California Air Resources Board

Revised Quantification Methodology for Land Restoration

California Climate Investments

April 27, 2020

Table of Contents

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

CARB staff developed this Land Restoration Quantification Methodology (QM) to provide guidance for estimating the net GHG benefit and selected co-benefits of land restoration. This methodology uses calculations to estimate carbon sequestration in soil from wetland and grassland restoration and in biomass from tree planting, and GHG emission changes from wetland restoration or enhancement. Programs this QM may be used for include, but are not limited to:

- The Wetlands Restoration for Greenhouse Gas Reduction Program[1], administered by the California Department of Fish and Wildlife (CDFW)
- Climate Adaptation Resiliency Program[2], administered by the Wildlife Conservation Board (WCB)

The Lands Restoration Benefits Calculator Tool (Tool) automates methods described in this document, provides a link to a step-by-step user guide with project examples, and outlines documentation requirements. Projects will report the total project GHG benefit and co-benefits estimated using the Tool as well as the total project GHG benefit per dollar of GGRF funds requested. The Land Restoration Benefits Calculator Tool is available for download at: http://www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate net GHG benefit, the Land Restoration Benefits Calculator Tool estimates the following co-benefits and key variables from Land Restoration projects:

[1] https://www.wildlife.ca.gov/Conservation/Watersheds/Greenhouse-Gas-Reduction
[2] https://wcb.ca.gov/Programs/Climate-Adaptation

- Nitrous Oxide (NO_x) Emission Absorption (in lbs)
- PM2.5 Emission Absorption (in lbs)
- Lands Restored/Treated (in acres)
- Trees Planted

Key variables are project characteristics that contribute to a project's net GHG benefit and signal an additional benefit. Additional co-benefits for which CARB assessment methodologies were not incorporated into the Wetlands Benefits Tool may also be applicable to the project. Applicants should consult the Wetlands Program Guidelines, Proposal Solicitation Notice materials, and/or website to ensure they are meeting Wetlands Program requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability[3]. CARB developed Quantification Methodology to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and
- Result in net GHG benefit estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the Land Restoration project types. CARB also consulted with agencies responsible for land restoration to determine project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level.

CARB released the Draft Revised Land Restoration Quantification Methodology and Draft Revised Land Restoration Benefits Calculator Tool for public comment in April 2020. This Final Land Restoration Quantification Methodology and accompanying Land Restoration Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to program guidelines."

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing

[3] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The Land Restoration Tool relies on project-specific outputs from the following tools:

SoilWeb is used to determine the dominant soil order at the project site. SoilWeb was developed by the California Soil Resource Lab at University of California, Davis (UCD) and University of California Agriculture and Natural Resources (UCANR) in collaboration with the US Department of Agriculture Natural Resources Conservation Service (NRCS). Applicants use SoilWeb to explore soil survey areas using an interactive Google map and view detailed information about soils on the project site. SoilWeb runs in any web browser and is compatible with desktop computers, tablets, and smartphones. SoilWeb is available at: https://casoilresource.lawr.ucdavis.edu/gmap/.

The US Forest Service (USFS) i-Tree Planting web based tool provides quantitative data for an individual or population of trees to be planted as part of the project including the amount of carbon stored and the estimated effects of tree shade on building energy use based on project characteristics such as the climate zone, tree species, tree age, and tree diameter at breast height (DBH). i-Tree Planting is available at: https://planting.itreetools.org/. A description about the tool is available at: https://planting.itreetools.org/help/.

SoilWeb and i-Tree Planting are used statewide, subject to regular updates to incorporate new information, free of charge, and publicly available to anyone with internet access.

In addition to the tools above, the QM relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the Land Restoration Tool to estimate the net GHG benefit and co-benefits of the proposed project. The Land Restoration Tool is available at: http://www.arb.ca.gov/cci-resources.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB revised the Land Restoration Quantification Methodology from the previous version[4] to enhance the analysis and provide additional clarity. The changes include:

- Addition of conversion from managed seasonal wetland to coastal tidal wetland as a project characteristic;
- Addition of Grassland project type; and
- Modification of the Land Restoration Calculator Tool to reflect these additions.

The Revised Land Restoration Quantification Methodology will be used to re-calculate projects submitted under the most recent previous version of the Quantification Methodology for the California Department of Fish and Wildlife Wetlands Restoration for Greenhouse Gas Reduction Grant Program[4].

[4] Please email GGRFProgram@arb.ca.gov to request a copy of the previous quantification methodology.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the Land Restoration Tool.

Land Restoration Project Types

Land Restoration programs restore or enhance degraded and altered ecosystems to provide climate resilient services to California's people, wildlife, and fish. There are five project types that meet the objectives of Land Restoration and for which there are methods to quantify a net GHG benefit. Other project features may be eligible for funding under an administering agency's program; however, to be quantified for benefits, each project requesting GGRF funding must include at least one of the following:

- Coastal Tidal Wetland Restoration
- Sacramento-San Joaquin Delta Wetland Restoration
- Mountain Meadow Restoration
- Seasonal Inland Wetland Restoration
- Grassland Restoration

General Approach

Methods used in the Land Restoration Tool for estimating the net GHG benefit and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefit calculator tools are developed and updated.

These methods account for carbon sequestration in restored soil and planted trees, and for changes in carbon dioxide and methane emissions due to wetlands restoration. In general, the Land Restoration Tool estimates the net GHG benefit using the approaches in Table 1. The Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate the net GHG benefit.

Table 1. General Approach to Quantification by Project Type

Coastal Tidal Wetland Restoration
Net GHG Benefit = Soil Carbon Sequestration from Wetland Restoration + Soil Carbon Sequestration from Grassland Restoration + Biomass Carbon Sequestration from Tree Planting + Avoided Carbon Dioxide Emissions from Drained Farmland and Wetland + Avoided Nitrous Oxide Emissions from Drained Farmland and Wetland + Avoided Nitrous Oxide Emissions from Fertilizer Application – Methane Emissions from Fresh Water Wetland Restoration.
Sacramento-San Joaquin Delta Wetland Restoration
Net GHG Benefit = Soil Carbon Sequestration from Wetland Restoration + Biomass Carbon Sequestration from Tree Planting + Avoided Carbon Dioxide Emissions from Drained Farmland + Avoided Nitrous Oxide Emissions from Drained Farmland + Avoided Nitrous Oxide Emissions from Fertilizer Application – Methane Emissions from Fresh Water Wetland Restoration.
Mountain Meadow Restoration
Net GHG Benefit = Soil Carbon Sequestration from Wetland Restoration + Biomass Carbon Sequestration from Tree Planting
Seasonal Inland Wetland Restoration
Net GHG Benefit = Soil Carbon Sequestration from Wetland Restoration + Soil Carbon Sequestration from Grassland Restoration + Biomass Carbon Sequestration from Tree Planting + Avoided Nitrous Oxide Emissions from Fertilizer Application – Methane Emissions from Seasonal Mineral Soil Fresh Water Wetland Restoration.
Grassland Restoration
Net GHG Benefit = Soil Carbon Sequestration from Grassland Restoration + Biomass Carbon Sequestration from Tree Planting + Avoided Nitrous Oxide Emissions from Fertilizer Application

A. GHG Benefit from Coastal Tidal Wetland Restoration

Equation 1 estimates the GHG benefit from conversion of farmland and degraded grassland to restored wetland and improved grassland. Equation 1 relies on seven other equations. Equation 2 estimates the value for the difference in carbon loss rates (ΔCLR_{dos}) from land-use change from drained organic soil on farmland that will be restored to coastal wetland. Equation 3 estimates increased methane emissions ($\Delta CH_{4,CTW}$) from wetland restoration. Equation 4 estimates the avoided N_2O emissions (ΔN_2O_{dos}) from restoration of drained organic soil in farmland. Equation 5 estimates the avoided N_2O emissions (ΔN_2O_{fert}) associated with fertilizer application. Equation 6 estimates the soil carbon sequestration benefit ($Cseq_{CTW}$) from coastal tidal wetland restoration. Equation 7 estimates the soil carbon sequestration benefit ($Cseq_G$) from upland grassland restoration. Equation 15 estimates the biomass carbon sequestration from tree plantings ($Cseq_T$).

Equation 1: GHG Benefit from Coastal Tidal Wetland Restoration

$$GHG_{CTW} = \left(\Delta CLR_{dos} - \Delta CH_{4,CTW} \times 25 + \left(\Delta N_2O_{dos} + \Delta N_2O_{fert}\right) \times 298\right) \times 50 + Cseq_{CTW} + Cseq_G + Cseq_T$$

Where,

			Units
GHG_{CTW}	=	GHG benefit of restoring coastal tidal wetlands and grassland	$MT\ CO_2e$
ΔCLR_{dos}	=	Avoided carbon loss rate from drained organic soil on farmland or managed seasonal wetland to be restored to coastal tidal wetlands (from Equation 2)	$\frac{MT\ CO_2e}{Year}$
$\Delta CH_{4,CTW}$	=	Increase in methane emissions from restoring coastal tidal wetlands (from Equation 3)	$\frac{MT\ CH_4}{Year}$
25	=	Methane global warming potential	$\frac{MT\ CO_2e}{MT\ CH_4}$
ΔN_2O_{dos}	=	Avoided nitrous oxide emissions from farmland on drained organic soil to be restored to coastal tidal wetlands (from Equation 4)	$\frac{MT\ N_2O}{Year}$
ΔN_2O_{fert}	=	Avoided nitrous oxide emissions from farmland due to avoided nitrogen fertilizer application (from Equation 5)	$\frac{MT\ N_2O}{Year}$
298	=	Nitrous oxide global warming potential	$\frac{MT\ CO_2e}{MT\ N_2O}$
50	=	Number of years of project life	Years
$Cseq_{CTW}$	=	Soil carbon sequestration increase from coastal tidal wetlands restoration (Equation 6)	$MT\ CO_2e$
$Cseq_G$	=	Soil carbon sequestration increase from grassland restoration (Equation 7)	$MT\ CO_2e$
$Cseq_T$	=	Biomass carbon sequestration increase from tree plantings (Equation 15)	$MT\ CO_2e$

Equation 2: Avoided Carbon Loss Rate from Drained Organic Soil on Farmland or Managed Seasonal Wetland to be restored to Permanent Coastal Tidal Wetland

$$\Delta CLR_{dos} = \frac{Freq_{drain}}{12} \times \left(0.05 \times 40{,}468{,}564 \div 1{,}000{,}000 \times \frac{44}{12}\right) \times A_{dos}$$

Where,

			Units
ΔCLR_{dos}	=	Avoided carbon loss rate from drained organic soil on farmland or managed seasonal wetland to be restored to wetlands	$\frac{MT\ CO_2e}{Year}$
$Freq_{drain}$	=	Number of months per year project site is drained for farmland or as a managed seasonal wetland	Months
12		Number of months per year	Months
0.05	=	Drained organic soil carbon loss rate	$\frac{g\ C}{cm^2\ Year}$
40,468,564	=	Conversion from acres to square centimeters	$\frac{cm^2}{Acre}$
1,000,000	=	Conversion from metric tons to grams	$\frac{g}{MT}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{MT\ CO_2}{MT\ C}$
A_{dos}	=	Area of farmland or managed seasonal wetland on drained organic soil to be restored to wetlands.	Acres

Equation 3: Increased Methane Emissions from Coastal Tidal Wetland Restoration

$$\Delta CH_{4,CTW} = 193.7 \times A_{CTW} \times \left(\frac{Freq_{Fresh} - Freq_{FreshWet}}{12}\right) \times 0.4047 \div 1{,}000$$

Where,

			Units
$\Delta CH_{4,CTW}$	=	Change in methane emissions from coastal tidal wetlands restoration	$\frac{MT\ CH_4}{Year}$
193.7	=	Methane emission factor for wetlands with salinity less than 18 ppt	$\frac{kg\ CH_4}{Hectare\ Year}$
A_{CTW}	=	Area restored to coastal tidal wetlands	Acres
$Freq_{Fresh}$	=	Number of months per year restored permanent wetland has salinity less than 18 ppt	Months
$Freq_{FreshWet}$	=	Number of months per year the project area existed as a seasonal wetland with salinity less than 18 ppt before conversion or restoration to permanent tidal wetland, equal to the smaller of $Freq_{Fresh}$ and $Freq_{Wet}$.	Months

Equation 4: Avoided Nitrous Oxide Emissions from Drained Organic Soils

$$\Delta N_2O_{dos} = \frac{Freq_{drain}}{12} \times 0.008 \times A_{dos} \times 0.4047 \times \frac{44}{28}$$

Where,			Units
ΔN_2O_{dos}	=	Avoided nitrous oxide emissions from drained organic soil on farmland or managed seasonal wetlands to be restored to wetlands	$\frac{\text{MT N}_2\text{O}}{\text{Year}}$
$Freq_{drain}$	=	Number of months per year project site is drained for farmland or as a managed seasonal wetland	Months
12		Number of months per year	Months
0.008	=	Nitrous oxide emission rate for cropped wetlands soils	$\frac{\text{MT N}_2\text{O} - \text{N}}{\text{Hectare Year}}$
A_{dos}	=	Area of farmland or managed seasonal wetland on drained organic soil to be restored to wetlands	Acres
0.4047	=	Conversion from acres to hectares	$\frac{\text{Hectares}}{\text{Acres}}$
$\frac{44}{28}$	=	Molecular weight ratio of nitrous oxide to nitrogen	$\frac{\text{MT N}_2\text{O}}{\text{MT N}}$

Equation 5: Avoided Nitrous Oxide Emissions from Nitrogen Application

$$\Delta N_2O_{fert} = 0.01 \times N_{fert} \times A_{fert} \div 2{,}204.62 \times \frac{44}{28}$$

Where,			Units
ΔN_2O_{fert}	=	Avoided nitrous oxide emissions from farmland due to avoided nitrogen fertilizer application	$\frac{\text{MT N}_2\text{O}}{\text{Year}}$
0.01	=	Nitrous oxide emission rate for nitrogen fertilizer application	$\frac{\text{lb N}_2\text{O} - \text{N}}{\text{lb N}}$
N_{fert}	=	Former nitrogen fertilizer application rate	$\frac{\text{lb N}}{\text{Acre Year}}$
A_{fert}	=	Area of farmland previously fertilized	Acres
2,204.62	=	Conversion from metric tons to pounds	$\frac{\text{lb}}{\text{MT}}$
$\frac{44}{28}$	=	Molecular weight ratio of nitrous oxide to nitrogen	$\frac{\text{MT N}_2\text{O}}{\text{MT N}}$

Equation 6: Soil Carbon Sequestration from Coastal Tidal Wetland Restoration

$$Cseq_{CTW} = 79 \times A_{CTW} \times \left(1 - \frac{Freq_{wet}}{12}\right) \times 4{,}046.86 \div 1{,}000{,}000 \times \frac{44}{12} \times 50$$

Where,			Units
$Cseq_{CTW}$	=	Soil carbon sequestration from coastal tidal wetlands restoration	$\mathrm{MT\ CO_2e}$
79	=	Annual soil carbon sequestration coefficient for coastal tidal wetland restoration	$\frac{\mathrm{g\ C}}{\mathrm{m^2\ Year}}$
A_{CTW}	=	Area restored to permanent coastal tidal wetlands	Acres
$Freq_{wet}$	=	Number of months per year project area existed as a seasonal wetlands before conversion or restoration to permanent wetlands	Months
12	=	Number of months per year	Months
4046.86	=	Conversion from acres to square meters	$\frac{\mathrm{m^2}}{\mathrm{Acres}}$
1,000,000	=	Conversion from metric tons to grams	$\frac{\mathrm{g}}{\mathrm{MT}}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{\mathrm{MT\ CO_2e}}{\mathrm{MT\ C}}$
50	=	Number of years of project life	Years

Equation 7: Soil Carbon Sequestration from Grassland Restoration

$$Cseq_G = \begin{pmatrix} CS_{ref} \times F_{LU,G} \times F_{GM,I} \times A_{IG} - CS_{ref} \times F_{LU,G} \times F_{GM,MD} \times A_{MDG} \\ -CS_{ref} \times F_{CM,FT} \times A_{F,G} \end{pmatrix} \times 0.4047 \times \frac{44}{12}$$

Where,

			Units
$Cseq_G$	=	Soil carbon sequestration from grassland restoration	$MT\ CO_2e$
CS_{ref}	=	Reference carbon stock for grassland IPCC soil type • Sandy (16) • Wetland (48) • Volcanic (124) • Spodic (86) • High Activity Clay Soil (37) • Low Activity Clay Soil (25)	$\frac{MT\ C}{Hectare}$
$F_{LU,G}$	=	Land use factor, grassland for warm temperate dry climate (1.37)	Unitless
$F_{GM,I}$	=	Grassland management factor, improved (1.14)	Unitless
A_{IG}	=	Area restored to improved grassland	Acres
$F_{GM,MD}$	=	Grassland management factor, moderately degraded (0.95)	Unitless
A_{MDG}	=	Area restored from moderately degraded grassland	Acres
$F_{CM,FT}$	=	Cropland management factor, Full Till (1)	Unitless
$A_{F,G}$	=	Area restored from farmland to grassland	Acres
0.4047	=	Conversion from acres to hectares	$\frac{Hectares}{Acres}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{MT\ CO_2e}{MT\ C}$

B. GHG Benefit from Sacramento-San Joaquin Delta Wetland Restoration

Equation 8 estimates the GHG benefit from Sacramento-San Joaquin Delta Wetland Restoration (GHG_{DW}). Equation 8 relies on three other equations. Equation 4 is used to determine the avoided N_2O emissions (ΔN_2O_{dos}) from restoration of drained organic soil in farmland. Equation 5 is used to determine the avoided N_2O emissions (ΔN_2O_{fert}) associated with fertilizer application. Equation 15 estimates the biomass carbon sequestration from tree plantings ($Cseq_T$).

Equation 8: GHG Benefit from Sacramento-San Joaquin Delta Wetland Restoration

$$GHG_{DW} = \left(\begin{array}{c} \left(0.05 \times 40{,}468{,}564 \div 1{,}000{,}000 \times \frac{44}{12} - 2.60 \times 0.4047\right) \times A_{RDW} \\ + \left(\Delta N_2O_{dos} + \Delta N_2O_{fert}\right) \times 298 \end{array} \right) \times 50 + Cseq_T$$

Where,

			Units
GHG_{DW}	=	GHG benefit of restored Delta wetlands	$MT\ CO_2e$
0.05	=	Drained organic soil carbon loss rate	$\frac{g\ C}{cm^2\ Year}$
40,468,564	=	Conversion from acres to square centimeters	$\frac{cm^2}{Acre}$
1,000,000	=	Conversion from metric tons to grams	$\frac{g}{MT}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{MT\ CO_2e}{MT\ C}$
2.60	=	Restored Delta wetland CO_2 and CH_4 emission rate	$\frac{MT\ CO_2e}{Hectare\ Year}$
0.4047	=	Conversion from acres to hectares	$\frac{Hectares}{Acres}$
A_{RDW}	=	Area of restored Delta wetlands	Acres
ΔN_2O_{dos}	=	Avoided nitrous oxide emissions from farmland on drained organic soil to be restored to wetland (from Equation 4)	$\frac{MT\ N_2O}{Year}$
ΔN_2O_{fert}	=	Avoided nitrous oxide emissions from farmland due to avoided nitrogen fertilizer application (from Equation 5)	$\frac{MT\ N_2O}{Year}$
298	=	Nitrous oxide global warming potential	$\frac{MT\ CO_2e}{MT\ N_2O}$
50	=	Number of years of project life	Years
$Cseq_T$	=	Biomass carbon sequestration increase from tree plantings (Equation 15)	$MT\ CO_2e$

C. GHG Benefit from Mountain Meadow Restoration

Equation 9 estimates the GHG benefit from Mountain Meadow Restoration (GHG_{MM}). Equation 9 relies on one other equation. Equation 15 estimates the biomass carbon sequestration from tree plantings ($Cseq_T$).

Equation 9: GHG Benefit from Mountain Meadow Restoration

$$GHG_{MM} = 95.40 \times A_{MM} \times 4{,}046.86 \div 1{,}000{,}000 \times \frac{44}{12} \times 50 + Cseq_T$$

Where,

			Units
GHG_{MM}	=	GHG benefit of restored mountain meadows	$\text{MT CO}_2\text{e}$
95.40	=	Annual soil carbon sequestered in restored mountain meadows, 50 Year timescale	$\frac{\text{g C}}{\text{m}^2\ \text{Year}}$
A_{MM}	=	Area of land restored to mountain meadows	Acres
4046.86	=	Conversion from acres to square meters	$\frac{\text{m}^2}{\text{Acres}}$
$1{,}000{,}000$	=	Conversion from metric tons to grams	$\frac{\text{g}}{\text{MT}}$
$\frac{44}{12}$	=	Molecular Weight Ratio of carbon dioxide to carbon	$\frac{\text{MT CO}_2\text{e}}{\text{MT C}}$
50	=	Number of years of project life	Years
$Cseq_T$	=	Biomass carbon sequestration increase from tree plantings (Equation 15)	$\text{MT CO}_2\text{e}$

D. GHG Benefit from Seasonal Inland Wetland Restoration

Equation 10 estimates the GHG benefit from Seasonal Inland Wetland Restoration (GHG_{SIW}). Equation 10 relies on four other equations. Equation 11 estimates the carbon sequestration ($Cseq_{SIW}$) from restoring seasonal inland wetlands. Equation 5 estimates the avoided N_2O emissions (ΔN_2O_{fert}) associated with fertilizer application. Equation 12 estimates the increase in CH_4 emissions ($\Delta CH_{4,SIW}$) from restored seasonal inland wetlands. Equation 15 estimates the biomass carbon sequestration from tree plantings ($Cseq_T$).

Equation 10: GHG Benefit from Seasonal Inland Wetland Restoration

$$GHG_{SIW} = Cseq_{SIW} + \left(\Delta N_2O_{fert} \times 298 - \Delta CH_{4,SIW} \times 25\right) \times 50 + Cseq_T$$

Where,

			Units
GHG_{SIW}	=	GHG benefit of restored seasonal inland wetlands project	$\text{MT CO}_2\text{e}$
$Cseq_{SIW}$	=	Soil carbon sequestered in seasonal inland wetland and adjacent grassland (from Equation 11)	$\text{MT CO}_2\text{e}$
ΔN_2O_{fert}	=	Avoided nitrous oxide emissions from farmland due to avoided nitrogen fertilizer application (Equation 5)	$\frac{\text{MT N}_2\text{O}}{\text{Year}}$
298	=	Nitrous oxide global warming potential	$\frac{\text{MT CO}_2\text{e}}{\text{MT N}_2\text{O}}$
$\Delta CH_{4,SIW}$	=	Increase in methane emissions from restored seasonal inland wetlands (Equation 12)	$\frac{\text{MT CH}_4}{\text{Year}}$
25	=	Methane global warming potential	$\frac{\text{MT CO}_2\text{e}}{\text{MT CH}_4}$
50	=	Number of years of project life	Years
$Cseq_T$	=	Biomass carbon sequestration increase from tree plantings (Equation 15)	$\text{MT CO}_2\text{e}$

Equation 11: Soil Carbon Sequestration from Seasonal Inland Wetland and Grassland Restoration

$$Cseq_{SIW} = \begin{pmatrix} CS_{wet} \times F_{LU,G} \times F_{GM,I} \times F_{GI,H} \times A_{SIW} \\ +CS_{ref} \times F_{LU,G} \times F_{GM,I} \times A_{IG} \\ -CS_{ref} \times F_{LU,G} \times F_{GM,MD} \times A_{MDG} \\ -CS_{ref} \times F_{LU,G} \times F_{GM,SD} \times A_{SDG} \\ -CS_{ref} \times F_{CM,FT} \times A_{farm} \end{pmatrix} \times 0.4047 \times \frac{44}{12} + Cseq_T$$

Where,			Units
$Cseq_{SIW}$	=	Soil Carbon sequestered in restored seasonal inland wetlands	$MT\ CO_2e$
CS_{wet}	=	Reference carbon stock for Wetland IPCC mineral soil (48)	$\frac{MT\ C}{Hectare}$
$F_{LU,G}$	=	Land use factor, grassland for warm temperate dry climate (1.37)	Unitless
$F_{GM,I}$	=	Grassland management factor, improved (1.14)	Unitless
$F_{GI,H}$	=	Grassland input factor, high (1.11)	Unitless
A_{SIW}	=	Area restored to seasonal inland wetlands	Acres
CS_{ref}	=	Reference carbon stock for current IPCC soil type • Sandy (16) • Wetland (48) • Volcanic (124) • Spodic (86) • High Activity Clay Soil (37) • Low Activity Clay Soil (25)	$\frac{MT\ C}{Hectare}$
A_{IG}	=	Area restored to improved grassland	Acres
$F_{GM,MD}$	=	Grassland management factor, moderately degraded (0.95)	Unitless
A_{MDG}	=	Area restored from moderately degraded grassland	Acres
$F_{GM,SD}$	=	Grassland management factor, severely degraded (0.7)	Unitless
A_{SDG}	=	Area restored from severely degraded grassland	Acres
$F_{CM,FT}$	=	Cropland management factor, Full Till (1)	Unitless
A_{farm}	=	Area restored from farmland	Acres
0.4047	=	Conversion from acres to hectares	$\frac{Hectares}{Acres}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{MT\ CO_2e}{MT\ C}$
$Cseq_T$	=	Carbon sequestration increase from tree plantings (Eq. 15)	$MT\ CO_2e$

Equation 12: Increased Methane Emissions from Seasonal Inland Wetland Restoration

$$\Delta CH_{4,SIW} = 126 \times 0.4047 \div 1{,}000 \times A_{SIW}$$

Where,

			Units
$\Delta CH_{4,SIW}$	=	Increase in methane emissions from restored seasonal inland wetlands	$\frac{\text{MT CH}_4}{\text{Year}}$
126	=	Methane emission rate for intermittent (seasonal) wetlands	$\frac{\text{kg CH}_4}{\text{Hectare Year}}$
0.4047	=	Conversion from acres to hectares	$\frac{\text{Hectares}}{\text{Acres}}$
1,000	=	Conversion from metric tons to kg	$\frac{\text{kg}}{\text{MT}}$
A_{SIW}	=	Area restored to seasonal inland wetlands	Acres

E. GHG Benefit from Grassland Restoration

Equation 13 estimates the GHG benefit from Grassland Restoration ($GHG_{G/W}$). Equation 13 relies on three other equations. Equation 14 estimates the soil carbon sequestration ($Cseq_{G/W}$) from restoring grassland. Equation 5 estimates the avoided N_2O emissions (ΔN_2O_{fert}) associated with fertilizer application. Equation 15 estimates the biomass carbon sequestration from tree plantings ($Cseq_T$).

Equation 13: GHG Benefit from Grassland Restoration

$$GHG_{GL} = Cseq_{G/W} + \left(\Delta N_2O_{fert} \times 298\right) \times 50 + Cseq_T$$

Where,

			Units
GHG_{GL}	=	GHG benefit of restored seasonal inland wetlands project	$\text{MT CO}_2\text{e}$
$Cseq_{GL}$	=	Soil carbon sequestered in grasslands (from Equation 14)	$\text{MT CO}_2\text{e}$
ΔN_2O_{fert}	=	Avoided nitrous oxide emissions from farmland due to avoided nitrogen fertilizer application (Equation 5)	$\frac{\text{MT N}_2\text{O}}{\text{Year}}$
298	=	Nitrous oxide global warming potential	$\frac{\text{MT CO}_2\text{e}}{\text{MT N}_2\text{O}}$
50	=	Number of years of project life	Years
$Cseq_T$	=	Biomass carbon sequestration increase from tree plantings (Equation 15)	$\text{MT CO}_2\text{e}$

Equation 14: Soil Carbon Sequestration from Grassland Restoration

$$Cseq_{GL} = \begin{pmatrix} CS_{ref} \times F_{LU,} \times A_{GL} \\ -CS_{ref} \times F_{LU,SA} \times A_{SA} \\ -CS_{ref} \times F_{LU,GL} \times F_{GM,MD} \times A_{MDG} \\ -CS_{ref} \times F_{LU,GL} \times F_{GM,SD} \times A_{SDG} \\ -CS_{ref} \times F_{CM,FT} \times A_{farm} \end{pmatrix} \times 0.4047 \times \frac{44}{12}$$

Where,			Units
$Cseq_{GL}$	=	Soil carbon sequestered in restored grasslands	$MT\ CO_2e$
CS_{ref}	=	Reference carbon stock for current IPCC soil type • Sandy (16) • Wetland (48) • Volcanic (124) • Spodic (86) • High Activity Clay Soil (37) • Low Activity Clay Soil (25)	$\frac{MT\ C}{Hectare}$
$F_{LU,GL}$	=	Land use factor, grassland for warm temperate dry climate (1.37)	Unitless
A_{GL}	=	Area restored to grasslands	Acres
$F_{LU,SA}$	=	Land use factor, set-aside for warm temperate dry climate (1.26)	Unitless
A_{SA}	=	Set-aside area (area not previously farmland or degraded grasslands) restored to grasslands and woodlands	Acres
$F_{GM,MD}$	=	Grassland management factor, moderately degraded (0.95)	Unitless
A_{MDG}	=	Area restored from moderately degraded grassland	Acres
$F_{GM,SD}$	=	Grassland management factor, severely degraded (0.7)	Unitless
A_{SDG}	=	Area restored from severely degraded grassland	Acres
$F_{CM,FT}$	=	Cropland management factor, Full Till (1)	Unitless
A_{farm}	=	Area restored from farmland	Acres
0.4047	=	Conversion from acres to hectares	$\frac{Hectares}{Acres}$
$\frac{44}{12}$	=	Molecular weight ratio of carbon dioxide to carbon	$\frac{MT\ CO_2e}{MT\ C}$

F. GHG Benefit from Planting Trees

Trees may be planted as part of any Land Restoration project. Refer to Wetlands Guidelines for guidance on tree selection and planting. Equation 15 estimates the GHG benefit from tree planting, based on the i-Tree Planting tool.

Equation 15: Biomass Carbon Sequestration Benefit from Tree Planting

$$Cseq_T = \frac{1}{2{,}204.62}\sum_i f_{GHG_{iT}}(location,\ species_i, number_i, 50{,}10\%, DBH)$$

Where,

			Units
$Cseq_T$	=	The biomass carbon sequestration benefit from planting trees, as calculated by i-Tree Planting	$MT\ CO_2$
$\frac{1}{2{,}204.62}$	=	Conversion from pounds to metric tons	$\frac{MT}{lbs}$
$f_{GHG_{iT}}$	=	GHG benefit as calculated by i-Tree Planting based on location, species, number of trees by species, lifetime, mortality, and DBH of trees at planting.	$lbs\ CO_2$
$location$	=	The state, county, and closest city to the project site.	unitless
$species$	=	The species of planted trees for each species group i.	unitless
$number$	=	The number of planted trees for each species group i.	unitless
50	=	Project lifetime	years
10%	=	Tree mortality over project lifetime	n/a
DBH	=	Diameter Breast Height (DBH) of trees at planting (default is 1)	inches

G. PM2.5 Emissions Co-benefit from Tree Absorption

Equation 16 estimates the PM2.5 emissions from the project based on the i-Tree Planting tool.

Equation 16: PM2.5 Emissions Co-benefit from Tree Absorption

$$PM2.5_{iT} = \sum_{i} f_{PM2.5_{iT}}(location,\ species_i, number_i, 50, 10\%, DBH)$$

Where,			Units
$PM2.5_{iT}$	=	The particulate matter less than 2.5 microns captured by planted trees, as calculated by i-Tree Planting	lbs PM2.5
$f_{PM2.5_{iT}}$	=	PM2.5 co-benefit as calculated by i-Tree Planting based on location, species, number of trees by species, lifetime, mortality, and DBH of trees at planting.	lbs PM2.5
location	=	The state, county, and closest city to the project site.	unitless
species	=	The species of planted trees for each species group i.	unitless
number	=	The number of planted trees for each species group i.	unitless
50	=	Project lifetime	years
10%	=	Tree mortality over project lifetime	n/a
DBH	=	Diameter Breast Height (DBH) of trees at planting (default is 1)	inches

H. NO_x Emissions Co-benefit from Tree Absorption

Equation 17 estimates the NO_x emissions from the project based on the i-Tree Planting tool.

Equation 17: NO_x Emissions Co-benefit from Tree Absorption

$$NO_{x_{iT}} = \sum_i f_{NO_{x_{iT}}}(location,\ species_i, number_i, 50{,}10\%, DBH)$$

Where,

			Units
NO_x	=	The nitrogen oxides captured by planted trees, as calculated by i-Tree Planting	lbs NO_x
$f_{NO_{x_{iT}}}$	=	NO_x co-benefit as calculated by i-Tree Planting based on location, species, number of trees by species, lifetime, mortality, and DBH of trees at planting.	lbs NO_x
location	=	The state, county, and closest city to the project site.	unitless
species	=	The species of planted trees for each species group *i*.	unitless
number	=	The number of planted trees for each species group *i*.	unitless
50	=	Project lifetime	years
10%	=	Tree mortality over project lifetime	n/a
DBH	=	Diameter Breast Height (DBH) of trees at planting (default is 1)	inches

Section C. References

The following references were used in the development of this Quantification Methodology and the Wetlands Benefits Tool.

American Carbon Registry. (2017). *Methodology for the Quantification, Monitoring, Reporting and Verification of Greenhouse Gas Emissions Reductions and Removals from the Restoration of California Deltaic and Coastal Wetlands.* Arlington: Deverel, S., Oikawa, P., Dore, S., Mack, S., and Silva, L. https://americancarbonregistry.org/carbon-accounting/standards-methodologies/restoration-of-california-deltaic-and-coastal-wetlands/ca-wetland-methodology-v1.1-November-2017.pdf.

Anderson, F. E., Bergamaschi, B., Sturtevant, C., et al. (2016). Variation of energy and carbon fluxes from a restored temperate freshwater wetland and implications for carbon market verification protocols. *Journal of Geophysical Research: Biogeosciences,* 121:777-795. https://agupubs.onlinelibrary.wiley.com/doi/10.1002/2015JG003083.

Callaway, J. C., Borgnis, E. L., Turner, R. E., Milan, C. S. (2012). Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands. *Estuaries and Coasts*, *35*, 1163-1181. https://link.springer.com/article/10.1007/s12237-012-9508-9.

California Department of Fish and Wildlife (2019). Wetlands Restoration for Greenhouse Gas Reduction Grant Program Proposal Solicitation Notice. https://www.wildlife.ca.gov/Conservation/Watersheds/Greenhouse-Gas-Reduction.

Deverel, S.J., Leighton, D.A. (2010) Historic, Recent and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. *San Francisco Estuary and Watershed Science*, *8*(2). https://escholarship.org/uc/item/7xd4x0xw.

Deverel, S. J., Ingrum, T., & Leighton, D. (2016). Present-day oxidative subsidence of organic soils and mitigation in the Sacramento-San Joaquin Delta, California, USA. *Hydrogeology Journal*, *24*(3), 569-586. https://link.springer.com/article/10.1007/s10040-016-1391-1.

Deverel, S., Jacobs, P., Lucero, C., Dore, S. Kelsey, T.R. (2017). Implications for Greenhouse Gas Emission Reductions and Economics of a Changing Agricultural Mosaic in the Sacramento-San Joaquin Delta. *San Francisco Estuary & Watershed Science, 15*(3). https://escholarship.org/uc/item/99z2z7hb.

Drexler, J.Z., Fuller, C.C., Orlando, J., Moore, P.E. (2015). Recent rates of carbon accumulation in montane fens of Yosemite National Park, California, U.S.A. *Arctic,*

Antarctic, and Alpine Research, *47*(4) 657-669.
https://pubs.er.usgs.gov/publication/70170222.

Intergovernmental Panel on Climate Change. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use.* IGES, Japan: Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

Intergovernmental Panel on Climate Change. (2014). *2013 Supplement to the 2016 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.* IGES, Japan: Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds). http://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf.

McNicol, G., Sturtevant, C.S., Knox, S.H., Dronova, I., Baldocchi, D.D., Silver, W.L. (2016). Effects of seasonality, transport pathway, and spatial structure on greenhouse gas fluxes in a restored wetland. *Global Change Biology*, *23*(7) 2768-2782. https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.13580.

Oikawa, P. Y., Jenerette, G. D., Knox, S. H., Sturtevant, C., Verfaillie, J., Dronova, I., Poindexter, C. M., Eichelmann, E., & Baldocchi, D. D. (2017). Evaluation of a hierarchy of models reveals importance of substrate limitation for predicting carbon dioxide and methane exchange in restored wetlands. *Journal of Geophysical Research: Biogeosciences*, *122*(1), 145-167.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016JG003438

United States Department of Agriculture. (2014). *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*. Washington, D.C.: Eve, M., Pape, D., Flugge, M., Steele, R., Man, D., Riley-Gilbert and M., Biggar, S. (eds).
https://www.usda.gov/oce/climate_change/Quantifying_GHG/USDATB1939_07072014.pdf.

Verified Carbon Standard. (2014). *Methodology for Coastal Wetland Creation.* Washington, D.C.: Louisiana Coastal Protection and Restoration Authority. http://verra.org/methodology/vm0024-methodology-for-coastal-wetland-creation-v1-0/.

Verified Carbon Standard. (2014). *Methodology for Tidal Wetland and Seagrass Restoration.* Washington, D.C.: Restore America's Estuaries, Silvestrum. http://verra.org/methodology/vm0033-methodology-for-tidal-wetland-and-seagrass-restoration-v1-0/.