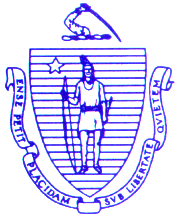


Blue Carbon Calculator:

A Simple Methodology for Determining the Green House Gas Budget of Aquatic Ecosystem Restoration Projects

May, 2016



Charles D. Baker

*Governor*

Karyn E. Polito

*Lieutenant Governor*

Matthew A. Beaton

*Secretary*

George N. Peterson, Jr.

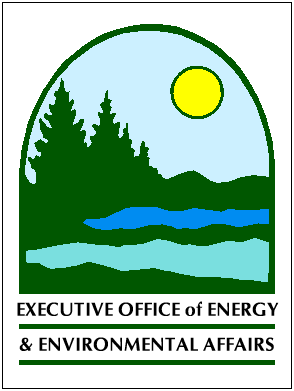
*Commissioner*

Mary-Lee King

*Deputy Commissioner*

Tim Purinton

*Director*



Adapted from ABT logo**Abt Associates**

55 Wheeler Street

Cambridge, MA 02138

*Acknowledgments*

Special thanks to Susan Bresney and Michelle Manion of Abt Associates and Stephen Crooks of ESA for their work on this report and the Blue Carbon Calculator.

Funding for this report and associated materials is courtesy of the Massachusetts Executive Office of Energy and Environmental Affairs and the Department of Fish and Game’s, Division of Ecological Restoration.

Thanks also to Waquoit Bay National Estuarine Research Reserve and Restore America’s Estuaries for their leadership on blue carbon research and policy in Massachusetts and nationally.

**Table of Contents**

[1. GHG Budget for Massachusetts Aquatic Ecosystem Restoration Projects 4](#_Toc438217187)

[1.1 Introduction 4](#_Toc438217188)

[1.2 Data 5](#_Toc438217189)

[1.2.1 Results of Literature Search 5](#_Toc438217190)

[1.2.2 The 2013 IPCC Wetlands Supplement and Prior Guidance 7](#_Toc438217191)

[1.2.3 Application of IPCC Guidance to Assessment of GHG Fluxes in Massachusetts 8](#_Toc438217192)

[1.2.4 Wetland Classification Schemes (MassGIS/MassDEP and IPCC) 9](#_Toc438217193)

[1.3 Methodology 11](#_Toc438217194)

[1.3.1 Development of Lookup Table 11](#_Toc438217195)

[1.3.2 Development of the Blue Carbon Calculator 17](#_Toc438217196)

[1.4 Results Summary 18](#_Toc438217197)

[1.5 On-Going Research Efforts 19](#_Toc438217198)

[1.6 Implications for Policy and Management 21](#_Toc438217199)

[1.7 References 23](#_Toc438217200)

[2. Appendix A **Error! Bookmark not defined.**](#_Toc438217244)

[2.1 Blue Carbon Calculator: Emissions Factors for Drainage of Inland Organic Soils 24](#_Toc438217245)

[2.2 Blue Carbon Calculator: Calculations 26](#_Toc438217246)

[2.2.1 Extraction Calculations 26](#_Toc438217247)

[2.2.2 Drainage Calculations 26](#_Toc438217248)

[2.2.3 Rewetting Calculations 27](#_Toc438217249)

[2.2.4 Wetlands remaining wetlands Calculations 27](#_Toc438217250)

[2.2.5 Resulting Emissions and Unit Conversions 28](#_Toc438217251)

[2.3 Blue Carbon Calculator: Analysis of Recent MassDER Projects 29](#_Toc438217252)

[2.3.1 Damde Meadows, Hingham 29](#_Toc438217253)

[2.3.2 Eel River, Plymouth 32](#_Toc438217254)

[2.3.3 Mill River, Taunton 35](#_Toc438217255)

[2.3.4 Muddy Creek, Chatham and Harwich 38](#_Toc438217256)

[2.3.5 Ox Pasture, Rowley 41](#_Toc438217257)

[2.3.6 Town Creek, Salisbury 44](#_Toc438217258)

[2.3.7 Wekepeke Brook, Lancaster 47](#_Toc438217259)

[2.3.8 Additional Restoration Projects 50](#_Toc438217260)

[2.4 Blue Carbon Calculator: Data Entry Figures 51](#_Toc438217261)

# GHG Budget for Massachusetts Aquatic Ecosystem Restoration Projects

## Introduction

Coastal wetlands are on the forefront of climate change impacts, susceptible to sea level rise and stress from direct human activity with potential impacts on carbon sequestration as well as other critical ecosystem services. Robust approaches to accounting for the greenhouse gas (GHG) emissions or removals associated with human activities (including wetlands ecosystem restoration and climate change response actions) are currently under development. As GHG accounting approaches improve, more effective policies for coastal carbon management – also known as “blue carbon” – can be established. If planned correctly, efforts to restore coastal and riverine ecosystems can reduce GHG emissions as well as improve other ecosystem service benefits that increase resiliency to changes in rainfall, sea level rise, and other climate change impacts ([Crooks et al. 2014](#_ENREF_6)).

It is important to keep in mind that GHG emissions are only one of a suite of ecosystem services which result when degraded ecosystems are improved, enhanced, or restored. Freshwater wetlands for example, if converted from uplands can result, in an increase in methane production. However, the restoration of freshwater wetlands is important for many reasons including water filtration, stormwater storage, and habitat improvement. And, as sea levels rise, freshwater wetlands are increasingly important along the Massachusetts coast as migration areas for salt marshes as sea level rises. The intent of this analysis is to gather a better understanding of one important ecosystem service, not prioritize all restoration efforts around GHG emissions impacts.

The Commonwealth of Massachusetts is taking a leadership role as one of the first states to invest in tools specific to the evaluation of fluxes in GHG emissions associated with the management of coastal, riverine, and inland wetlands. The Massachusetts Division of Ecological Restoration (MassDER) in the Department of Fish and Game has implemented over 100 aquatic ecosystem restoration projects, restoring 1,582 acres of coastal and near coastal wetlands ([Commonwealth of Massachusetts 2015](#_ENREF_5)) and removing 40 dams, restoring aquatic system connectivity and ecological processes ([Commonwealth of Massachusetts 2015](#_ENREF_5)).

For purpose of this report, “Aquatic Ecosystem Restoration Projects” include freshwater and saltwater wetland and river restoration efforts. Not included in the analyses are certain types of freshwater restoration such as vernal pool, lake and pond enhancement efforts or near shore restoration such as eel grass or shellfish, although these restoration project types may be added as the Calculator is revised.

The goal of this report is to provide MassDER and the Executive Office of Energy and Environmental Affairs (EEA) with an initial methodology and Blue Carbon Calculator for estimation of fluxes in GHG emissions from coastal, riverine, and inland wetland ecosystems in Massachusetts. The Calculator is an easy-to-use spreadsheet intended to help MassDER and other users incorporate GHG considerations into the process of selecting and prioritizing future aquatic ecosystem restoration projects.

The Blue Carbon Calculator is based upon the following sources:

* Results of a literature search, emphasizing empirical evidence specific to wetlands ecosystems in the northeastern U.S.;
* Wetlands classification system used by Massachusetts GIS (MassGIS) and Massachusetts Department of Environmental Protection (MassDEP); and
* Recent guidance from the Intergovernmental Panel on Climate Change (IPCC) on accounting for GHG emissions and removals associated with wetlands management.

The Blue Carbon Calculator includes the following:

* A look-up table containing best available data and GHG emission factors for estimation of fluxes in GHG emissions from managed wetland soils within Massachusetts; and
* A spreadsheet-based tool for estimating changes in GHG emissions and sequestration from soils resulting from changes to wetlands due to restoration and management activities, based on land cover data and emissions factors detailed in the look-up table.

Despite the importance of wetlands ecosystems within the climate system, significant gaps in empirical data and information exist. As such, we note that this Blue Carbon Calculator should be considered a first-order tool which is designed to accommodate continuous refinement, as more regionally-specific data become available, to improve the accuracy and precision of estimates. We designed the analytic approach in the calculator to be compatible with recently initiated federal activities to recognize management of coastal wetlands within the EPA’s National Report on GHG Emissions and Sinks ([U.S. EPA 2015](#_ENREF_15)).

## Data

Data and methods used to develop our analytic approach are based on results of a literature search, data from MassDEP and MassGIS, and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (*Wetlands Supplement,* IPCC 2014)*.* In this section, we describe the results of a literature search on GHG emissions from wetlands in the northern and eastern United States. We then describe why these findings justify use of a Tier 1 level of analysis as outlined in IPCC’s *Wetlands Supplement* (described in Figure 1).

### Results of Literature Search

Figure 1. IPCC’s Guidance on Wetlands GHG Inventories

*The IPCC provides guidance on GHG emissions from wetlands management activities according to three categories, or ‘tiers’, which correspond to varying levels of accuracy and precision. While all tiers are designed to provide unbiased estimates of GHG emissions and removals, accuracy and precision are expected to improve with a move from Tier 1 to Tier 3.*

***Tier 1:*** *The IPCC provides mathematical equations for estimating emissions/removals and default emissions factors to use in generating first-order estimates. Default values are a result of an extensive and exhaustive review of the literature on wetland GHG emissions worldwide. Emissions factors are disaggregated by wetland type, management activity, and climate region.*

***Tier 2****: Available country-specific data and more regional-specific information such as climate sub-domain, nutrient status, and drainage/rewetting timescales, are used to estimate fluxes.*

***Tier 3:*** *The most robust analysis is conducted by modelling and/or empirical measurement of emissions at the geographic site under analysis.*

While some empirical data describing GHG fluxes in wetlands that could potentially support a Tier 2-level analysis for Massachusetts wetlands are available, these data are not sufficient to cover all wetland types or changes to wetlands resulting from management activities under consideration. One study measured annual fluxes of carbon from a wetland in New Jersey which was restored from a degraded upland habitat to a coastal, tidal wetland ([Artigas et al. 2015](#_ENREF_1))—this example is similar to certain restoration projects in Massachusetts. This is the only study reviewed which measures GHG fluxes consistently throughout the year that is both relatively local and recent. Other studies provide more limited relevant information, either due to limited study periods (e.g., single day) which are insufficient to support an annual analysis ([Bresney et al. 2015](#_ENREF_4); [Howes et al. 1985](#_ENREF_9); [Bernal and Mitsch 2012](#_ENREF_3)), fluxes during anthropogenically manipulated nutrient availability and/or salinity[[1]](#footnote-2) ([Moseman-Valtierra et al. 2011](#_ENREF_12); [Helton et al. 2014](#_ENREF_7)), fluxes of only certain GHGs ([Moseman-Valtierra et al. 2015](#_ENREF_13)) or fluxes measured less recently ([Howes et al. 1985](#_ENREF_9)).

Because data describing local conditions are lacking, we primarily use IPCC’s Tier 1 default values to develop the look-up table and Blue Carbon Calculator for Massachusetts. Although the literature is not yet sufficient to support a Tier 2 analysis, it is important to also recognize that data gaps exist even at the Tier 1 level. When we compare IPCC values with those from the limited results from the literature (shown in Table 1‑1 below), we see that the IPCC values are relatively comparable for CO2-C[[2]](#footnote-3), to some studies ([Artigas et al. 2015](#_ENREF_1); [Houghton and Woodwell 1980](#_ENREF_8); [Bernal and Mitsch 2012](#_ENREF_3)). However, other studies provide values for CO2-C that vary greatly ([Howes et al. 1985](#_ENREF_9); [Moseman-Valtierra et al. 2011](#_ENREF_12); [Bresney et al. 2015](#_ENREF_4)). This suggests that currently available data are not yet robust enough to support a Tier 2 level analysis. Similarly, three studies suggest significant N2O emissions from salt marshes in the eastern U.S., specifically when exposed to high nutrient concentrations ([Moseman-Valtierra et al. 2011](#_ENREF_12); [Moseman-Valtierra et al. 2015](#_ENREF_13); [Howes et al. 1985](#_ENREF_9)), but at the IPCC Tier 1 level, N2O emissions are considered insignificant. Additionally, it is important to note that the IPCC methods and the tools provided in this analysis only consider emissions and reductions from wetland soils resulting from wetland management activities, and do not include emissions or reductions from aboveground biomass growth (IPCC, 2014). All of this provides more evidence that use of a Tier 1 analysis in the accompanying Calculator is an appropriate starting point for GHG emissions estimates for Massachusetts wetlands, but the limitations should be considered when analyzing results from these tools, and the tool should, and can be expanded upon as research advances.

Table 1‑1 Comparison of Emissions Factors from Literature and the IPCC for Northeastern U.S. Wetlands

|  |  |  |  |
| --- | --- | --- | --- |
| Source | Location | Wetland Type | Emissions Factor (metric tons CO2-C/ha/yr) |
| IPCC *Wetlands Supplement* |  | Coastal, tidal marsh (rewetted) | -0.91 |
| [Artigas et al. 2015](#_ENREF_1) | New Jersey | Salt marsh (rewetted) | -2.13 |
| [Houghton & Woodwell 1980](#_ENREF_5) | New York | Salt marsh | -3.02 |
| [Howes et al. 1985](#_ENREF_6)A | Massachusetts | Salt marsh | -0.88 |
| [Moseman-Valtierra et al. 2011](#_ENREF_10)B | Massachusetts | Salt marsh | 0.27 |
| IPCC *Wetlands Supplement* |  | Temperate inland organic soils (rewetted) | -0.23 – 0.5 |
| ([Bresney et al. 2015](#_ENREF_4))C | Maine | Riverine wetland | -53.7 |
| ([Bernal and Mitsch 2012](#_ENREF_3))D | Ohio | Riverine marsh | -1.05 |

A Data collection sporadic during 10 months out of the year.

B Samples collected during July only.

C Value likely higher because samples were collected during one day in July.

D Only three samples collected during this study, and timing of sampling is unknown.

### The 2013 IPCC Wetlands Supplement and Prior Guidance

The IPCC’s 2013 *Wetlands Supplement* fills in some of the accounting gaps for activities specific to wetlands which to date have been incomplete in previous IPCC guidance documents (i.e., *2006 IPCC Guidelines for National Greenhouse Gas Inventories*)The Wetlands Supplement includes updated and new methodological guidance for a few categories of human-induced changes: anthropogenic GHG emissions and removals from drained inland and rewetted organic soils, and changes to coastal wetlands and inland wetland mineral soils (IPCC 2014).

It is important to note that the *Wetlands Supplement* maintains the IPCC’s general approach, that is, the IPCC estimates GHG emissions and removals associated with human activities to the wetlands, e.g., extracting, draining, or rewetting a wetland, or any combination of the three. As such, the IPCC’s emission factors are specific to wetland management *activities* rather than changes in the emissions profiles of the types of wetlands resulting from those management activities. While some wetland restoration activities do fall into these categories, the majority of restoration projects result in *conversion* from one type of wetland to another (e.g., freshwater to saltwater marsh) as a result of restoration, i.e., a difference between emissions from a type of wetland prior to and following a restoration project. However, this is an area where IPCC guidance has not yet been developed. Because the ultimate goal of the Calculator is to estimate GHG emissions and reductions associated with any and all wetland restoration projects, assumptions were developed for this analysis until these data gaps are addressed and filled in the future.

The *Wetlands Supplement* provides data and methodology for estimating soil emissions resulting from three management activities:

* **Drainage and extraction** represents wetlands destruction, or wetlands that are converted to non-wetland classes resulting in exposure of soils to oxygenated conditions.
* **Rewetting** represents wetlands creation or activities where current non-wetland lands that were previously drained are converted back to wetlands and through this process establish or reestablish soil carbon pool rebuilding. The IPCC defines rewetted soils as “…wetlands that have been drained for forestry, crop production, grazing, peat extraction or other purposes, and have subsequently been rewetted to re-establish water saturation” (IPCC 2014).

In addition, the *Wetlands Supplement* provides guidance for two wetland categories:

* **Inland Wetlands:** Guidance is provided for drainage of inland wetlands with organic soils[[3]](#footnote-4), rewetting of inland wetlands with organic soils[[4]](#footnote-5), and drainage and rewetting of inland mineral wetland soils[[5]](#footnote-6) .
* **Coastal Wetlands:** Guidance is provided for extraction, drainage, and rewetting of mangroves, seagrass meadows and tidal marshes with mineral and organic soils[[6]](#footnote-7).

### Application of IPCC Guidance to Assessment of GHG Fluxes in Massachusetts

Terminology used in the *Wetlands Supplement* is focused upon the requirements of GHG inventory developers and may be unfamiliar at first to restoration practitioners. This terminology reflects reporting requirements which account for GHG emissions or removals that are associated with an activity such as a conversion of wetlands to non-wetland land cover class, or a project that restores non-wetland classes back to wetlands. We have attempted to bridge this gap by using terms and categories that are relevant to wetland restoration in Massachusetts. In their guidance, the IPCC refers to anthropogenic changes to wetlands as “management activities.” Throughout the remainder of this analysis and within the Blue Carbon Calculator provided, we will refer to these as “wetland changes” or “change types”. This is to more easily translate between Massachusetts wetland restoration projects and IPCC methods and to make the Calculator provided here more user-friendly.

The IPCC’s default emissions factors can inform state-level GHG inventory of wetlands when regionally-specific data are unavailable, as is the case in Massachusetts. As such, default values from the IPCC are used here to provide a Tier 1 assessment of GHG emissions and removals associated with restoration activities on aquatic ecosystems in the Commonwealth. Data gaps still remain even at IPCC’s Tier 1 level. Most notably, IPCC does not provide specific default value emission factors for the following categories:

* Impounded waters,
* Conversion of impounded waters to wetlands, or
* Converting between wetland types (freshwater to saltwater).

Two of the major forms of wetland restoration within Massachusetts are (1) restoration of tidal wetlands through reconnection of impounded waters to the ocean and (2) dam removal resulting in the restoration of floodplain wetlands. To estimate emissions and reductions associated with these types of restoration projects, this analysis follows assumptions for emissions factors stated in more detail in Section 1.3.2 and . Additionally, as mentioned above, the IPCC methods, and therefore the lookup table and Calculator provided here, only consider emissions and reductions from wetland soils, and do not include reductions associated with the growth of aboveground vegetation.

### Wetland Classification Schemes (MassGIS/MassDEP and IPCC)

MassGIS and MassDEP developed their land cover classification scheme for regulatory and planning purposes, and not for accounting for GHG emissions and removals. However, many of the land cover classes used in the MassGIS/MassDEP’s classification share common emissions factors as recognized under an IPCC Tier 1 assessment. To simplify the calculator and ensure the ease of adding future data from ongoing studies and the IPCC, we have grouped MassGIS/MassDEP wetland land classes based upon emissions factors.

Table 1‑2 shows how we created a “crosswalk” between the MassGIS/MassDEP wetland categories, the IPCC methods for emissions estimation, and the look-up table used in the Blue Carbon Calculator provided in this analysis.

The IPCC guidelines stratify wetlands depending upon coastal/inland, salinity (in coastal areas) and whether soils are organic or mineral. Although the Commonwealth’s classification scheme does not currently do this, the option to stratify wetlands based upon salinity and soil classification is provided in the Blue Carbon Calculator. Cranberry bogs are assumed to be an upland category with mineral soils as suggested by MassDER. All floodplain forest categories are assumed to be forested wetlands. For our analysis, we assumed that all land cover classes consist of organic soils except cranberry bogs. Because organic and mineral soils in freshwater wetlands have varying emissions, this is an area that should be improved in the future.

Table 1‑2 Crosswalk between Massachusetts Wetland Categories, IPCC Methods and Blue Carbon Calculator

| MassGIS/MassDEP Land Use Category | IPCC Method and Source | Land Use Category in Calculator’s Look-up Table |
| --- | --- | --- |
| Inland Wetland | | |
| DEEP MARSH | Organic:  *Wetlands Supplement*  Chapters 2 and 3  Mineral:  *Wetlands Supplement*  Chapter 5 | Fresh Water Wetland |
| SHALLOW MARSH, MEADOW, OR FEN |
| BOG |
| SHRUB SWAMP |
| WOODED SWAMP DECIDUOUS | Organic:  *Wetlands Supplement*  Chapters 2 and 3  Mineral:  *Wetlands Supplement*  Chapter 5 | Fresh Water Forested Wetland |
| WOODED SWAMP CONIFEROUS |
| WOODED SWAMP MIXED TREES |
| FLOODPLAIN FOREST DECID |
| FLOODPLAIN FOREST CONIF |
| FLOODPLAIN FOREST MIX |
| OPEN WATER (FRESH) | Organic and Mineral:  Kroeger and Crooks (in prep) | Open water (fresh) |
|  | Coastal Wetland |  |
| PHRAGMITES DOMINATED - WETLAND | Organic and Mineral:  *Wetlands Supplement*  Chapter 4 | Phragmites Wetland |
| SALT MARSH - HIGH | Organic and Mineral:  *Wetlands Supplement*  Chapter 4 | Saline/brackish Wetland |
| SALT MARSH - LOW |
| BARRIER BEACH-BOG |
| BARRIER BEACH-SALT MARSH |
| BARRIER BEACH-DEEP MARSH |
| BARRIER BEACH-MARSH |
| BARRIER BEACH-SHRUB SWAMP | Organic and Mineral:  *Wetlands Supplement*  Chapter 4 | Saline/brackish Forested Wetland |
| BARRIER BEACH-WOODED SWAMP DECIDUOUS |
| BARRIER BEACH-WOODED SWAMP CONIFEROUS |
| BARRIER BEACH-WOODED SWAMP MIXED TREES |
| TIDAL FLAT | NA | No guidance- Assumed that no emissions or reductions are associated with these land cover types |
| COASTAL BEACH |
| COASTAL DUNE |
| BARRIER BEACH SYSTEM |
| ROCKY INTERTIDAL SHORE |
| COASTAL BANK BLUFF OR SEA CLIFF |
| BARRIER BEACH-COASTAL BEACH |
| BARRIER BEACH-COASTAL DUNE |
| OPEN WATER (SALT) | Organic and Mineral:  Kroeger and Crooks (in prep) | Open water (salt) |
| BARRIER BEACH-OPEN WATER |
| Upland | | |
| FORESTED UPLAND DECIDUOUS | NA | Forest1 |
| FORESTED UPLAND CONIFEROUS |
| FORESTED UPLAND MIX |
| CRANBERRY BOG | NA | Grassland1 |
| GRASSLAND UPLAND |

1Emissions factors for these land classes are not provided by the IPCC and therefore, have not been included in the Lookup Table nor are emissions from land covered by these categories computed in the Blue Carbon Calculator. These rows are only included for future development.

## Methodology

### Development of Lookup Table

The look-up table below (Table 1‑3) provides soil emissions factors for each type of wetland change, as defined by IPCC, under each of our broad wetland classes. This table is a compilation of Tier 1 default emissions factors from the *Wetlands Supplement* and, for forested wetlands, emissions factors are based on an analysis of terrestrial GHG fluxes conducted as part of this project. Table 1‑4 shows the sources of each set of values in the Lookup table. All values are based on the IPCC’s temperate or cold temperate wet climate types (IPCC 2001), depending on the level of specification within the *Wetlands Supplement* chapters.

As previously noted, there is currently a gap in the IPCC guidance for emissions factors for saturated areas (wetlands or open water) that undergo tidal reconnection but remain saturated. Because this is typical of Massachusetts restoration projects, we have developed a temporary wetland change category called “Wetlands remaining wetlands” and accompanying methodology for analyzing this type of situation. This is described in more detail below and in Section 1.3.2. Within each wetland change type, emissions factors are given for various types of emissions: soil carbon stock, dissolved organic carbon (DOC), CO2, and CH4.

* **Extraction:** Emission factors for extraction activities are shown under “Wetlands Destruction” in the look-up table (Table 1‑3). Emissions from soil carbon stock are only accounted for only if the soil is removed by extraction, and these values quantify the emissions resulting from oxidizing soils that are being removed. Guidance on accounting for GHG emissions associated with extraction of inland/freshwater organic wetlands was not provided in the *2006 IPCC Guidance* or the *Wetlands Supplement* and therefore is an area that should be investigated further in the future.

**Examples of extraction activities include:**

* Excavation to enable port, harbor, and marina construction and filling
* Removal of soils for channel, ditch or land surface alteration resulting in soil material being placed in an oxygenated environment
* **Drainage:** Emissions factors for drainage are shown under “Wetlands Destruction” in the lookup table (Table 1‑3). These factors quantify emissions resulting from changes in microbial communities and soil composition following the drying of soils. Currently, the IPCC provides very specific emissions factors for CO2 and CH4 associated with the draining of inland/freshwater organic wetlands, reflecting specific conditions (e.g. water table). These factors are provided based on the land use classification of the land subsequent to draining, i.e., forest land, grassland, cropland or peatland. Because of this, we have not provided an emissions factor for drained inland organic wetlands but leave the selection of an appropriate emissions factor to be included within the Calculator to the user. Because of higher resolution data for inland organic soils, the *Wetlands Supplement* includes a specific factor for dissolved organic carbon (DOC) within the total flux calculation (provided in the look-up table). For coastal wetlands, at the Tier 1 level, a simple emissions factor is given for the drainage of organic and mineral soils. This factor assumes a depth of influence of 1 meter and that DOC is implicitly accounted for in the net change. This Tier 1 value is included in the calculator. In **Error! Reference source not found.** we have provided a table of these more specific factors for a temperate climate zone. If needed, one of these values may be selected and added to the calculator, which is discussed more thoroughly in Section 1.3.2 below.

**Examples of activities resulting in drainage:**

* Building of berms and ditching of wetland soils to lower water tables
* Diking and draining to create pastures, croplands, and settlements
* Pumping of ground water resulting in draining
* **Rewetting**: Rewetting is a central process required for the restoration of wetlands from a drained state. Emission factors for the rewetting of wetland soils are shown under “Wetlands Restoration” in the look-up table (Table 1‑3). These factors quantify the emissions resulting from changes in microbial communities and soil composition following the wetting of soils. Rewetting organic soils halts ongoing emissions of CO2 and, depending upon salinity, may increase CH4 emissions. Carbon sequestration is typically higher in coastal wetlands than terrestrial wetlands due to the type of species involved and additional process of soil building and burial. As mentioned previously, DOC emissions are only quantified for drained and rewetted inland organic wetland soils and are provided in the look-up table for those categories. Emission factors for CO2 from inland organic wetlands vary with nutrient status. These wetlands sequester CO2 when lacking in nutrients, and are a source of CO2 when rich in nutrients. There is a data gap in CO2 emissions from rewetted inland mineral soils; the IPCC does not report any values for these soils. In coastal organic and mineral soil wetlands, emissions are dependent on re-establishment of vegetation. Recovery of vegetation, through natural recruitment or planting, results in reestablishment of organic accumulation within soils. Similar to CO2, CH4 emissions vary with nutrient availability, but all inland wetlands and phragmites-dominated wetlands are a source for CH4 regardless of nutrient availability. At the Tier 1 level, emissions of CH4 from all tidal wetlands except phragmites are considered zero. Emission factors from open water are not provided in the *Wetlands Supplement* and therefore follow Kroeger and Crooks ([in prep](#_ENREF_10)), which assumes that as a first-order approximation, CH4 emissions factors for vegetated wetlands can be applied to open water of comparable salinity.

**Examples of activities resulting in rewetting:**

* Removal of fill to restore tidal wetlands
* Removal of barriers to hydrologic flow such as a levee where the land behind the obstruction is in a drained state prior to restoration
* Adjustment in water management activities on land behind tide gates resulting in recovery of wetland soils.
* **Wetlands remaining wetlands**: ‘Wetlands remaining wetlands’ is a category developed for the purposes of this analysis, in order to apply IPCC methods to Massachusetts restoration projects which do not fall within the activity categories described above. This category represents activities occurring on lands that would be considered saturated under the pre-and post-restoration condition, but which may alter the GHG emissions on those lands. This includes alteration of salinity and conversion from open water to vegetated wetlands and vice versa. Emission factors for wetlands remaining wetlands were developed based on rewetting emission factors and other assumptions, but calculations of resultant emissions are slightly different and explained in further detail in Section 1.3.2 below. As guidance becomes available, these emissions factors and methodology for calculations should be updated.

**Examples of activities resulting in wetlands remaining wetlands:**

* Land that is converted from open water to wetlands as a result of removal of a dam or other obstruction
* Removal or replacement of culvert or tide gate, where the area behind the obstruction is saturated (wetlands or open water) prior to removal.
* Restoring hydrologic connection to convert freshwater wetlands to saline wetlands
* Converting open salt water to fresh or vice versa

The emissions factors reported in this category are slightly different than the emission factors for the other three categories because there is no direct guidance by IPCC for this scenario. The IPCC does not provide emissions factors for “unmanaged,” or “baseline” wetlands, or wetlands which are not undergoing any activity. Additionally, the IPCC does not provide guidance for activities which result in a wetland being converted to another wetland, and therefore does not result in exposing soil to oxygen, drying or wetting soil. Because of this, the emission factors we have developed in Table 1‑3 are assumed to be “baseline” emissions. The Calculator then computes the difference between the “baseline” emissions prior to the restoration, and the “baseline” emissions after. For most categories, these values are the same as the rewetting emission factors (Table 1‑4). However, the emissions resulting from rewetting nutrient rich[[7]](#footnote-8) inland organic soils are positive, due to the initial microbial respiration associated with rewetting these types of soils. Overtime, this initial increase in respiration decreases and; therefore, the assumed “baseline” emissions factor for inland organic wetlands is assumed to be zero instead of this positive number (Table 1‑3).

Table 1‑3 Look-up Table for Soil Emissions Factors of CO2-C and CH4-C

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Location | Soil Type | Land Use Category | *Wetlands Destruction* | | | | *Wetlands Restoration* | | | | |
| Extraction | Drained | | | Rewetting | | | Wetlands Remaining Wetlands | |
| Soil C stock: tons C/ha | EF tons DOC- C/ha/yr | EF tons CO2- C/ha/yr | EF tons CH4-C/ha/yr | EF tons DOC- C/ha/yr | EF tons CO2-C/ha/yr | EF tons CH4-C/ha/yrA | EF tons CO2-C/ha/yrE | EF tons CH4-C/ha/yrD |
| Inland Wetland | Organic | Freshwater Wetland |  | 0.31 |  |  | 0.24 | -0.23B,C 0.5C,D | 0.092B 0.216D | 0 | 0.092 |
| Freshwaster Forested Wetland |  | 0.31 |  |  | 0.24 | -0.23B,C 0.5C,D | 0.092B 0.216D | 0 | 0.092 |
| Open water fresh |  |  |  |  |  | 0 | 0.092B 0.216D | 0 | 0.092 |
| Mineral | Freshwater Wetland | 128 |  | 6.4 | 0 |  |  | 0.177 | 0 | 0 |
| Freshwater Forested Wetland | 128 |  | 6.4 | 0 |  |  | 0.177 | 0 | 0 |
| Open water fresh |  |  |  | 0 |  | 0 | 0.177 | 0 | 0 |
| Coastal Wetland | Organic | Phragmites Wetland | 340 |  | 7.9 | 0 |  | -0.91 | 0.146 | -0.91 | 0.146 |
| Saltwater/brackish Wetland | 340 |  | 7.9 | 0 |  | -0.91 | 0 | -0.91 | 0 |
| Salt water/brackish Forested Wetland | 340 |  | 7.9 | 0 |  | -0.91 | 0 | -0.91 | 0 |
| Open water salt |  |  |  | 0 |  | 0 | 0 | 0 | 0 |
| Mineral | Phragmites Wetland | 226 |  | 7.9 | 0 |  | -0.91 | 0.146 | -0.91 | 0.416 |
| Saltwater/brackish Wetland | 226 |  | 7.9 | 0 |  | -0.91 | 0 | -0.91 | 0 |
| Freshwater Tidal Forested Wetland | 226 |  | 7.9 | 0 |  | -0.91 | 0 | -0.91 | 0.416 |
| Open water salt |  |  |  | 0 |  | 0 | 0 | 0 | 0 |

A In the IPCC Wetlands Supplement Chapters 4 and 5, EF for CH4 is reported in kg CH4/ha/yr and in Chapters 2 and 3 EF for CH4 is reported in kg CH4-C/ha/yr. For consistency across chapters and with CO2, all EF values are reported here in tons CH4-C/ha/yr. Similar to CO2-C mentioned previously, CH4-C refers to the mass of carbon only in a given mass of CH4. The atomic weight of carbon is 12 grams, and the atomic weight of CH4 is 16 grams, therefore, 12 tons of CH4-C is equivalent to 16 tons of CH4. Scientists often used CO2-C because it simplifies following carbon fluxes in the carbon cycle.

B Value for nutrient poor wetland.

C Values were reported as not significantly different from zero.

D Value for nutrient rich wetland.

EBecause there is no guidance provided by IPCC for "natural" wetlands, or wetlands occurring before and after an activity, these values were derived from the IPCC values to represent the wetland emissions prior to and after the restoration project. The difference between them is considered to be the emissions resulting from the project.

EF represents emissions factors. Negative values indicate removal (accumulation) of C. Where cells are blank, emissions factors were not provided in the 2006 IPCC Guidelines nor the Wetlands Supplement. These are treated as EFs of zero in the Calculator. These are areas where the Look-up Table and Calculator should be developed in the future.

Table 1‑4 Sources for Values in the Look-up Table

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *Location* | *Soil Type* | *Wetlands Destruction* | | | | Wetlands Restoration | | | | |
| **Extraction** | **Drained** | | | **Rewetting** | | | **Wetlands Remaining Wetlands** | |
| **Soil C stock** | **EF DOC** | **EF CO2** | **EF CH4** | **EF DOC** | **EF CO2** | **EF CH4** | **EF CO2** | **EF CH4** |
| Inland Wetland | Organic | No guidance | WS Table 2.2 | WS Table 2.1 | WS Table 2.3 | WS Table 3.2 | WS Table 3.1 | WS Table 3.3 | No guidance | WS Table 3.3 |
| Mineral | WS Table 5.2 | No guidance | | | No guidance | | WS Table 5.4 | No guidance | WS Table 5.4 |
| Coastal Wetland | Organic | WS Table 4.11 | WS Table 4.13 | | | No guidance | WS Table 4.12 | WS Table 4.14 | WS Table 4.12 | WS Table 4.14 |
| Mineral |

Notes: WS stands for Wetlands Supplement. Where no guidance is provided, emissions factors were left blank in the Lookup Table, or developed based on assumptions and are treated as zeros by the calculator.

### Development of the Blue Carbon Calculator

The Blue Carbon Calculator is a first-generation tool to calculate GHG emissions from soils resulting from specific wetlands management activities. For the activities of extraction, drainage, and rewetting, the Calculator estimates the emissions or reductions in emissions resulting from carrying out that specific activity. The Calculator also estimates the GHG emissions resulting from changes to microbial communities resulting from exposing soil to oxygen (extraction), drying soil (drainage) or wetting soils (rewetting). For “wetlands remaining wetlands” management scenarios, the Calculator includes emission factors for “unmanaged” wetlands, and calculates the difference between the emissions before and after the “wetlands remaining wetlands” project. The Calculator can be downloaded at [mass.gov/der](file://///ENVCAUHOME/fweshared/DER/Director/Blue%20Carbon/Blue%20Carbon%20Calculator/Outreach%20Materials/Final%20Materials%20for%20EEA%20Review/mass.gov/der).

For each type of wetland change resulting from a project, the user enters land cover classification depending on the types of wetland changes occurring from that project on the “Data Entry” worksheet. For extraction, the land cover for the wetland area that will be removed is entered. The new land cover following removal is not entered. For drainage, the land cover for the wetland area that will be drained is entered. The new land cover resulting from the project is not entered. For rewetting, the wetland area that will result from the restoration is entered. The land cover area prior to the project is not entered. For wetlands remaining wetlands, the land cover before and after the restoration project is entered. It is worth noting that only the land area covered by a wetland, either occurring prior to or following the project, should be entered into the Calculator. While there are rows included in the Calculator to enter upland land cover classes, this is strictly so the Calculator may be developed to include this in the future. If the need arises to enter data into these rows, reconsider why upland areas need to be included. If the area is being converted to upland, it should most likely be entered into the drainage columns. If the area is converting from upland to wetland, the resulting wetland area should be entered into the rewetting columns.

Some restoration projects may result in many different changes to the wetland within a single project. An example of this may be removal of a dam from a river where some areas upstream of the dam may convert from open water to upland (draining) or open water to wetland (wetlands remaining wetlands) and some areas downstream of the dam may convert from upland to wetland (rewetting) once the dam has been removed. For projects that contain multiple activity types, the portion of area that falls within each activity category should be entered into those columns. For the Calculator to run correctly, it is important that the same area is not entered into multiple activity categories, i.e. if an area is being rewetted, the resulting wetland should not also be entered into the “post” column for wetlands remaining wetlands.

Once data has been entered, annual emissions resulting from each activity are calculated on each activity’s “Calculator” worksheet. These calculations are based on formulas provided in the *Wetlands Supplement,* where the area of land within each land cover class (taken from the user inputs on the “Data Entry” worksheet) is multiplied by the sum of emissions factors for that land cover class (from the lookup table, stored as a separate worksheet within the calculator) and activity. Annual emissions for each land cover class are summed for each activity, and annual emissions from each activity are summed for all data entered. Depending on the changes to the wetland, total emissions are applied for varying periods of time from one to 50 years following the activity. All calculations are described in detail in **Error! Reference source not found.**.

Calculated emissions and removals resulting from each wetland change are given in four different units:

* Tons CO2-C: mass of carbon (in tonnes) resulting from CO2 only[[8]](#footnote-9)
* Tons CH4-C: mass of carbon (in tonnes) resulting from CH4 only
* Tons CO2e: mass of CO2 equivalents resulting from CO2 and CH4 combined
* Gallons of gasoline: Equivalent of CO2 emissions from consumption of gasoline (CO2 and CH4 combined)

Resulting emissions/removals from each activity and summed emissions/removals for each project are relative to emissions/removals prior to the project. Therefore, negative emissions resulting from these calculations may mean a decrease in emissions compared to prior conditions, not necessarily sequestration. This is better shown by the examples in Appendix A. Emissions are shown as cumulative where total emissions are given at time points between one and 50 years since the activity occurred. For example, at 50 years the emissions or removals shown do not occur at year 50, but have occurred between year one and 50. See examples in Appendix A for further clarification.

## Results Summary

Table 1‑5 presents the Blue Carbon Calculator results for the select restoration projects in terms of cumulative GHG emissions (tons CO2e) one to 50 years following the activity.

Table 1‑5 Summary of GHG Impacts from Select Ecological Restoration Projects

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Restoration Project | Management/ Wetland Change Activity | Cumulative GHG emissions (tons CO2e)A | | | | | |
| **Years Post Project** | | | | | |
| **1** | **10** | **20** | **30** | **40** | **50** |
| Damde Meadows | Wetlands remaining wetlands | -22.55 | -225.52 | -451.05 | -676.57 | -902.10 | -1,127.62 |
| Eel River | Rewetting | 152.17 | 1,521.66 | 3,043.33 | 4,564.99 | 6,086.65 | 7,608.32 |
| Mill River | Wetlands remaining wetlands | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Muddy Creek | Wetlands remaining wetlands | -47.98 | -479.77 | -959.54 | -1,439.31 | -1,919.09 | -2,398.86 |
| Ox Pasture | Wetlands remaining wetlands | -0.29 | -2.93 | -5.86 | -8.79 | -11.72 | -14.65 |
| Town Creek | Wetlands remaining wetlands | -249.89 | -2,498.91 | -4,997.82 | -7,496.73 | -9,995.64 | -12,494.55 |
| Wekepeke Brook | Wetlands remaining wetlands | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Total** | | **-168.54** | **-1,685.47** | **-3,370.94** | **-5,056.41** | **-6,741.89** | **-8,427.35** |

A Negative values represent net GHG benefits.

## On-Going Research Efforts

While this study adopts IPCC Tier 1 default values to develop Table 1‑3, a number of relevant and timely studies are nearing completion in Massachusetts and elsewhere, and we expect that these studies will inform the development of regionally-specific Tier 2 emission factors. In addition, other national-level research projects are exploring monitoring and reporting of GHG emissions and removals associated with management activities on coastal wetlands. These efforts are described in more detail below:

**“Bringing Wetlands to Market” (2011-2014):** This study is a comprehensive study of coastal wetlands investigating whole marsh carbon dynamics (quantification of carbon dioxide and nitrous oxide gas exchange, carbon storage as well as lateral flux of dissolved organic and inorganic carbon) for wetlands.[[9]](#footnote-10) Key project activities included: (1) collection of new data on carbon sequestration and GHG fluxes across salt marsh sites along a gradient of land use and nitrogen loading, as well as in response to sea level rise and experimental warming; (2) development of a model to guide evaluation of potential blue carbon sites; (3) development of a Verified Carbon Standard-approved methodology for participation of blue carbon projects in carbon markets; (4) routine collaborative workshops with “end users”, including local and state agencies; and (5) an economic analysis of market potential of a proposed ~1,000 acre salt marsh restoration in Wellfleet and Truro. Research was completed in 2015. Publications are in preparation documenting carbon sequestration rates and GHG fluxes for salt marshes.

A follow-up study is underway with the NOAA National Estuary Research Reserve Science Collaborative, which will focus on baseline calculations of emissions and removals associated with the Herring River Restoration Project in Massachusetts. This study would estimate carbon stocks and emissions from existing lands including open saline and fresh waters, as well as soils and biomass of adjacent wetlands. This study will provide a significant step towards Tier 2 emissions factors for typical restoration activities in Massachusetts, and particularly climate mitigation impact data for this large restoration activity.

**Evaluating Salt Marsh Ecosystem Restoration: Quantifying Soil Carbon Accumulation and Greenhouse Gas Emissions Across a 122-yr Chronosequence:** This is a new Massachusetts-based project[[10]](#footnote-11) with an objective of providing data on carbon storage and fluxes for proposed and recent tidal wetland restorations, and is very much targeted at supporting quantification for the Commonwealth’s GHG inventory. In the course of landscape development, several thousand salt marshes in New England alone have been degraded due to impaired tidal flushing, which results due to under-sizing of culverts built in conjunction with roads, railroads and other development. DER has restored salt marshes by removing culverts (and similar structures) that restricted tidal exchange between marshes and estuaries. Reductions in methane emissions from marsh restoration are potentially significant, but evaluating such impacts of restoration activities is rarely undertaken. This one-year pilot study seeks to addresses this knowledge gap by quantifying differences in soil carbon accumulation rates, pore water chemistry, and GHG fluxes across marshes where tidal connectivity has been restored, including the Herring River and nearby smaller estuaries. As such, this study will directly address one of the largest areas of missing information in Table 1‑3, i.e., quantifying methane emissions on impounded freshwater and the likely reduction that occurs when impounded waters are reconnected to saline water bodies.

**Linking Satellite and Soil Data to validate Coastal Wetland “Blue Carbon” Inventories:** This project, funded by NASA, is a national collaboration to extend the NASA Carbon Monitoring System to fill missing gaps in coastal wetland carbon accounting. This project aims to fill existing gaps by: (1) providing a national-scale data framework to integrate and extrapolate field measurements that support national and state-level GHG inventory requirements; and (2) testing data needs for quantification of stock-based carbon changes in coastal wetland soil carbon and vegetation. From this study, involving 6 ‘sentinel sites’ (one of which is Cape Cod), verified monitoring will be developed to support policy and market interventions. The approach involves use of Landsat-based Coastal Change Analysis Program, with carbon-relevant attributes from finer scale NASA-derived spectral and RADAR data, as well as expansive field-data collected by partner agencies. The developed tools will be used to extend the IPCC 2013 Guidance Tier 1 default values to a fuller assessment of activities in coastal settings, coupled with additional Tier 2 default values for changes in soil carbon stocks. This assessment will also describe changes in tidal marsh carbon sequestration in response to sea level rise.

**The Blue Carbon Baseline Assessment:** This NOAA-funded project, established to synthesize developing science to enable inclusion of coastal wetland GHG emissions and fluxes into the EPA’s Report on the U.S. Inventory of GHG Emissions and Sinks. Under this activity, a Coastal Wetland Carbon Working Group (CWCWG) has been formed, comprised of federal agency and science community representatives working on coastal carbon fluxes and tracking land use change. By December 2015, the CWCWG procedures will complete the procedures for completing a full inventory-quality accounting of GHG emissions and removals on coastal wetlands in 2016. Compilation of the inventory is guided by the IPCC 2013 Wetlands Supplement. Depending upon data availability a combination of Tier 1 level (using a global default value for emissions or storage) and Tier 2 / Tier 3 values (country-specific and sub-national emissions and removals) will be used. The NASA/USGS Blue Carbon Monitoring System will likely provide the platform for data gathering and reporting at higher tier levels. This analysis will likely provide refined emissions factors for activities on coastal wetlands within the climate region covering Massachusetts.

**U.S. Blue Carbon Network (BCN):** Established in 2015, the BCN is a group of state and federal agencies engaged in carbon and wetlands management and working to inform programmatic science and policy development on blue carbon, as well as developing methodologies for projects that may participate in voluntary and compliance carbon markets. BCN identified one of the main items missing in this type of management are “look up tables” of regionally-specific data on carbon sequestration, storage, and induced emissions and removals with management of U.S. coastal wetlands. Such data will facilitate the development of both compliance and voluntary market projects, as well incorporation of wetland carbon into federal and state policies (such as the National Environmental Policy Act) and GHG inventories.

**Summary of Key Research Gaps/Information Needs:** Overall, there is a lack of data on emissions and reductions for activities on wetlands within Massachusetts. Some data gaps on carbon stocks, carbon accumulation rates and in some cases methane emissions are being filled for tidal wetlands through the above studies. For many of the cells in the Blue Carbon Calculator, there is an absence of data to support calculation. Particular focus on the emissions and removals with activities on cranberry bogs, standing waters, and inland organic soils (including forested wetlands) would greatly improve the application of the Calculator.

## Implications for Policy and Management

Globally, land use change accounts for about one-quarter of anthropogenic GHG emissions. Although wetlands represent a relatively small area of the landscape, improved management of these areas offers additional climate mitigation benefits in addition to a wider suite of environmental benefits such as improvements to water quality, storm buffering, supporting fisheries, etc.

An opportunity for the Commonwealth to elevate the potential role and value of blue carbon management activities (and associated GHG reductions) is to conduct a review of all state policies and regulations which affect wetlands management and restoration. At the Federal level, agencies are reviewing regulations which govern wetland management to assess the potential to include GHG mitigation benefits ([Pendleton et al. 2015](#_ENREF_14)). Federal agencies are also exploring options to enhance land management activities which fall within their jurisdiction. The application of carbon markets is also being explored as a potential mechanism to provide funding for improved wetlands management activities.

California is an example of a state which has adjusted policy to include wetlands within the scope of their climate change mitigation plans and activities. In May 2015, the California Department of Fish and Wildlife (CDFW) announced the selection of 12 projects which will receive grant funding to restore wetlands that sequester GHGs and provide other ecological benefits. The Wetland Restoration for Greenhouse Gas Reduction Grant Program focuses on projects with measureable objectives that lead to GHG reductions in wetlands from mountain meadows and coastal lowlands. These grants are CDFW’s first distribution of funds from California’s cap-and-trade program for mitigating climate change. While data and tools are not yet robust enough to include wetlands management activities within carbon markets, such a policy approach could be a useful interim step which recognizes the value that wetlands bring to state-level climate mitigation activities and goals, while waiting for the science and high-quality dataset to develop.

Through this project the Commonwealth has developed a first-generation prototype calculator for estimating emissions and reductions associated with wetlands restoration projects. Data gaps exist, particularly in ascribing emissions factors to management activities typical to Massachusetts, such as restoring floodplain and forested wetlands, and cranberry bog naturalization, as well as methane emissions from standing waters behind artificial barriers to drainage. Research to fill remaining data gaps would not only enable the Commonwealth to improve the Calculator and generate more accurate assessments of the GHG mitigation implications of management activities and restoration of wetlands, it would also improve regional and Federal estimates of GHG emissions associated with land use change.

Finally, the lowest hanging fruit in terms of GHG benefits for coastal wetlands comes not through carbon sequestration (which results in small positive carbon gains) but through avoiding emissions with rewetting drained organic soils, and particularly for the Commonwealth, reducing methane emissions by reconnecting disconnected tidal waters. Avoiding methane emissions offers an immediate, long-term and permanent benefit that can be recognized for many years after the restoration activity.

## References

Artigas, Francisco, Jin Young Shin, Christine Hobble, Alejandro Marti-Donati, Karina V. R. Schäfer, and Ildiko Pechmann. 2015. Long term carbon storage potential and CO2 sink strength of a restored salt marsh in New Jersey. *Agricultural and Forest Meteorology* 200:313-321.

Beals and Thomas Inc. 2015. *Damde Meadow Salt Marsh Restoration, World’s End Reservation* [cited Aug 27, 2015. Available from <http://www.bealsandthomas.com/portfolio-items/damde-meadows-salt-marsh-restoration/>.

Bernal, Blanca, and William J. Mitsch. 2012. Comparing carbon sequestration in temperate freshwater wetland communities. *Global Change Biology* 18 (5):1636-1647.

Bresney, Susan R., Serena Moseman-Valtierra, and Noah P. Snyder. 2015. Observations of Greenhouse Gases and Nitrate Concentrations in a Maine River and Fringing Wetland. *Northeastern Naturalist* 22 (1):120-143.

Commonwealth of Massachusetts. 2015. Email correspondence with Tim Purinton of the Massachusetts Division of Ecological Restoration.

Crooks, Stephen, I. von Emmer, M. Under, B. Brown, M.K. Orr, and D. Murdiyarso. 2014. Guiding Principles for Delivering Coastal Wetland Carbon Projects. *United Nations Environment Program and Center for International Forestry Research.*

Helton, AshleyM, EmilyS Bernhardt, and Anna Fedders. 2014. Biogeochemical regime shifts in coastal landscapes: the contrasting effects of saltwater incursion and agricultural pollution on greenhouse gas emissions from a freshwater wetland. *Biogeochemistry* 120 (1-3):133-147.

Houghton, R.A., and G.M. Woodwell. 1980. The flax pond ecosystem study: exchanges of CO2 between a salt marsh and the atmosphere. *Ecology* 61 (6):1434-1445.

Howes, Brian L., John W. H. Dacey, and John M. Teal. 1985. Annual Carbon Mineralization and Belowground Production of Spartina Alterniflora in a New England Salt Marsh. *Ecology* 66 (2):595-605.

Kroeger, K., and S. Crooks. in prep. Avoided greenhouse gas emissions through tidal reconnection in degraded and impounded wetlands: The lowest hanging fruit in blue carbon?

MIT Sea Grant. *Evaluating Salt Marsh Ecosystem Restoration: Quantifying Soil Carbon Accumulation and Greenhouse Gas Emissions Across a 12-y Chronosequence* n.d. [cited July 21, 2015. Available from <http://seagrant.mit.edu/proj_desc.php?prjID=1338>.

Moseman-Valtierra, Serena, Rosalinda Gonzalez, Kevin D. Kroeger, Jianwu Tang, Wei Chun Chao, John Crusius, John Bratton, Adrian Green, and James Shelton. 2011. Short-term nitrogen additions can shift a coastal wetland from a sink to a source of N2O. *Atmospheric Environment* 45 (26):4390-4397.

Moseman-Valtierra, Serena, Kevin D. Kroeger, John Crusius, Sandra Baldwin, Adrian Green, T. Wallace Brooks, and Emily Pugh. 2015. Substantial nitrous oxide emissions from intertidal sediments and groundwater in anthropogenically-impacted West Falmouth Harbor, Massachusetts. *Chemosphere* 119:1281-1288.

Pendleton, L.H., A.E. Sutton-Grier, Gordon D.R., B.C. Murray, B.E. Victor, R.B. Griffis, J.A.V. Lechuga, and C. Giri. 2015. Considering “Coastal Carbon” in Existing U.S. Federal Statutes and Policies. *Coastal Management* 41:439-456.

U.S. EPA. *U.S. Greenhouse Gas Inventory Report: 1990-2013*, July 21, 2015 2015 [cited Aug 28, 2015. Available from <http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html>.

# Appendix A

## Blue Carbon Calculator: Emissions Factors for Drainage of Inland Organic Soils

Table 2‑1 Replication of Table 2.1: Emissions Factors for CO2 for Drained Inland Organic Soils in the *Wetlands Supplement*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Land-use category | Climate / vegetation zone | Emission factora (tons CO2-C ha-1yr-1) | 95% Confidence intervalb | | No. of sites | IPCC Citations/comments |
| Forest Land, drained | Temperate | 2.6 | 2 | 3.3 | 8 | Glenn et al., 1993; Minkkinen et al., 2007b; von Arnold et al., 2005a, b; Yamulki et al., 2013 |
| Cropland, drained | Boreal and Temperate | 7.9 | 6.5 | 9.4 | 39 | Drösler et al., 2013; Elsgaard et al., 2012; Grønlund et al., 2008; Kasimir-Klemedtsson et al., 1997; Leifeld et al., 2011; Maljanen et al., 2001a, 2003a, 2004, 2007; Morrison et al., 2013; Petersen et al., 2012 |
| Grassland, drained, nutrient-poor | Temperate | 5.3 | 3.7 | 6.9 | 7 | Drösler et al., 2013; Kuntze, 1992 |
| Grassland, deep-drained, nutrient-rich | Temperate | 6.1 | 5 | 7.3 | 39 | Augustin, 2003; Augustin et al., 1996; Czaplak & Dembek, 2000; Drösler et al., 2013; Elsgaard et al., 2012; Höper, 2002; Jacobs et al., 2003; Kasimir-Klemedtsson et al., 1997; Langeveld et al., 1997; Leifeld et al., 2011; Lorenz et al., 1992; Meyer et al., 2001; Nieveen et al., 2005; Okruszko, 1989; Schothorst, 1977; Schrier-Uijl et al., 2010a, c; Veenendaal et al., 2007; Weinzierl, 1997 |
| Grassland, shallow-drained, nutrient-rich | Temperate | 3.6 | 1.8 | 5.4 | 13 | Drösler et al., 2013; Jacobs et al., 2003; Lloyd, 2006 |
| Peatland Managed for Extractionc | Boreal and Temperate | 2.8 | 1.1 | 4.2 | 20 | Ahlholm & Silvola, 1990; Glatzel et al., 2003; McNeil & Waddington, 2003; Shurpali et al., 2008; Strack & Zuback, 2013; Sundh et al., 2000; Tuittila & Komulainen, 1995; Tuittila et al., 2000, 2004; Waddington et al., 2010 |
| Settlements | All climate zones | There is no fixed default emission/removal factor for Settlements. See additional information in the *Wetlands Supplement.* | | | | |
| Other Land | All climate zones | Other Land Remaining Other Land: 0  Land Converted to Other Land: maintain emission factor of previous land-use category | | | | |

a Mean

bSome confidence intervals contain negative values. These were mathematically calculated based on error propagation of uncertainties. However, all underlying CO2 fluxes were positive.

cOn-site CO2-C emissions from drained peat deposits only. For off-site CO2-C emissions from peat extracted for horticultural or energy use, see Chapter 7, Volume 4, 2006 IPCC Guidelines.

Source: *Wetlands Supplement*

Table 2‑2 Replication of Table 2.3: Emissions Factors for CH4 for Drained Inland Organic Soils in the *Wetlands Supplement*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Land-use category | Climate / vegetation zones | Emission factora  (kg CH4 ha-1yr-1) | 95% confidence intervalb (centred on mean) | | No. of sites | IPCC Citations/comments |
| Forest Land, drained | Temperate | 2.5 | -0.6 | 5.7 | 13 | Glenn et al., 1993; Moore & Knowles, 1990; Sikström et al., 2009; von Arnold et al., 2005a, b; Weslien et al., 2009; Yamulki et al., 2013 |
| Cropland, drained | Boreal and Temperate | 0 | -2.8 | 2.8 | 38 | Augustin, 2003; Augustin et al., 1998; Drösler et al., 2013; Elsgaard et al., 2012; Flessa et al., 1998; Kasimir-Klemedtsson et al., 2009; Maljanen et al., 2003a, b, 2004, 2007; Petersen et al., 2012; Regina et al., 2007; Taft et al., 2013 |
| Grassland, drained, nutrient-poor | Temperate | 1.8 | 0.72 | 2.9 | 9 | Drösler et al., 2013; Kasimir-Klemedtsson et al., 2009; van den Bos, 2003 |
| Grassland, deep-drained, nutrient-rich | Temperate | 16 | 2.4 | 29 | 44 | Augustin et al., 1996; Best & Jacobs, 1997; Drösler et al., 2013; Flessa & Beese, 1997; Flessa et al., 1998; Jacobs et al., 2003; Kroon et al., 2010; Langeveld et al., 1997; Meyer et al., 2001; Nykänen et al., 1995; Petersen et al., 2012; Schrier-Uijl et al., 2010a, b; Teh et al., 2011; van den Bos, 2003; van den Pol-van Dasselaar et al., 1997; Wild et al., 2001 |
| Grassland, shallow-drained, nutrient-rich | Temperate | 39 | -2.9 | 81 | 16 | Augustin, 2003; Drösler et al., 2013; Jacobs et al., 2003; van den Pol-van Dasselaar et al., 1997 |
| Peat Extraction | Boreal and Temperate | 6.1 | 1.6 | 11 | 15 | Hyvönen et al., 2009; Nykänen et al., 1996; Strack & Zuback, 2013; Sundh et al., 2000; Tuittila et al., 2000; Waddington & Day, 2007 |
| Settlements | All climate zones | There is no fixed default emission/removal factor for Settlements. See the Wetlands Supplement for more information. | | | | |
| Other Land | All climate zones | Other Land Remaining Other Land: 0  Land Converted to Other Land: maintain emission factor for previous land-use category | | | | |

|  |
| --- |
| a Mean  b Some confidence intervals contain negative values. This indicates that, while the mean emission factor is zero or a net CH4 emission, a net CH4 uptake has been observed in some studies. |

## Blue Carbon Calculator: Calculations

### Extraction Calculations

Where

*L*=Land use class

*AL*=Area within a land use class prior to extraction

*SCL*= Soil carbon stock for extraction for a specific land use class

Values for *AL* are entered by the user on the “Data Entry tab”. Values for *SCL* are from the “Extraction” columns in Table 1‑3 and are referenced in the calculator from the “Lookup Table” tab. All carbon from soil is assumed to be released into the air as CO2 and therefore is counted as CO2 emissions. This is assumed to occur at the time of extraction and therefore all emissions resulting from this management activity are counted in the first year following extraction. No additional emissions are considered in the years following.

### Drainage Calculations

Where

*L*=Land use class

*AL*=Area within a land use class prior to draining

*=* Draining emissions factor for dissolved organic carbon for a specific land use class

=Draining emissions factor for CO2-C from soil for a specific land use class

*EFCH4L*= Draining emissions factor for CH4-C from soil for a specific land use class

Values for *AL* are entered on the “Data Entry tab”. Values for *,* and are from the “Drained” columns Table 1‑3 and are referenced in the calculator from the “Lookup Table” tab. All dissolved organic carbon is assumed to be released into the atmosphere as CO2 emissions. The calculator assumes CO2 and CH4 emissions from all types of drained wetlands continue accumulating linearly for 20 years following drainage. After 20 years, all emissions from organic soils continue accumulating linearly until 50 years and all emissions from mineral soils stop.

### Rewetting Calculations

Where

*L*=Land use class

*AL*=Area within a land use class after rewetting

*=* Rewetting emissions factor for dissolved organic carbon for a specific land use class

=Rewetting emissions factor for CO2-C from soil for a specific land use class

= Rewetting emissions factor for CH4-C from soil for a specific land use class

Values for *AL* are entered on the “Data Entry tab”. Values for *,* , and are from the “Rewetting” columns in Table 1‑3 and are referenced in the calculator from the “Lookup Table” tab. The calculator assumes CO2 and CH4 emissions from all types of rewetted wetlands continue accumulating linearly for 50 years following rewetting.

### Wetlands remaining wetlands Calculations

-

Where

*L*=Land use class

*APre,L*=Area of within a land use class prior to conversion

*APost,L*=Area of land within a land use class after conversion

*=* Wetlands Remaining Wetlands emissions factor for dissolved organic carbon for a specific land use class

= Wetlands Remaining Wetlands emissions factor for CO2-C from soil for a specific land use class

= Wetlands Remaining Wetlands emissions factor for CH4-C from soil for a specific land use class

Values for *AL* are entered on the “Data Entry tab”. Values for *,* , and are from the “Wetlands Remaining Wetlands ” columns in Table 1‑3 and are referenced in the calculator from the “Lookup Table” tab. The calculator assumes CO2 and CH4 emissions from all types of converted wetlands continue accumulating linearly for 50 years following the project.

### Resulting Emissions and Unit Conversions

Annual differences in emissions/removals relative to pre-management conditions resulting from each management activity are given on each “Calculator” tab. Cumulative change in emissions for each activity are given for 1, 10, 20, 30, 40 and 50 years following the activity on the “Results Summary” tab in the pink, lime green, purple and orange rows. Total cumulative emissions, summed across all activities are shown in the bright green and blue rows on the same worksheet and also shown in graphs. It is important to remember that these emissions or removals are relative to emissions or removals prior to the management. Therefore, negative emissions resulting from these calculations may mean a decrease in emissions compared to prior conditions, not necessarily sequestration. This is better shown with examples in Section 2.4. Emissions are shown as cumulative. Each time point gives total emissions since the activity occurred. For example, at 50 years the emissions or removals shown do not occur at year 50, but have occurred since year 1. All results are provided in four different units:

* Tons CO2-C: mass of carbon (in tons) resulting from CO2 only
* Tons CH4-C: mass of carbon (in tons) resulting from CH4 only
* Tons CO2e: mass of CO2 equivalents resulting from CO2 and CH4 combined
* Gallons of gasoline: Equivalent of CO2 emissions from the consumption of gasoline (CO2 and CH4 combined)

Calculations for unit conversions are described below:

**Conversion to CO2e:**

Where:

= CO2 equivalents

=mass of carbon (in tons) resulting from CO2

=mass of carbon (in tons) resulting from CH4

= Global warming potential of CH4 in a 100 year period.

**Conversion to gallons of gasoline:**

## Blue Carbon Calculator: Analysis of Recent MassDER Projects

### Damde Meadows, Hingham

Data for the Damde Meadows project supplied by the MassDER was entered into the Calculator, as shown in Figure 2‑15. Because the entire project results in converting saturated land (phragmites dominated wetland and open water) to other saturated land (high and low salt marsh and tidal flat) all data was entered into the “Wetlands Remaining Wetlands” columns. However, it has been noted that a portion of this project did include dredging in order to create open channels ([Beals and Thomas Inc.](#_ENREF_2) 2015). If this area resulted in the removal of wetland sediment and therefore oxidation of the sediment, the area of the wetland that was dredged should be entered into the “Extraction” columns. Also, if this dredging resulting in draining or lowering the water table in any portion of the wetland, data for this area should be entered into the “Draining” columns. We did not have sufficient information at the time of this analysis to determine this, and therefore all data was entered as shown in Figure 2‑15.

Figure 2‑1 and Figure 2‑2 show estimated reductions in GHG emissions from the restoration project, as calculated by the Blue Carbon Calculator. From this project we see a net benefit in both CO2 emissions and CH4 emissions, as shown by the negative values and negative slopes in Figure 2‑1 and Figure 2‑2. The benefit from CO2 sequestration is associated with an increase in wetland area, from 3.2 acres of phragmites-dominated wetland to 3.2 acres high saltmarsh and 8.8 acres low salt marsh (some of this area was converted from open salt water). Additionally, the change in salinity associated with, converting from phragmites (fresh water/tidal) to salt marsh results in a reduction of CH4 emissions. Over 50 years, it is estimated that this project results in 1,128 fewer tons of CO2-equivalentin the atmosphere, the equivalent of avoiding combustion of 127,422 fewer gallons of gasoline as compared to the world without this project (Figure 2‑1). It is important to note that the Calculator only accounts for changes in emissions and reductions from the soil, and the added benefits of carbon sequestration related with increased plant cover is not accounted for, therefore, this is likely an underestimation of GHG benefits.

Figure 2‑1 Cumulative emissions and reductions of GHGs resulting from the Damde Meadows restoration project as calculated by the Blue Carbon Calculator.



Figure 2‑2 Graphs showing cumulative emissions and reductions of GHGs resulting from the Damde Meadows restoration project as calculated by the Blue Carbon Calculator.



### Eel River, Plymouth

The Eel River restoration project is a cranberry bog naturalization project which results in rewetting of cranberry bogs. As previously stated, we have assumed that cranberry bogs are an upland land class characterized by mineral soils as described by the MassDER. For the portion of the area that converts cranberry bog to wetland categories, these areas have been entered into the “Rewetting” columns with mineral soils because the water table is being raised in what is currently a dry, upland, cranberry bog (Figure 2‑16). It has been assumed that the area of open water and shrub swamp prior to restoration remains so following restoration. Data for this area has been entered into the “Wetlands remaining wetlands” columns, although, because the area is the same before and after, this will not result in any net GHG emissions or removals (Figure 2‑16).

Figure 2‑3 and Figure 2‑4show that this project results in no net change in CO2 and an increase in CH4 emissions. Because the soils are mineral, and CO2 emissions factors for wetland mineral soils is not provided by the IPCC, CO2 emissions resulting from this activity are assumed to be zero. However, rewetted mineral soils do result in CH4 emissions. Over the course of 50 years, this project could result in 7,161 more tons of CO2 equivalent in the atmosphere (all sourced from CH4 emissions), the equivalent of combusting of 809,167 more gallons of gasoline as compared to the world without this project (Figure 2‑3). It is important to note that the Calculator only determines emissions from soils, and therefore sequestration benefits from any vegetation (i.e., trees, shrubs) are not included. It is possible that the benefits from vegetation growth outweigh CH4 emissions. To better understand these comparisons, this is an area on which to focus future improvements to the Calculator.

Figure 2‑3 Cumulative emissions and reductions of GHGs resulting from the Eel River restoration project as calculated by the Blue Carbon Calculator.

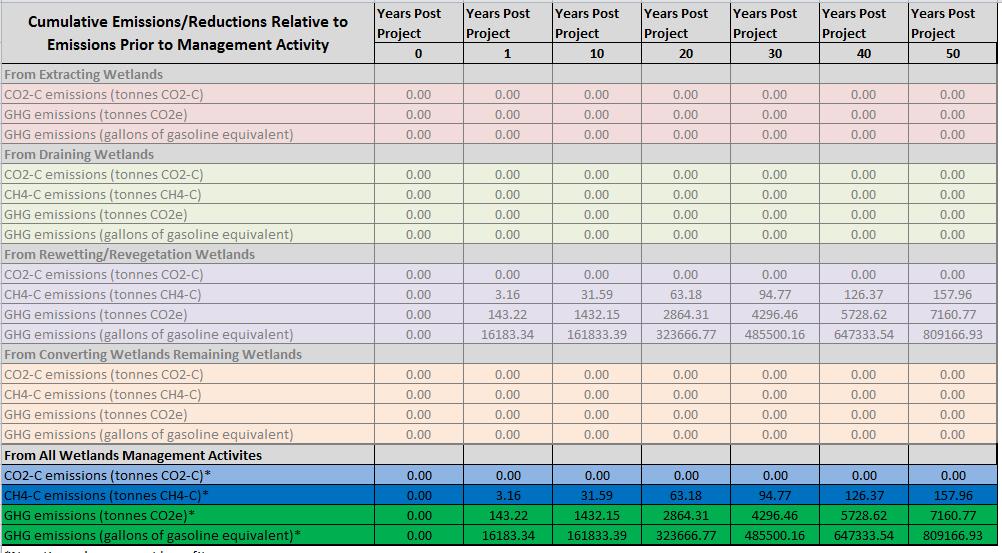
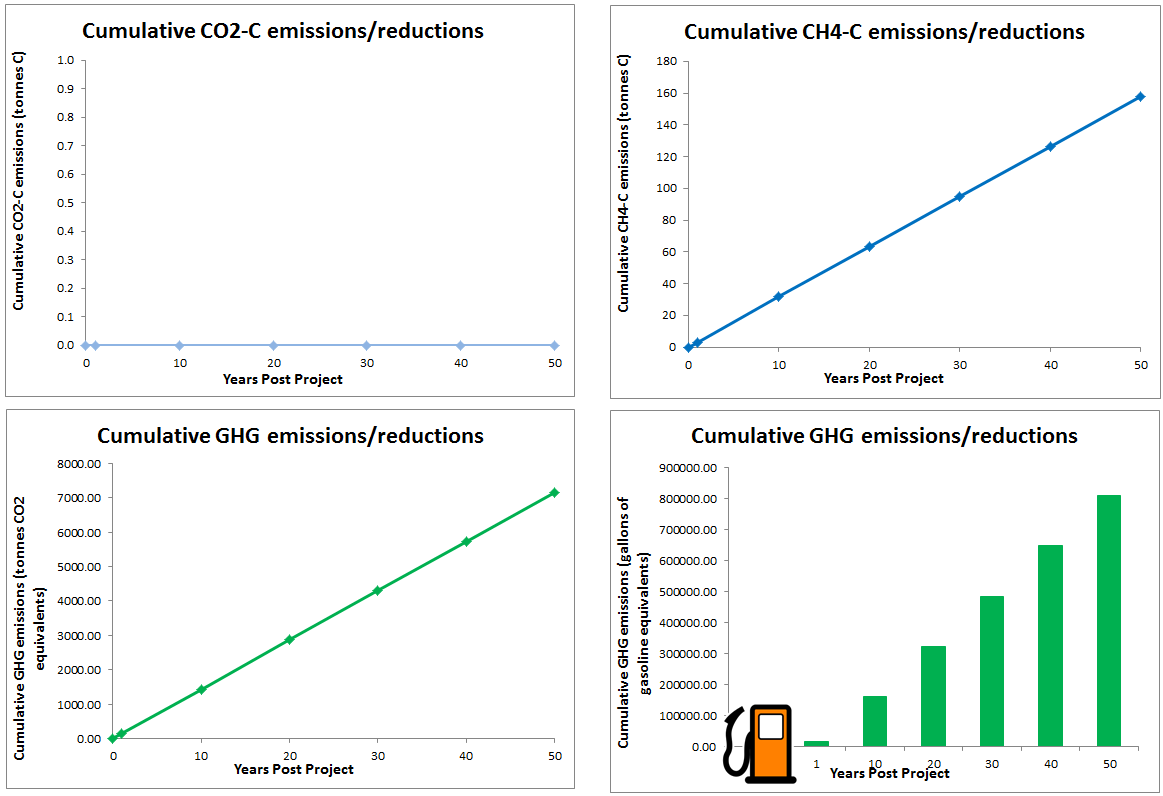


Figure 2‑4 Graphs showing cumulative emissions and reductions of GHGs resulting from the Eel River restoration project as calculated by the Blue Carbon Calculator.



### Mill River, Taunton

The Mill River restoration project, similar to others, involves conversion between saturated land classes to other saturated land classes, and therefore, all data was entered into the “Wetlands remaining wetlands” columns (Figure 2‑17). Because we have assumed, based on Kroger and Crooks ([in prep](#_ENREF_10)) that open water has the same emissions as a wetland with the same soil type and salinity, we do not see any changes in emissions resulting from this project (Figure 2‑5 and Figure 2‑6). It should be noted that there are likely benefits in carbon sequestration from increased vegetation growth associated with this project, however, the calculator only considers changes in soil emissions. Therefore the zero net change is likely an understatement of the GHG benefits from this project.

Figure 2‑5 Cumulative emissions and reductions of GHGs resulting from the Mill River restoration project as calculated by the Blue Carbon Calculator.



Figure 2‑6 Graphs showing cumulative emissions and reductions of GHGs resulting from the Mill River restoration project as calculated by the Blue Carbon Calculator.



### Muddy Creek, Chatham and Harwich

Muddy Creek, again, is a project that falls under the “wetlands remaining wetlands” category because all saturated lands (shallow marsh, wooded swamp, phragmites, salt marsh and open salt water, tidal flat) are being converted into other saturated land classes (Figure 2‑18). Because this project results in a reduction of all freshwater wetlands, and an increase in saline land cover categories, it results in a net reduction of CH4, as the emissions of CH4 associated with the fresh water wetlands are eliminated (Figure 2‑7, Figure 2‑8). Because the overall area covered by saline wetlands remains the same prior to and following the project, and because freshwater wetlands and open salt water both have zero CO2 emissions (Table 1‑3), there is no change in CO2 emissions resulting from this project (Figure 2‑7).

Figure 2‑7 Cumulative emissions and reductions of GHGs resulting from the Muddy Creek restoration project as calculated by the Blue Carbon Calculator.



Figure 2‑8 Graphs showing cumulative emissions and reductions of GHGs resulting from the Muddy Creek restoration project as calculated by the Blue Carbon Calculator.



### Ox Pasture, Rowley

The Ox Pasture restoration project involves conversion between saturated land classes to other saturated land classes, and therefore, all data was entered into the “Wetlands remaining wetlands” columns (Figure 2‑18). Conversion from open fresh water to mainly shallow freshwater marsh results in little change in emissions (Figure 2‑9, Figure 2‑10) The small decrease in CO2 and CH4 emissions is associated with the 0.05 acres converted from open fresh water to a low salt marsh, due to the change in salinity (Figure 2‑9, Figure 2‑10). Over the course of 50 years, this project will result in 15 fewer tons of CO2-equivalent in the atmosphere, the equivalent of combusting 1,655 fewer gallons of gasoline as compared to the world without this project (Figure 2‑9). As has been previously stated, the benefits of increasing vegetation cover and associated carbon sequestration are not captured by the Calculator, and therefore this is likely an understatement of the GHG benefits of this project.

Figure 2‑9 Cumulative emissions and reductions of GHGs resulting from the Ox Pasture restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results spreadsheet

Figure 2‑10 Graphs showing cumulative emissions and reductions of GHGs resulting from the Ox Pasture restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results graphs

### Town Creek, Salisbury

The Town Creek project, similar to many other DER restoration projects, is a “wetlands remaining wetlands” project (Figure 2‑20) consisting of conversion from mostly fresh and some salt water wetlands to mostly salt and some fresh water wetlands. Because of the decrease in the area covered by freshwater and an increase in the saltwater saturated area, a decrease in both CO2 and CH4 emissions is expected. The decrease in CO2 emissions is associated with a greater area sequestering carbon (salt water areas). The CH4 decrease is associated with a small area producing CH4 (freshwater areas). (Figure 2‑11, Figure 2‑12).

Figure 2‑11 Cumulative emissions and reductions of GHGs resulting from the Town Creek restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results spreadsheet

Figure 2‑12 Graphs showing cumulative emissions and reductions of GHGs resulting from the Town Creek restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results graphs

### Wekepeke Brook, Lancaster

The Wekepeke Brook project, similar to the Mill River project, results in no net change in either CO2 or CH4 emissions because it is a “wetlands remaining wetlands” project (Figure 2‑21) that consists of conversion from a freshwater saturated land cover to another freshwater saturated land cover class. Because open fresh water is assumed to have the same emissions as freshwater wetlands, no net change in emissions is produced by this project (Figure 2‑13, Figure 2‑14). It should be stated that the benefits in carbon sequestration from increasing vegetation cover by converting open water to wetland is not captured by the Calculator, and therefore these results are likely an understatement of the GHG benefits that may result from this restoration effort.

Figure 2‑13 Cumulative emissions and reductions of GHGs resulting from the Wekepeke Brook restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results spreadsheet

Figure 2‑14 Graphs showing cumulative emissions and reductions of GHGs resulting from the Wekepeke Brook restoration project as calculated by the Blue Carbon Calculator.

Screen shot of Calculator results graphs

### Additional Restoration Projects

For the Broad Meadows, Red Brook and Third Herring Brook projects, the area of land prior to restoration and the area post-restoration in the data provided were not equal, and therefore they have not been included in this analysis. For complex projects such as the Cotely River and Tidemarsh projects, respectively, we could not make accurate assumptions as to which categories were being converted into others, i.e., which areas were being drained, rewetted or were wetlands remaining as wetlands; therefore, we could not accurately enter the data into the various columns within the calculator. With more knowledge of these specific projects, they can be analyzed with the Calculator.

## Blue Carbon Calculator: Data Entry Figures

Figure 2‑15 Data entry into the Blue Carbon Calculator for Damde Meadows restoration project.

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

Figure 2‑16 Data entry into the Blue Carbon Calculator for the Eel River restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

Figure 2‑17 Data entry into the Blue Carbon Calculator for the Mill River restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

Figure 2‑18 Data entry into the Blue Carbon Calculator for the Muddy Creek restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from prevous page

Figure 2‑19 Data entry into the Blue Carbon Calculator for the Ox Pasture restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

Figure 2‑20 Data entry into the Blue Carbon Calculator for the Town Creek restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

Figure 2‑21 Data entry into the Blue Carbon Calculator for the Wekepeke Brook restoration project

Screen shot of Calculator results spreadsheet

Screen shot of Calculator results spreadsheet continued from previous page

1. Fluxes from anthropogenically manipulated nutrient status and salinity may not reflect nutrient and salinity fluctuation occurring at natural or restored wetland sites and therefore are likely not widely applicable to Massachusetts wetland restoration projects. [↑](#footnote-ref-2)
2. CO2-C denotes the mass of carbon within a given mass of CO2. Because the atomic weight of carbon is 12 grams and the atomic weight of carbon dioxide is 44 grams (12 grams of carbon+32 grams of oxygen) 12 metric tons of CO2-C is equivalent to 44 metric tons of CO2. Scientists often used CO2-C because it simplifies following carbon fluxes in the carbon cycle. [↑](#footnote-ref-3)
3. Provided in Chapter 2 of the *Wetlands Supplement.* [↑](#footnote-ref-4)
4. Provided in Chapter 3 of the *Wetlands Supplement.* [↑](#footnote-ref-5)
5. Emissions regarding both the draining and rewetting of inland mineral wetland soils is provided in Chapter 5 of the *Wetlands Supplement.* [↑](#footnote-ref-6)
6. Provided in Chapter 4 of the *Wetlands Supplement.* [↑](#footnote-ref-7)
7. The IPCC default assumption for inland organic soils in temperate zones is that these are nutrient rich systems. [↑](#footnote-ref-8)
8. Throughout this report, we use the term “tons” or “tonnes” to indicate metric tons. [↑](#footnote-ref-9)
9. The study was funded by a research grant from the National Oceanic and Atmospheric Administration (NOAA) Science Collaborative titled: “Carbon and Nitrogen Management in Coastal Wetlands: Quantifying Carbon Storage and Greenhouse Gas Emissions by Tidal Wetlands to Support Development of Policy Frameworks and Market-based Mechanisms”. It is a collaborative effort between Waquoit Bay National Estuarine Research Reserve (WBNERRWB), NOAA, the U.S. Geological Survey (USGS) Woods Hole Coastal & Marine Science Center and the Ecosystems Center, Marine Biological Laboratory, Woods Hole Oceanographic Institution (WHOI), University of Rhode Island, Restore America’s Estuaries, and several other institutions. [↑](#footnote-ref-10)
10. Supported by WHOI, USGS, NOAA, National Park Service Water Quality Partnership, National Science Foundation and the MIT Sea Grant College program ([MIT Sea Grant n.d.](#_ENREF_11)). [↑](#footnote-ref-11)