthermore, NECB provides critical information about export of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC) and particulate organic carbon (POC) from vegetated wetlands to adjacent estuarine waters, where the lateral aquatic flux of carbon provides the basic fuel for complex food webs, including fisheries and other fauna, across these estuarine habitats. For example, lateral aquatic export of carbon from the wetland supports adjacent estuarine benthic communities, which then provide habitat and/or trophic support for higher trophic level fauna. Carbon exported from wetlands also becomes mineralized in the water providing nutrients for phytoplankton, forming the base of the pelagic food web. Simply, carbon is the currency of the estuarine food web and quantifying the source of this currency is critical to assessing trophic level function. Our approach provides a crucial input for mixing models of the carbonate system of the wetland-estuary-ocean continuum that determines how much DIC and alkalinity is exported from wetlands to the open ocean. Such modeling would require additional efforts beyond the scope of this proposal, though synergistic efforts could be found with other projects at USGS. Also, biomass of fish/nekton represent additional carbon fluxes from estuary to ocean that would need to be further quantified using appropriate models (such as the Comprehensive Aquatic Systems Model (CASM)), which may use our wetland carbon exports (such as POC) as an inputs to aquatic systems (Lewis et al., 2021).

Figure 2. Conceptual model of the LUCAS decision-support tool.



To assess the impact of restoration on coastal wetland NECB, we have developed an assessment tool using a modeling framework composed of integrated sub-models of landscape change and carbon dynamics, where changes in land cover (pre-spill/post-spill time scales) dictate changes in carbon stocks and fluxes (Figure 2, Figure 4), to project historic and future estimates of NECB with uncertainty estimates. Developed by the USGS over the past decade, the **L**and **U**se **CA**rbon **S**imulator (LUCAS) model has assessed management activities in terrestrial ecosystems at multiple scales (Daniel et al., 2018; Sleeter et al., 2022), and the wetland model has been developed and validated using *in-situ* field data collected over the last decade in 24 sites across the Mississippi River Deltaic Plain (Holm et al., 2016; Baustian et al., 2017; 2021; Krauss et al., 2016; Stagg et al., 2017; 2018; Cadigan et al., 2022; Schoolmaster et al., 2022). Leveraging over a decade of USGS data collection and research from 24 sites in the region, this proposed activity would build off the existing model to expand to all coastal wetlands of Louisiana, incorporate improved estimates of NECB, including export from vegetated wetlands to adjacent estuarine waters. Accurately assessing NECB requires quantifying the lateral flux component, and there are currently only two other coastal sites in the United States that use this approach in a comprehensive way. Using this approach, we will provide spatially-explicit assessments of NECB for all coastal wetlands in Louisiana, at 30-meter resolution, allowing trustees to see *where* and how restoration activities impact NECB. Spatially-explicit assessments with uncertainty are critical to informing ecosystem restoration and conservation performance within the context of NRDA.

Built upon our existing LUCAS model, our framework will allow models of restoration and carbon dynamics to continually adapt and improve as new data become available and as understanding evolves over time. For example, results from the Louisiana Coastal Master Plan (LA CMP, 2023) will directly inform the LUCAS land cover change sub-model, providing high resolution wetland class maps that will improve historic and future scenarios of land cover change and NECB. The framework and information produced will allow decision makers involved in the design and implementation of Louisiana's restoration portfolios to assess and compare alternative model projections for local accuracy and relevance, thus building confidence over time in their forecasts.

Objectives and Tasks

The objective of this activity will be to provide Trustees with baseline estimates of net ecosystem carbon balance (NECB) for a fresh marsh and salt marsh that will be used to develop a decision support tool that will assess the impact of various restoration types and approaches on coastal wetland ecosystem health, as indicated by NECB. The targeted data collection at the fresh marsh and salt marsh sites leverages years of USGS field data collection from 24 coastal wetland sites (including the two proposed monitoring sites) across the Mississippi River Deltaic Plain used to parameterize and validate the carbon budget model. The targeted data collection from the fresh marsh and salt marsh monitoring sites will be fully integrated over space and time to provide a robust estimate of NECB. In combination with the extensive existing field dataset, the targeted NECB data will be used to develop a decision support tool that will provide spatially-explicit assessments of NECB for all coastal wetlands in Louisiana, allowing Trustees to see where the oil spill and restoration activities affect ecosystem health.

This activity will fill many of the knowledge gaps necessary to develop a SMART objective (#1b) to "Quantify wetland net ecosystem carbon balance at pre-spill/post-spill time scales and basin/sub-basin spatial scales, including export to nearshore Gulf of Mexico", which will address the fundamental objective to "Maximize the combined benefits of the various Restoration Types and approaches across the overall restoration portfolio". The MAM activity described here will include specific tasks provided in the LA TIG MAM Strategy "Within the next 5 years, targeted numerical modeling based upon available/collected data to calculate carbon capture of flora, fauna, and soils, associated with restoration portfolio; synthesize as carbon budget and calculate carbon export to nearshore marine systems". The activity proposed here will focus on quantifying carbon capture of flora and soils, and export of dissolved and particulate carbon to adjacent estuarine waters. Therefore, additional activities beyond this proposal will be needed to address the remaining MAM needs to quantify faunal carbon and export to the nearshore environment.

This activity will include several key tasks, including:

Task 1: Targeted data collection to develop baseline NECB in two major wetland ecosystems at the upper and lower end of the salinity gradient, a fresh marsh and a salt marsh. Three primary components of NECB: vertical and lateral fluxes, and soil storage, will be quantified at two established monitoring in the Barataria Basin (Figure 3). The fresh marsh site is co-located with CRMS3166, and the salt marsh site is co-located with CRMS0224.

a. ***Quantify Vertical Gas C Fluxes*** including CO_2 and CH_4, for two years in a fresh marsh and a salt marsh using eddy covariance towers;
b. ***Quantify Lateral Aquatic C Fluxes*** including DIC, DOC, POC, TA, for two years in a fresh marsh and a salt marsh using continuous and discrete porewater and surface water sampling to i) quantify water fluxes (i.e., discharge), ii) quantify lateral carbon fluxes, and iii) identify carbon sources;
c. ***Quantify Soil C Storage and Turnover*** in a fresh marsh and a salt marsh using gamma spectroscopy and 14C dating;

d. ***Produce NECB Budget*** for the fresh marsh and the salt marsh site;

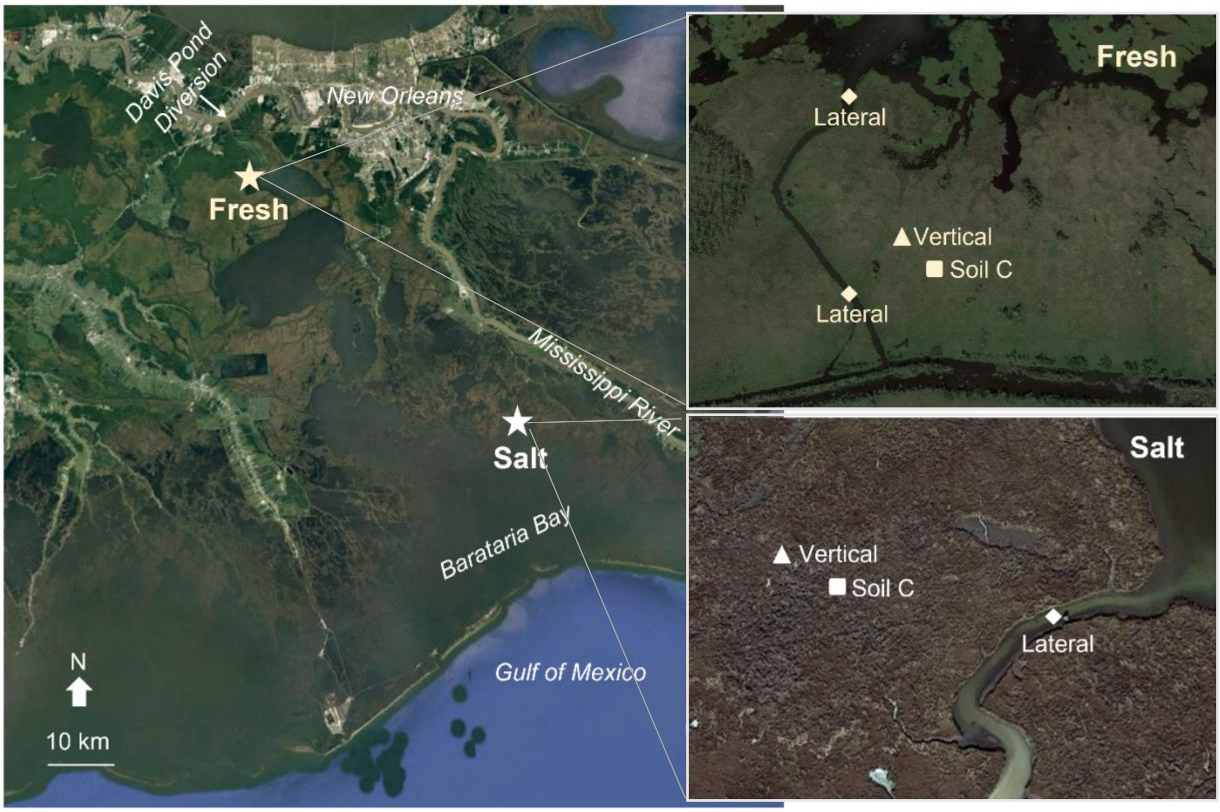


Figure 3. Monitoring stations (fresh marsh, CRMS3166: 29.86° N, 89.29° W; salt marsh, CRMS0224: 29.49° N, 89.91° W) in Barataria Basin, Louisiana. The vertical flux station, lateral flux station, and soil C site locations were established in the salt marsh site in 2019. The vertical flux station in the fresh marsh was also established in 2019. The location of the lateral flux stations and soil C sites in the fresh marsh will be confirmed following initial hydrologic characterization of the fresh site (tentative locations shown here).

Task 2: Modeling to quantify historic and future NECB in coastal wetlands and export to adjacent waters under multiple scenarios of restoration. The Land Use Carbon Simulator (LUCAS) model (Figure 4) will be parameterized, calibrated and validated using the data collected from Task 1.

a. ***Develop Landscape Change Model*** for capturing the changes over time of two wetland land cover classes: palustrine emergent wetland (i.e. fresh marsh) and estuarine emergent wetland (i.e. salt marsh) - for use within the LUCAS framework;
b. ***Develop Carbon Budget Model*** to provide updated estimates of NECB for two wetland state classes - palustrine emergent wetland (i.e. fresh marsh) and estuarine emergent wetland (i.e. salt marsh) - for use within the LUCAS framework;

c. ***Quantify Impacts of Oil Spill and Restoration Activities on NECB*** across all basins in coastal Louisiana including projections of historic (pre-spill/post-spill) and future estimates of NECB with uncertainty estimates.

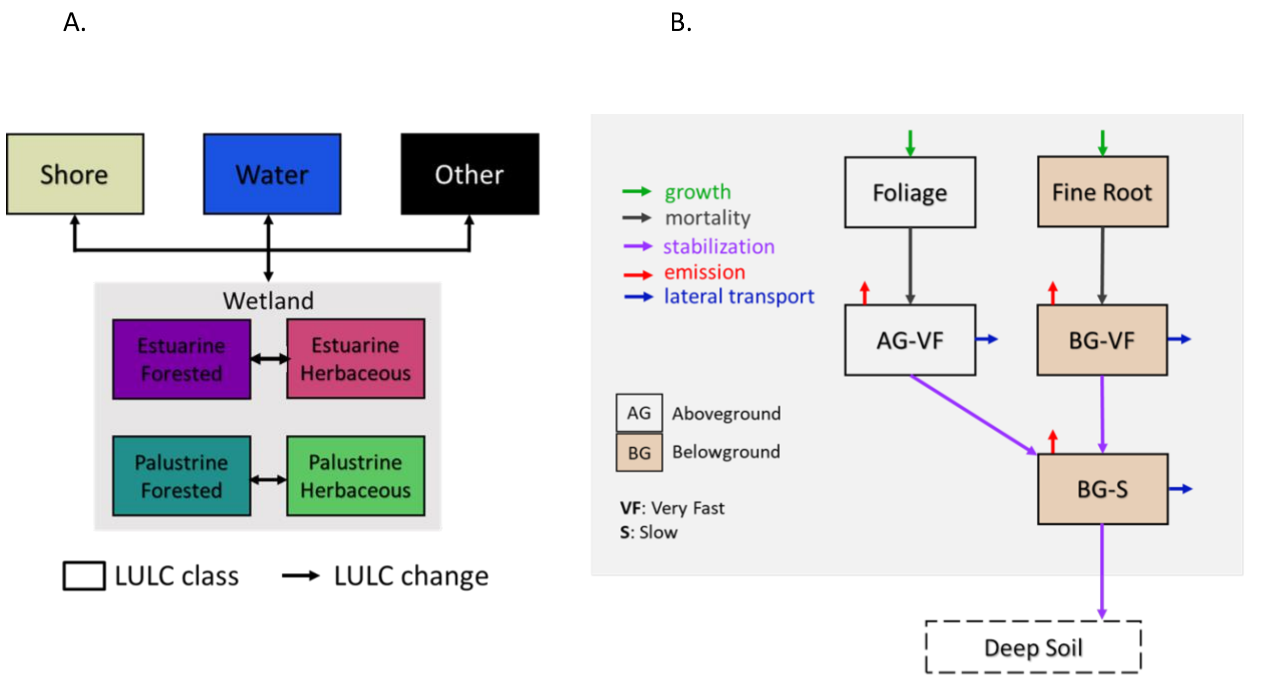


Figure 4. LUCAS nested sub-models. A. Land use land cover change model illustrating potential transitions (arrows) among wetland classes (boxes). B. Carbon budget model illustrating carbon stocks (boxes) and fluxes (arrows) for the palustrine emergent wetland class (fresh marsh). A unique carbon budget model is developed for each cover class.

Intended Outcomes

The results from this activity will provide a cross-restoration assessment tool, and it will inform the development of the SMART objective Cross Restoration Type 1.b. The assessment tool can be used by NRDA decision makers to identify the historic impacts of previous land management activities and future benefits (or losses) of planned activities to coastal wetland carbon sequestration. The results from this activity will provide spatially-explicit NECB estimates for two major wetland habitats, and quantify export from the vegetated wetlands to adjacent open waters. The scenario-based modeling framework will allow users to define specific restoration scenarios (for example, Mississippi River diversion) and generate projections that quantify the impact of those activities on NECB. Because the model output, NECB, is an integrative metric of ecosystem resilience, it provides data on both the sustainability of habitat in the face of stressors (such as sea-level rise and hurricanes), as well as the amount of carbon available to support wetland and aquatic food webs in the estuary complex. Annual meetings (2-days each) will be held with Trustees to identify the scenarios of interest and ensure relevant outcomes. The output from this activity will leverage existing funded projects, including Coastwide Reference Monitoring System (CRMS), the Coastal Protection and Restoration Authority's (CPRA) Louisiana Coastal Master Plan, and the Basinwide Model, and will compliment other MAIPs funded by LA-TIG, such as the

Oyster MAIP (#302) and the Lower Trophic Level MAIP (#269), that could use the lateral carbon flux data to improve their modeling efforts, independently from this activity. Future updates to coastal Louisiana ecosystem modeling could also benefit from this additional information and data describing lateral labile C fluxes from marshes to immediately adjacent estuarine waters.

Outputs of all Tasks from this activity:

- Annual progress reports, including progress on deliverables and working group feedback.
- Final report with estimates of a closed carbon budget, net ecosystem carbon balance, for fresh and salt marsh ecosystems.
- Annual working group meetings (2 days) with Trustee subject matter experts to develop features of the decision support tool (land use change/restoration scenarios).
- Coastwide 30-m scale projections of NECB for multiple future restoration scenarios, published as a USGS ScienceBase data release.
- Tabular NECB data for multiple future restoration scenarios, published as a USGS ScienceBase data release.
- Databases used to estimate NECB, component databases (e.g. DIC/DOC/POC fluxes and soil carbon accretion rates (gC m^{-2} y^{-1}), will be published as tabular data releases through USGS ScienceBase. Vertical flux data ($C0_2/CH_4$) will be published as a tabular data release through Ameriflux.
- Publicly available desktop model with tutorial, and all code published in R and within the free, publicly available LUCAS model computing environment.
- Develop a synthesis report detailing the coastal carbon budget for wetland and export to adjacent estuarine water that can be incorporated in a future draft objective (CRT 1.b) for TIG consideration.

Budget

The total budget requested for this MAM activity is $4,107,927. The MAIP will leverage past LA TIG investments in monitoring activities (e.g. CRMS) as well as other past investments in LA coastal ecosystems (e.g., historical USGS datasets). This MAIP will leverage existing investments in CRMS.

Table 1. U.S. Geological Survey budget for the net ecosystem carbon balance monitoring and adaptive management activity by general cost category for the total study duration (FY24-FY28).

Cost Items	***Cost Estimate***
Labor and Benefits	$1,225,943
Travel	$89,861
Contracts	$1,640,930
Supplies and Equipment	$198,892
Bureau Indirect Support	$701,022
DOI Indirect Support	$206,449
SUBTOTAL	**$4,063,097**
Trustee Participation CPRA	$25,000
Trustee Participation NOAA	$19,200
TOTAL ESTIMATED COST	**$4,107,927**

Activity implementation

Task Descriptions

Task 1: Targeted data collection to develop baseline NECB in two major wetland ecosystems at the upper and lower end of the salinity gradient, a fresh marsh and a salt marsh

a. ***Quantify Vertical Gas C Fluxes:*** Vertical carbon gas fluxes (CO_2 and CH_4) will be measured using eddy covariance methodology for two years in the fresh marsh (CRMS3166) and the salt marsh (CRMS0224) (Burba, 2013) (Figure 5). The eddy covariance towers (~ 3 m tall) are located on semi-permanent platforms (3 x 3 m) elevated 1 m above soil surface within uniform wetland areas. Horizontal supporting booms are used to attach instruments far enough as to not disturb air flow. Eddy covariance techniques measure 3-dimensional wind speed and gas concentrations at high temporal resolution (~10 times per second) from the air flow of rotating eddies, which vary in size and have both vertical and horizontal components. Vertical half-hourly gas fluxes (i.e. total amount of gases moving though a unit area) will be calculated from, the covariance of the vertical wind velocity and gas concentration for the area of interest (i.e. footprint). The footprint of each half-hourly flux depends on sensor height, horizontal wind velocity, canopy height and roughness.

   Eddy covariance instruments will record 10 Hz measurements of H_2O, CO_2 and CH_4 concentrations using open path gas analyzers (LI-7500 and LI-7700, LI-COR Environmental) and wind direction/speed using sonic anemometer (Windmaster Pro, Gill Instruments). We will also record environmental covariates at half-hourly timescale: soil temperature, air temperature, relative humidity, downwelling and upwelling long and shortwave radiation, downwelling photosynthetically active radiation. Using EddyPro software (LI-COR Environmental) we will process 10 Hz measurements to half-hourly estimates on biweekly basis. Biweekly maintenance (24 trips/year) will be required to maintain optics of gas analyzer sensors and other consumables.

In the first year, measurements of CO_2 and CH_4 respiration fluxes will be estimated once per month using chamber measurements that include plants and soil (n=9 per site), using a GasScouter portable gas analyzer (Picarro G4301, Inc.). Chamber dimensions will vary by the sampling type (i.e. soil-atmosphere interface vs water-atmosphere interface) and by appropriate height for vegetation. This will provide us with an estimate of the contribution of different cover patches (i.e. vegetation

Figure 5. Vertical flux station located in the fresh marsh. Vertical greenhouse gas data collection from A) chambers and B) eddy covariance tower.

types, bare soil, open water) to ecosystem vertical flux. We will assess agreement of flux rates at the chamber and ecosystem scales using spatial analysis of patch-type contribution to the eddy covariance footprint and remotely sensed landcover. Eddy covariance footprint will be modeled for every half hour flux implemented in EddyPro software (Kjiun, 2004). Planet Scope imagery (~3 m resolution) will be used to classify the landscape using randomForest package (Liaw, 2002). Ecosystem carbon uptake and emissions will be analyzed in respect to environmental drivers and disturbances, such as storm events. The r package REddyProc gap filling algorithms will be used for summarizing monthly, seasonal and annual fluxes, based on meteorological and hydrological covariates (Wutlzer, 2018). Vertical carbon fluxes will be integrated with lateral fluxes and burial at appropriate timescales as specified in NECB Budget section below.

b. ***Quantify Lateral Aquatic C Fluxes:***

Quantify discharge: Bottom-mounted, upward-looking acoustic Doppler profilers (ADPs) will be deployed at each site to measure current velocity profiles (at multiple depths throughout the water column) continuously. The ADP (20 cm x 10 cm) will be mounted on a horizontal metal plate attached to a platform (2, 4”x4” posts) installed in the waterway that can be moved vertically with a winch to deploy it at the bottom of the channel and to remove it from the water for periodic servicing (Figure 6). In addition to current velocity measurements, the bottom-mounted ADPs are also equipped with a vertical beam to measure distance to the water surface, which can serve as a proxy for water depth. ADPs will be deployed at the salt marsh site (CRMS0224) and the fresh marsh site (CRMS3166) to measure oscillatory water fluxes through the tidal creek. ADPs will be serviced (cleaned, downloaded, re-powered) approximately monthly, and data will be collected for three years.

A cross-channel transect will be established within 20 m of each ADP. During each ADP servicing visit, a series of at least four discharge measurements will be made with a raft-mounted acoustic Doppler current profiler (ADCP). As it is pulled across a waterway along a transect perpendicular to the channel axis and water flow, the ADCP measures water velocity in multiple depth cells from the surface to bottom, and also water depth, and from this information calculates water flux (i.e., discharge) in the waterway across the transect. Additionally, the ADCP calculates the cross-sectional area of the transect and can derive mean cross-sectional velocity by dividing the measured discharge by the measured cross-sectional area. Following Levesque and Oberg (2012), an index-velocity rating will be assembled at each ADP station. The basic premise behind the index-velocity approach is that discharge ($m^3\ s^{-1}$) is the product of channel cross-sectional area (m^2) and mean cross-sectional velocity ($m\ s^{-1}$), and that the cross-sectional area is primarily determined by stage (water level) and the mean cross-sectional velocity varies directly with the index velocity (the index velocity is the velocity measured by the ADP). The stage-area relation is assessed by regressing the measured cross-sectional area from ADCP transects against the coincident water level measured by the deployed ADP, and the mean cross-sectional velocity obtained from the ADCP transects is regressed against the coincident index velocity measured by the deployed ADP. Using the resulting regression equations, a time series of cross-sectional area can be produced from a time series of water level, and a time series of mean cross-sectional velocity can be produced from a time series of index velocity. A time series of water discharge can then be calculated as the product of the area and cross-sectional velocity time series. The time series water discharge will then be used to quantify lateral carbon fluxes.

Figure 6. Lateral flux station located at the salt marsh site. The acoustic doppler profiler (ADP), YSI, EXO2 multiparameter water quality sonde and the Pro-Oceanus dissolved CO2 data logger are mounted on the platform.

<u>Quantify lateral carbon fluxes:</u> Lateral carbon fluxes will be calculated by multiplying high-frequency water fluxes (i.e., discharge) and high-frequency carbon concentrations. High-frequency carbon concentrations can be derived by multilinear regression models between time-series sensor measurements and discrete carbon concentrations (Wang et al., 2016; Bogard et al., 2020). Time series data will be collected at three flux stations. Two new stations will be established and monitored at the fresh marsh site and one existing station at the salt marsh will continue to be monitored (Figure 3). At each time series lateral flux station, pH, dissolved O_2, turbidity, fDOM, salinity and temperature will be continuously recorded using a YSI EXO2 Multiparameter Water Quality Sonde with pH/ORP, optical DO, turbidity, fDOM, conductivity/temperature sensors installed. At each lateral flux station, dissolved CO_2 (pCO_2) will also be continuously measured using a Pro-Oceanus dissolved CO_2 datalogger system. Both of the YSI EXO2 Sonde and the Pro-Oceanus CO_2 datalogger will be mounted on a platform installed in the waterway (Figure 6).

Monthly trips will be made to maintain the YSI EXO2 and CO_2 sensors, which are prone to biofouling. During each of the maintenance trip, the dirty field sensors will be replaced with cleaned and calibrated sensors to maintain high quality of the sensor data. A pre-established data calibration procedure will be conducted in the field to evaluate the drift of the sensors during the month-long deployment. At least five YSI EXO2 sondes and five CO_2 sensors will be available for time-series data collection to allow the sonde/sensor replacement/switch during monthly maintenance trips. The recovered field sensors will be brought back to the laboratory for data downloading, cleaning, and calibration.

We plan to collect discrete water samples for DIC, DOC, TA, and POC analyses from surface and bottom of the tidal creek when arriving and leaving the lateral flux stations during the monthly sensor maintenance trips. Additional trips to the fresh marsh will be made based on the Davis Pond Diversion operation to collect discrete carbon samples from the tidal creek (surface and bottom) and porewater (three depths: 10, 25, 80 cm) for a better coverage of the carbon concentration range needed to develop regression-based carbon parametrization models. All discrete carbon samples will be analyzed at the Louisiana State University Marine Chemistry lab for DIC, DOC, TA, and POC using well established protocols (Santos et al., 2019; He et al., 2022). Discrete YSI parameters will also be measured in-situ using a handheld meter at the same time and location of the discrete carbon sample collection for regression analysis and to further evaluate data integrity. The salt marsh site currently has sufficient discrete data coverage to construct the regression models as a part of a different project.

Discrete carbon concentrations and corresponding YSI EXO2 data will be utilized to develop multi-regression-based models relating YSI parameters to carbon concentrations. This will allow the development of continuous carbon species concentrations in these water bodies from the YSI time-series data collected at each lateral station. Lateral fluxes of carbon can be calculated using time series carbon concentration data together with discharge data to support carbon mass balance calculations.

Identify carbon source: Lateral DOC and DIC exports can be derived from multiple sources, including produced outside the wetland (e.g. allochthonous) and produced within the wetland (e.g. autochthonous). For NECB estimates, we are primarily interested in wetland-derived carbon. Geochemical tools can help identify source. We will use the stable C isotope signature of DOC and DIC to identify carbon derived from Spartina-dominated marshes and from marine sources (Raymond and Bauer 2001; Mortazavi and Chanton 2004; Bouillon et al. 2003). Discrete surface water DOC and DIC samples for isotopic analysis will be collected in glass jars concurrently with continuous lateral flux data to measure concentrations, with the same dataloggers described above for the lateral flux effort. Similarly, samples of end member carbon sources (e.g. porewater as representative of *Spartina* and wetland carbon and incoming water from the adjacent estuary) will also be collected concurrently with the lateral flux discrete sampling described above. We will then employ stable isotope mixing models to calculate the “actual amount of carbon” delivered from various sources in carbon within tidal channels (Ray et al. 2021). Isotope ratios for DOC, DIC, and POC samples from representative endmembers will be collected to define sources (marsh, marine) and analyzed according to: DOC on an OI Analytical Aurora 1030 TIC/TOC Combustion Analyzer coupled to an isotope ratio mass spectrometer at the USGS/WHOI Dissolved Carbon Isotope Lab (Lalonde et al., 2014); DIC on a GasBench II system interfaced to a Delta V Plus IRMS at the UC Davis

Stable Isotope Facility; POC on a Continuous-Flow Isotope Ratio Mass Spectrometer at the Marine Biological Laboratory Stable Isotope Laboratory.

c. ***Quantify Soil C Storage and Turnover****:*

Quantify soil C accretion rates and source: Soil carbon storage rates and stocks will be assessed at both sites, as this is a critical term in the NECB (Figure 1). CRMS site standard practice evaluates soil stocks to 24 cm and measures soil accretion through surface elevation change through time (e.g. feldspar marker horizons, typically ~10-15 years of data) (e.g. Suir et al. 2019). This approach is conducive to large spatially distributed sampling efforts, but does not provide the temporal resolution and extended time scale to address key components of the NECB as proposed here. We propose a new set of soil core analyses that provides both comparable data to integrate with existing CRMS soil core data, as well as the expanded temporal scale and soil organic carbon source measurements needed to evaluate soil organic carbon storage and turnover and integrate these fluxes and processes into the LUCAS model. New core collections will be done at the fresh site (CRMS3166), while at the salt marsh site (CRMS0224), existing data will be used (Baustian et al., 2021). Briefly, soil cores (1 to 2-meters long, n = 3 cores) will be collected from the marsh platform using a modified piston coring system to minimize compaction. With this method of soil core collection a gasketed-piston is placed inside the core barrel and placed on the marsh surface. Tension is placed on the piston and a vacuum essentially holds the soil in place as the core barrel is pushed down around the piston (see further field methods in Gonneea et al. 2019). The cores will be sectioned at 2-cm intervals to provide material for ^{210}Pb and ^{137}Cs analysis (0-~60 cm) on gamma counters and ^{14}C analysis (deeper depths >50 cm). Gamma analysis (n=~60 per core) will be done at the USGS WHSC Radioisotope Laboratory using planar-type gamma counters to measure ^{137}Cs, ^{210}Pb, and ^{226}Ra (to correct for supported ^{210}Pb) at 661.6, 46.5 and 352 KeV energies respectively (Canberra Inc., USA). The final gamma analysis depth will be determined based on the measured ^{210}Pb profile, with analysis ceasing once excess ^{210}Pb is below detection. Based on existing studies, this may be between 60 and 80 cm (Baustian et al. 2021). If a useable ^{137}Cs peak is detected, it will provide additional age constraint. In addition, to provide independent age information, ^{14}C analysis (n=3 per core) will be done at the National Ocean Science Accelerator Mass Spectrometry (NOSAMS) facility at Woods Hole Oceanographic Institution. The age data from these analyses will be implemented within a Bayesian framework (*rplum*, Aquino-Lopez et al., 2018) geochronology model which incorporates the decadal to century time scale of ^{210}Pb and ^{137}Cs with the multi-century time scale of ^{14}C to understand how rates of carbon storage have changed through time due to environmental drivers and management impacts. Variation in time can inform NECB models when processes operate on different time scales. An aliquot of sample will be ground in a ball mill and then analyzed for organic and inorganic carbon concentration and δ13C at the U.C. Davis Stable Isotope Facility with an Elementar Vario EL Cube elemental analyzer. Stable isotope data will be used to determine whether soil organic carbon is produced in situ (autochthonous) or produced outside the wetland ecosystem and stored in the soil (allochthonous), as these components are integrated into NECB separately. Accretion data from the age models (e.g. grams sediment/meter^2/year) and carbon analysis (e.g. weight percent carbon) will then be combined to produce measurements of carbon storage rates (e.g. grams carbon/meter^2/year). Importantly, the high temporal resolution age models from these cores will then be used to determine rates of soil C turnover (see next section).

Define soil C pools and turnover rates: Soil carbon consists of various pools that are characterized by different rates of decomposition, which ultimately impact soil carbon fluxes over both short and long-time scales. In addition, turnover time, or how long different soil carbon pools are stable for, is needed for the NECB calculation and LUCAS modeling (Task 2). We will assess soil carbon turnover time using thermal properties and reactivity indices characterized *via* ramped pyrolysis oxidation (RPO), which involves heating samples to 1000 °C and measuring the carbon evolved with a flow-through gas analyzer, producing thermographs. We will use the ratio of carbon evolved under low (200 °C–465 °C) versus high (465 °C–650 °C) temperatures to determine the ratio of reactive versus stable carbon pools using the Python package *rampedpyrox* (Hemingway et al., 2017a, 2017b). In addition, $\delta^{13}C$ and $F^{14}C$ of CO_2 evolved during RPO will be measured on select samples to assess carbon source and age. From the carbon source and age data, and the soil core chronologies produced (see previous section) at both sites, we will construct models of soil carbon turnover as described by first-order kinetics as the carbon concentration of various reactive pools changes with time (i.e., soil core chronology) (Manzoni et al., 2009; Luk et al. 2021). The RPO analysis and associated $\delta^{13}C$ and $F^{14}C$ measurements will be done on homogenized soil samples from various core depths at the NOSAMS facility.

d. ***Produce NECB Budget***: We will synthesize the primary production (vertical gas flux), respiration (vertical gas flux and soil cores), soil carbon storage (soil cores) and lateral flux measurements to determine the Net Ecosystem Carbon Balance (NECB; Chapin et al. 2006) for each marsh. Since these measurements inherently span a variety of time scales, for example from high frequency CO_2 measurements to lower temporal resolution soil carbon processes, we will integrate across yearly time scales to relate all fluxes. In addition, it is important to convert carbon fluxes to marsh area-normalized fluxes for each measurement. This is straight forward and readily defined for soil carbon fluxes, which are measured on discrete wetland soil samples, as well as gas fluxes where the footprint of the tower is determined from wind speed and direction. For lateral fluxes, the marsh drainage area that influences the dissolved and particulate fluxes will be assessed using a vegetation-corrected, LiDAR-derived digital elevation model (DEM), and a water drop analysis routine (Wang et al., 2016). Ultimately, NECB will be reported for each marsh in units of grams of carbon per square meter per year. The estimates of NECB and export will be used in Task 2 to update the LUCAS carbon budget model for both wetland habitats.

Task 2: Modeling to quantify historic and future NECB in coastal wetlands to nearshore habitats under multiple scenarios of restoration.

In this task the Land Use and Carbon Simulator (LUCAS; Sleeter et al., 2018, Sleeter et al., 2019, Sleeter et al. 2022) will be used to estimate changes in NECB in response to both past land cover change and future possible restoration activities (Figure 2). LUCAS is an open-source stochastic simulation model that links a spatially-explicit simulation model of landscape change with an empirically-based carbon budget model (Daniel et al., 2016, Daniel et al., 2018

a. **Develop Landscape Change Model:** The first step in preparing LUCAS for use in this project will be to parameterize its landscape change sub-model for the two wetland communities found in coastal Louisiana: palustrine emergent wetlands (i.e. fresh marsh) and estuarine emergent wetlands (i.e. salt marsh). Parameterization of this sub-model will be based on time series of historical remotely-sensed land cover data for the coastal Louisiana, separated into pre- and post-spill periods. Once parameterized, this landscape change sub-model will then be used to generate spatially-explicit simulations of pre- and post-spill wetland land cover change for the region.

b. **Develop Carbon Budget Model:** With a landscape change sub-model in place, the next step will involve parameterizing the LUCAS carbon budget sub-model for the region in order to track changes in NECB within these same two wetland communities (i.e. fresh and salt marshes). Data collected in Task 1 above will be used to fit this model specifically to conditions found in Louisiana coastal wetlands. With both the landscape change and carbon budget sub-models parameterized for coastal Louisiana wetlands, LUCAS will then be used to generate estimates of historical changes in NECB associated across both the pre- and post-spill historical periods.
c. **Quantify Impacts of Restoration Activities on NECB:** The final step under this task will be to use LUCAS to quantify the impacts of restoration activities on NECB across all basins in coastal Louisiana, including projections of historic (pre-spill/post-spill) and future estimates of NECB. Building on the actual historical land cover scenario outlined above (i.e. the historical "reference" scenario), in consultation with LA-TIG up to three alternative restoration scenarios will also be characterized, parameterized and run through the LUCAS model. These scenarios could include, for example, future with and without NRDA restoration activities. The difference between the NECB forecast for each of these alternative scenarios and the NECB forecast for the reference scenario would then represent a "best available science" estimate of the gain (or loss) in NECB associated with each management activity.

Timeline

The activities described above will be conducted over a five (5) year project implementation period (Table 2). Task 1, collecting data to estimate NECB for the fresh marsh and salt marsh site (vertical gas flux, lateral aquatic flux, and soil carbon storage) will occur during study years one, two and three. Analysis/synthesis of these datasets will occur during years three and four, and Task 1 will culminate with writing of the report describing the findings, lessons learned, gaps identified, etc. during the fourth year. Results from analysis and synthesis conducted during the four years will be integrated into development of the LUCAS modeling framework to be conducted during Task 2.

Task 2, which covers the development and application of the decision support tool using the LUCAS framework, will be initiated at the beginning of project year one and continuing for a total of five (5) years, ending in year five. Years one, two, and three will focus on the development of the landscape simulation model, carbon budget model, and scenario development. Year four will focus on calibrating the carbon budget model with results from Task 1 (integrated NECB estimates) and running the integrated LUCAS framework to assess historic and future scenarios on wetland NECB. Year five will culminate with writing of the report describing the findings of the model analysis. A synthesis to contribute to a future SMART objective for net ecosystem carbon balance will be developed during year five. Working group meetings with Trustee subject matter experts will be conducted during years one through five (two days per year) to facilitate the development of scenarios that are relevant to the trustees and identify remaining needs to develop the draft SMART objective.

Table 2. Summary of timeline for implementing the proposed MAM Activity.

Year	Task	Activities
1,2,3	1	Data collection: vertical gas flux, lateral aquatic flux, and soil carbon storage datasets.
3,4	1	Data analysis and synthesis: estimate NECB for fresh and salt marsh.
4	1	Final analysis and synthesis of NECB data, report writing for Task 1.
1,2,3	2	Development of landscape simulation model, carbon budget model and restoration scenarios.
4	2	Calibrate carbon budget model using Task 1 data and run integrated LUCAS model for historic and future scenarios.
1,2,3,4,5	1,2	Annual Trustee working group meetings
5	2	Finalize analysis of integrated LUCAS model, report writing for Task 2.
5	1,2	Development of initial SMART objectives report.

Data management and reporting

The DWH Trustees, as stewards of public resources under OPA, will inform the public on the MAM activity's progress and performance. Therefore, DOI will report the status of the proposed activity via the Data Integration, Visualization, Exploration, and Reporting (DIVER) Restoration Portal annually, as outlined in Chapter 7 of the PDARP/PEIS (*DWH* Trustees, 2016). All reports and final datasets created as part of this activity will also be stored on the DIVER Restoration Portal. Data storage and accessibility will be consistent with the guidelines in Section 3.1.3 of the MAM Manual (DWH NRDA Trustees 2021). In the event of a public records request related to data and information that are not already publicly available, the Trustee to whom the request is addressed would provide notice to the other Louisiana TIG members prior to releasing any data that are the subject of the request.

Consistency of MAM Activity with the PDARP/PEIS

The PDARP/PEIS establishes goals to restore a variety of interspersed and ecologically connected coastal habitats in each of the five Gulf states to maintain ecosystem diversity, with particular focus on maximizing ecological functions…and restore for injuries to habitats in the geographic areas where the injuries occurred, while considering approaches that provide resiliency and sustainability (Section 5.5.2

in PDARP/PEIS). This activity is designed to address information gaps and critical uncertainties regarding baseline measures of comprehensive ecosystem function, as indicated by net ecosystem carbon balance, and impacts of restoration activities on NECB. The objective of this activity is to quantify baseline condition NECB in two major wetland ecosystem complexes, a fresh marsh and a salt marsh, which will be used to assess restoration activities as described in the PDARP/PEIS (Section 5.5. in PDARP/PEIS). We will develop an assessment tool that will project the potential impacts of different restoration scenarios on ecosystem health using the metrics developed in this activity. We will provide spatially-explicit assessments of NECB for all coastal ecosystems in Louisiana, at 30-meter resolution, allowing trustees to see *where* restoration activities impact NECB. Spatially-explicit forecasting with uncertainty is critical to informing ecosystem restoration and conservation strategies within the context of the PDARP/PEIS. Thus this work consistent with the Monitoring and Adaptive Management goals (Section 5.5.15 in PDARP/PEIS) to increase the likelihood of successful restoration and provide feedback for management decisions.

Evaluation of NEPA Requirements

The Trustees' approach to compliance with NEPA summarized in this section is consistent with, and tiers where applicable from the PDARP/PEIS Section 6.14.4. Resources considered and impacts definitions (minor, moderate, major) align with the PDARP/PEIS. Relevant analyses from the PDARP/PEIS are incorporated by reference. Such incorporation by reference of information from existing plans, studies or other material is used in this analysis to streamline the NEPA process and to present a concise document that briefly provides sufficient evidence and analysis to address the Open Ocean TIG's compliance with NEPA (40 CFR 1506.3, 40 CFR § 1508.9). All source documents relied upon are available to the public and links are provided in the discussion where applicable.

As discussed in Chapter 6 of the PDARP/PEIS, a TIG may propose funding a planning phase (e.g., initial engineering, design, and compliance) in one plan for a conceptual project, or for studies needed to maximize restoration planning efforts. This would allow the TIG to develop information needed leading to sufficient project information to develop a more detailed analysis in a subsequent restoration plan, or for use in the restoration planning process. Where these conditions apply and activities are consistent with those described in the PDARP/PEIS, NEPA evaluation is complete, and no additional evaluation of individual activities is necessary at this time.

NEPA Review of MAM Activity

Analysis of the data collected, planning meetings, and preparation of reports are data-based components of this activity that would have no potential to cause adverse environmental impacts. Consistent with the impacts considered in the PDARP/PEIS, this activity would include minimally intrusive field activities as well as data-based model development and analyses. Temporary impacts to the biological and physical environment could include short-term, temporary disturbance of habitats and species, and minor disturbance to terrestrial, estuarine, and marine environments through the placement of instrumentation at field sites. Consistent with the analysis in Section 6.14.4 of the PDARP/PEIS, environmental consequences would be direct, short-term, minor impacts through the associated field work. Field activities will be associated with long-term Coastwide Reference Monitoring System monitoring sites CRMS3166 (fresh marsh) and CRMS0224 (salt marsh). Sites are in undeveloped coastal marshes within the Barataria Basin estuary. Navigation from the launches to the monitoring sites will be in a small watercraft or airboat. For each data collection event, crews of 2-4 people will be on site collecting data. All activities will be on the marsh surface at the monitoring site locations and through continuous hydrologic recorders in nearby water that will be deployed for the duration of the study (not transported in and out of the site). Existing structures include a temporary data collection platform (3m x3m) on the marsh surface (Figure 5) at both sites CRMS0224 and CRMS3166, and a temporary data collection post (4”x4”) with attached sondes in the tidal creek (Figure 6) at site CRMS0224. Additional structures at CRMS3166, in fresh marsh, will include the light construction of two 4”x4” posts with continuous hydrologic recorders fastened to them and navigation to the sites (Figure 6). The hydrologic recorder posts will be installed, driven by hand, in the tidal creek adjacent to the marsh at CRMS3166, within the 1-km CRMS site boundary. This minimal installation of two posts is not expected to have any effects on EFH. The equipment installed at the site does not make noise. The installation of the platform and collection of 3 soil cores, each 1-2 meters long, at CRMS3166 would temporarily disturb substrates, but disturbance would be highly localized and would fill back in naturally over time. Additional information about the methods of equipment deployment and data collection can be found in the BE form.

The data gathered would lead to beneficial effects to biological resources through increased understanding of ecosystem function, i.e., NECB, in areas monitored in this study. Field-based tasks will also include scientific collection (soil coring, vegetation harvest, grab samples) of soil, vegetation and water at established field sites. USGS adheres to existing federal and state permits for land access and field activities, including CRMS sampling and access permits, and would be obtained and prior to any field activities. Based on review of the proposed activities against those actions previously evaluated in the PDARP/PEIS and actions to be authorized under ESA permit, no additional NEPA evaluation is necessary.

NEPA Conclusion

After review of the proposed activities against those actions previously evaluated in the PDARP/PEIS, the Louisiana TIG determined that the environmental consequences resulting from this MAM activity falls within the range of impacts described in Section 6.4.14 of the PDARP/PEIS, thus no additional NEPA evaluation is necessary at this time.

Compliance with Environmental Laws and Regulations

The Louisiana TIG has completed technical assistance with the appropriate regulatory agencies for this project. Project Task 2 consists of analysis of existing data and thus permits and consultations are not required. Task 1 of this project includes field sampling activities, and thus may require permitting and consultations with relevant state and federal agencies; where possible, existing permits and consultations will be reviewed to determine if they are sufficient to complete the work or if additional compliance work is needed. The status of federal regulatory compliance reviews is outlined in table 3 below.

Federal environmental compliance responsibilities and procedures follow the Trustee Council Standard Operating Procedures (SOP), which are laid out in Section 9.4.6 of that document. Following the SOP, NOAA as the Implementing Trustee will ensure that the status of environmental compliance (e.g., completed vs. in progress) is tracked in DIVER.

Documentation of regulatory compliance will be available in the Administrative Record that can be found at the DOI's Online Administrative Record repository for the DWH NRDA (https://www.doi.gov/deepwaterhorizon/adminrecord). The current status of environmental compliance can be viewed at any time on the Trustee Council's website: http://www.gulfspillrestoration.noaa.gov/environmental-compliance/.

Table 3. Status of federal regulatory compliance reviews and approvals for the proposed project: Quantifying Restoration Impacts on Wetland Ecosystem Health and Carbon Export

Federal Statute	Compliance Status
Bald and Golden Eagle Protection Act (USFWS)	Complete
Coastal Barrier Resources Act (USFWS)	Not Applicable
Coastal Zone Management Act	Complete
Endangered Species Act (NMFS)	Complete
Endangered Species Act (USFWS)	Complete
Essential Fish Habitat (NMFS)	Complete
Marine Mammal Protection Act (NMFS)	Complete
Marine Mammal Protection Act (USFWS)	Complete
Migratory Bird Treaty Act (USFWS)	Complete
National Historic Preservation Act	Under Evaluation
Rivers and Harbors Act/Clean Water Act	Not Applicable

Federal environmental compliance responsibilities and procedures follow the Trustee Council Standard Operating Procedures (SOP), which are laid out in Section 9.4.6 of that document. Following the SOP, the Implementing Trustees for each activity will ensure that the status of environmental compliance (e.g., completed vs. in progress) is tracked through the Restoration Portal.
Documentation of regulatory compliance will be available in the Administrative Record that can be found at the DOI's Online Administrative Record repository for the DWH NRDA (https://www.doi.gov/deepwaterhorizon/adminrecord). The current status of environmental compliance can be viewed at any time on the Trustee Council's website: http://www.gulfspillrestoration.noaa.gov/environmental-compliance/.

Activity Close Out

In accordance with Section 9.5.1.6 of the TC SOPs, the Implementing Trustee shall provide the LA TIG with a closeout report after all activities and expenditures have been accomplished. The Final Report shall include a description and any documentation of the completed activity, estimated benefits to natural resources, the final funding balances and any transfers described in Section 7 of the TC SOPs, a summary of the results of monitoring, and any recommendations on adaptive management for the activity. Upon request, the Implementing Trustee shall provide the LA TIG with additional information and supporting documents to complete the closeout report.

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